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The palaeogeographic outlines of the Caucasus in the Jurassic: The Caucasian Sea and the Neotethys Ocean

Dmitry A. Ruban

Abstract. The Caucasian Sea, fringing the northern margin of the Jurassic Neotethys Ocean, largely covered the Caucasus. Continental, shallow-marine and deep-marine palaeoenvironments delineate palaeogeographic outlines for three significant time slices: the Late Toarcian, the Early Bajocian and the Middle Oxfordian. These new palaeogeographic outlines of the Caucasus and adjacent territories match the Neotethys Ocean reconstructions. In the Late Toarcian, the Caucasian Sea embraced the Greater Caucasus Basin and the Black Sea – Caspian Sea Basin, which were divided by the Northern Transcaucasian Arc; it opened to the Neotethys Ocean which covered the Exterior Caucasian Basin. In the Early Bajocian, the Caucasian Sea only embraced the Greater Caucasus Basin; it opened the epicontinental seas of the Russian Platform, connecting them with the Neotethys Ocean by straits between islands of the Transcaucasian Arc. In the Middle Oxfordian, the Caucasian Sea which further embraced the Greater Caucasus Basin had its outer shelf fringed by carbonate build-ups. The connection between the Russian Platform shallow sea and the Neotethys Ocean was maintained. In the course of the Jurassic, a seaway developed along the northern margin of the Neotethys, of which the Caucasian Sea became a significant part.

Key words: sea, seaway, basin, arc, Jurassic, Caucasus, Neotethys.

Апстракт. Кавкаско море захватало је северни обод јурског Неотетиског океана и великим делом је прекривало Кавказ. Континенталне, плитководне и дубоководне палеосредине оцртавају палеогеографске оквире три значајна временска раздобља: горњи тоар, доњи бајес и средњи оксфорд. Ове нове палеогеографске границе Кавказа и суседних области уклапају се у реконструкцију Неотетиског океана. У горњем тоару Кавкаско море је обухватало Велики Кавкаски басен и Црно море – Каспијски морски басен, који су били раздвојени Северним транскавкаским луком који се отварао према Неотетиском океану који је прекривао спољашњи Кавкаски басен. За време доњег бајеса, Кавкаско море је захватало само Велики Кавкаски басен; оно је било отворено према епиконтиненталном мору Руске платформе повезујући га са Неотетиским океаном земљоузима између острва Транскавкаског лука. Током средњег оксфорда стварале су се карбонатне наслаге по ободу спољашњег шелфа Кавкаског мора, које је и даље захватало Велики Кавкаски басен. Одржавала се веза између плитководне Руске платформе и Неотетиског океана. У току јуре постојао је морски пролаз дуж северног обода Неотетиса, где је Кавкаско море заузимало његов значајни део.

Кључне речи: море, морски пролаз, басен, лук, јура, Кавказ, Неотетис.

Introduction

The Caucasus stretches over about 1000 km between the Black and Caspian seas (Fig. 1). In the Jurassic, it was located on the northern margin of the Neotethys Ocean, forming a “key” transition between western and central parts of the Northern Neotethys (Stampfli & Borel, 2002; Golonka, 2004). Not only palaeogeographically and palaeotectonically, but also palaeobiogeographically, the Caucasus was an important region. Westermann (2000) after Uhlig (1911) have defined the Mediterran-Caucasian Subrealm of the Mesozoic Tethyan Realm.

In spite of its importance, the Caucasusian Jurassic palaeogeography is still poorly known. Previous publications are often only available in Russian and/or lack

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the incorporation of modern palaeogeographic and palaeotectonic concepts. Outdated "formation" analysis or geosynclinal theory are the basis of many studies. To date, plate-tectoinc and terrane analysis of the Caucasus still remains sporadic and schematic. In many Russian reconstructions, the Caucasus was viewed as an isolated region and its border often delineated by the boundaries of the former USSR. To avoid misunderstanding, which is inevitable when dealing with a high amount of the sufficiently reliable sources, in this paper only a few Russian works have been considered. The first one is a book by JASAMANOV (1978), who presented general palaeogeographic information on the Caucasus for each of the Jurassic stages, while the second is a review by LORDKIPANIDZE *et al*. (1984), who presented the most acceptable palaeotectonic reconstructions, based on palaeomagnetic data. Tectonic models proposed by ERSHOV *et al*. (2003) were also employed.

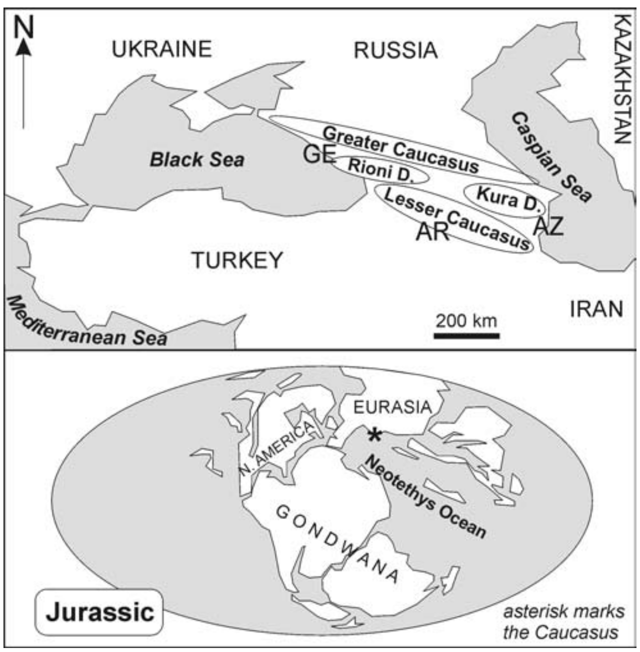

Fig. 1. Geographic location of the studied region. GE – Georgia, AR – Armenia, AZ – Azerbaijan. The position of the Caucasus in the Jurassic is shown on the palaeogeographic map, strongly simplified after SCOTESE (2004).

Thus, in any somewhat more detailed palaeogeographic reconstruction of a larger portion of the Jurassic Northern Neotethys, the Caucasus remained a blank space. The general target of this article is to initiate a discussion on the highlighted topic. Simplified Jurassic palaeogeographic outlines of the Caucasus are proposed and discussed. It should be emphasized that this attempt is based on personal field investigations, as well as a revision of the available and trustwarthy data from recent studies of the entire Jurassic Neothethys (STAMPFLI & BOREL, 2002; GOLONKA, 2004).

Geologic setting

The Caucasus consists of three main segments: (1) the Greater Caucasus, (2) the Lesser Caucasus (or the Transcaucasus) and (3) the Kura-Rioni Depression (or the Rioni Depression and the Kura Depression, also called the Transcaucasian Depressions) (Fig. 1). Their tectonic settings have been briefly overviewed by SAINTOT & ANGELIER (2002), ALLEN *et al*. (2003) and ERSHOV *et al*. (2003).

The Jurassic deposits, widely distributed within the Caucasus, vary in distinct areas. Their stratigraphy has been reviewed by ROSTOVTSEV *et al*. (1992). The stratigraphic scale used in the Caucasus was revised by the author according to new developments in the Jurassic chronostratigraphy, using ammonoids, brachiopods (for detail see RUBAN, 2003), foraminifers and marker horizons (Fig. 2). Stratigraphic suggestions from both International Commission on Stratigraphy and the Groupe Français d'Étude du Jurassique (CARIOU & HANTZPERGUE, 1997) were taken account in doing this. A correspondence between the chronstratigraphic stages and substages (after GRADSTEIN *et al.,* 2004) and stages in the regional sense (after ROSTOVTSEV *et al.,* 1992) was established. The precise revision of the regional ammonoid-based zonation is a task for further special studies. It is also necessary to note that traditionally the Callovian stage in the Caucasus is attached to the Upper Jurassic (ROSTOVTSEV *et al.,* 1992), in contrast to the present scale, recommended by the International Commission on Stratigraphy (GRADSTEIN *et al.,* 2004).

Jurassic lithostratigraphy of the Caucasus has been reviewed in detail by ROSTOVTSEV *et al*. (1992). In general, two major sedimentary complexes are identified. The Sinemurian-Bathonian complex comprises argillaceous and clastic deposits with a total thickness upto 10000 m. The Callovian-Tithonian complex is represented chiefly by carbonates (thickness up to 3000 m) and also evaporites in the upper part. The accumulation of the Late Jurassic deposits was connected with the evolution of a large carbonate platform rimmed by carbonate buildups (KUZNETSOV, 1993; AKHMEDOV *et al.,* 2003; RUBAN, 2005). In some areas (especially in the Lesser Caucasus), substantial amounts of volcanoclastic deposits are present. Two major regional hiatuses encompass the Hettangian-Early Sinemurian and the Bathonian.

In the Jurassic, the Caucasus was located in the central part of the northern margin of the Neotethys Ocean (Fig. 1) (STAMPFLI & BOREL, 2002; GOLONKA, 2004). Tectonic activity resulted from the dynamics between the terranes, which contacted with each other, and also with the larger Eurasian Plate. Several parallel subduction and spreading zones were located in this territory (LORDKIPANIDZE *et al.,* 1984; ERSHOV *et al.,* 2003), although a precise interpretation of the Jurassic geodynamics in this region has not been made yet and many questions remain open.

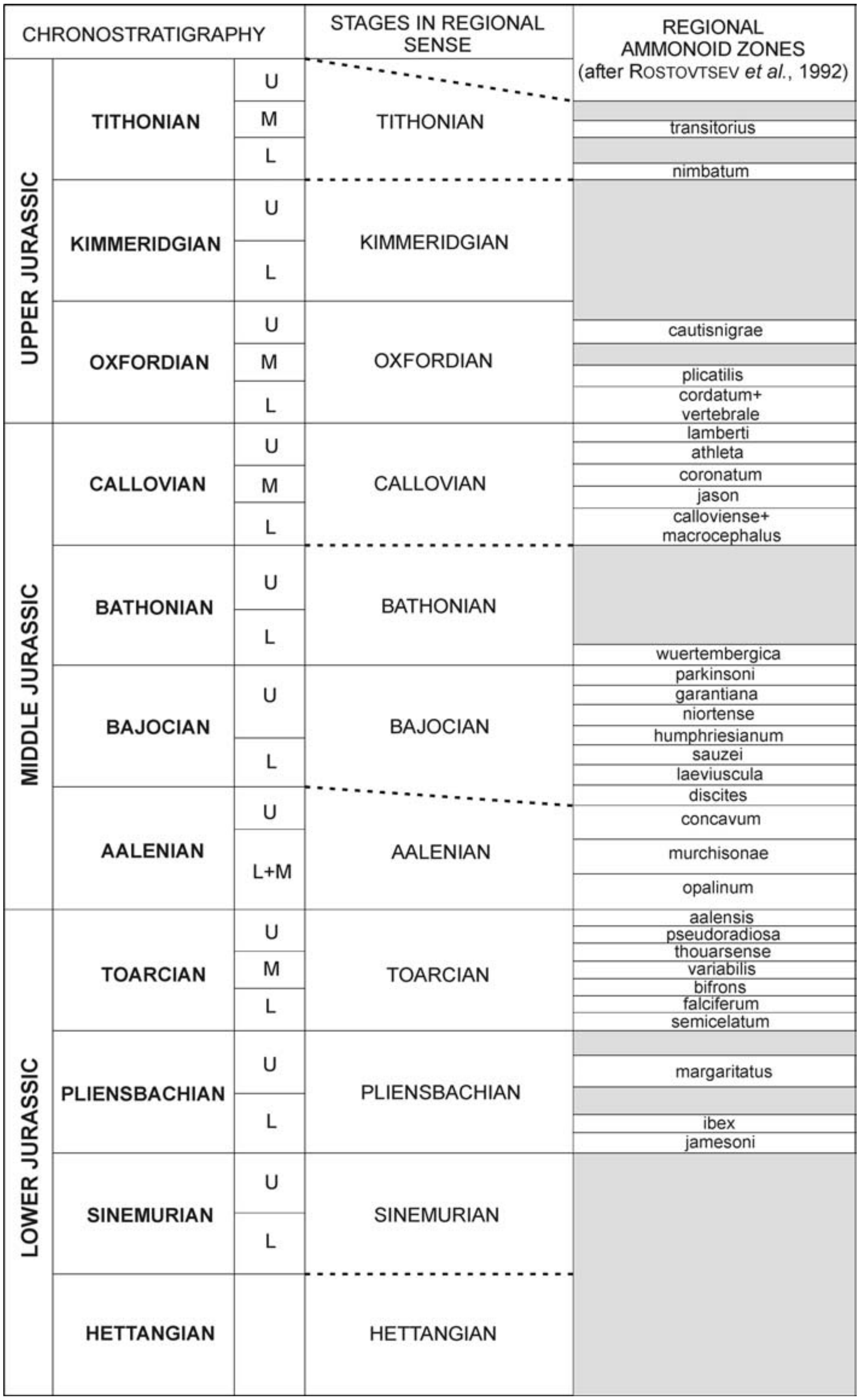

Fig. 2. Corrected stratigraphic scale of the Jurassic used in the Caucasus. Abbreviations: L – Lower, M – Middle, U – Upper. Unzoned intervals are shaded as gray. Dashed lines mark uncertainty in the boundary definition. Regional ammonoid zonation does not correspond on this scale to the shown chronostratigraphy (it seems to be impossible to correlate them at present), but only to the stages in a regional sense. The Callovian *macrocephalus* and calloviense regional zones, and the Oxfordian *vertebrale* and *cordatum* regional zones are evidently not separated in the regional ammonoid succession.

In the Early-Middle Jurassic, the Caucasus was located in a subtropical to moderate humid zone. The Toarcian palaeotemperatures are estimated as 15–20°C; in the Early Aalenian, they decreased to 5–15°C, but in the Late Aalenian, the temperatures increased again to 20–25°C, and apparently constant until the end of the Jurassic (JASAMANOV, 1978). After the beginning of the Callovian, the climate became subtropical to tropical and semi-humid. In the Late Kimmeridgian-Tithonian, evaporites were accumulated (JASAMANOV, 1978; ROSTOVTSEV *et al.*, 1992), which indicated arid conditions. In the Early-Middle Jurassic, dysoxic to anoxic palaeoenvironments were typical for the Caucasian basins (RUBAN, 2004; EFENDIYEVA & RUBAN, 2005; RUBAN & TYSZKA, 2005). The palaeobiogeographic position of the Caucasus is uncertain. While DOMMERGUES (1987) places it in the Euro-Boreal domain for the Early Jurassic, WESTERMANN (2000) includes it into the Tethyan Realm. An analysis of brachiopods suggests a rather transitional position (RUBAN, 2003).

Methods

Essentially, this study relies on palaeoenvironmental interpretation, realized in the same way as described by RUBAN (2006). The territory of the Caucasus is subdivided into several dozens of particular areas, which are traditionally called "zones". They are distinguished by the facies composition of the Jurassic succession. A total of 36 "zones" delineate the Hettangian-Bathonian interval (Fig. 3A), and 26 the Callovian-Tithonian interval (Fig. 3B) (ROSTOVTSEV *et al.*, 1992). A palaeoenvironmental interpretation for all formations in each "zone" was made. The comprehensive information of ROSTOVTSEV *et al.* (1992) and personal field observations in the Labino-Malkinskaya (see also EFENDIYEVA & RUBAN, 2005; RUBAN & TYSZKA, 2005), Lago-Nakskaja and Labinskaja "zones" were used.

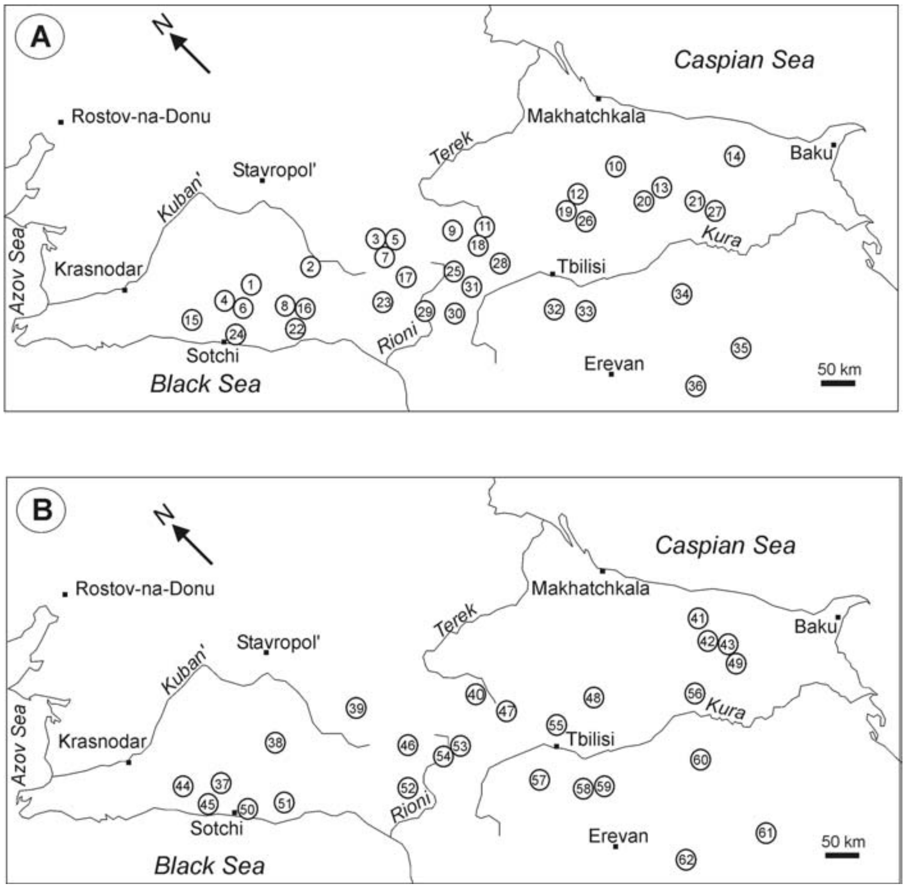

Fig. 3. Location of the Jurassic "zones" (marked by circles) in the Caucasus (after ROSTOVTSEV *et al.,* 1992). A, Hettangian-Bathonian "zones" (1–36); B, Callovian-Tithonian "zones" (37–62). "Zones" ("subzones" and regions of ROSTOVTSEV *et al.* (1992) are mentioned here as "zones"): 1, Western Labino-Malkinskaja; 2, Central Labino-Malkinskaja; 3, Eastern Labino-Malkinskaja; 4, Western Pshikish-Tyrnyauzskaja; 5, Eastern Pshikish-Tyrnyauzskaja; 6, Northern Arkhyz-Guzeripl'skaja; 7, Eastern Arkhyz-Guzeripl'skaja; 8, Southern Arkhyz-Guzeripl'skaja; 9, Digoro-Osetinskaja; 10, Agwali-Khivskaja; 11, Western Bokovogo Khrebta; 12, Central Bokovogo Khrebta; 13, Eastern Bokovogo Khrebta; 14, Southeastern Bokovogo Khrebta; 15, Gojtkhsko-Atchishkhinskaja; 16, Severoabkhazskaja; 17, Svanetskaja; 18, Western Glavnogo Khrebta; 19, Central Glavnogo Khrebta; 20, Tfanskaja; 21, Durudzhinskaja; 22, Western Gagra-Dzhavskaja; 23, Eastern Gagra-Dzhavskaja; 24, Amuksko-Lazarevskaja; 25, Sakaojskaja; 26, Shakrianskaja; 27, Vandamskaja; 28, Kakhetino-Letchkhumskaja; 29, Tskhenistskali-Okribskaja; 30, Southwestern Dzirul'skaja; 31, Northeastern Dzirul'skaja; 32, Loksko-Khramskaja; 33, Alaverdskaja; 34, Shamkhorsko-Karabakhskaja; 35, Kafanskaja; 36, Araksinskaja; 37, Lago-Nakskaja; 38, Labinskaja; 39, Malkinskaja; 40, Kabardino-Dagestanskaja; 41, Jugo-Vostotchnogo Dagestana; 42, Sudurskaja; 43, Shakhdagskaja; 44, Abino-Gunajskaja: 45, Novorossijsko-Lazarevskaja, 46, Svanetsko-Verkhneratchinskaja; 47, Liakhvi-Aragvinskaja; 48, Kakhetinskaja; 49, Dibrarskaja; 50, Akhtsu-Katsyrkha; 51, Dzhirkhva-Akhibokhskaja; 52, Tkvartcheli-Okribskaja; 53, Ratchinskaja; 54, Tsessi-Kortinskaja; 55, Iori-Tsitelitskarojskaja; 56, Vandamskaja; 57, Khramskaja; 58, Lalvarskaja; 59, Idzhevanskaja; 60, Dashkesano-Karabakhskaja; 61, Kafanskaja; 62, Nakhitchevanskaja.

Three main types of the palaeoenvironments were distinguished in general: continental, shallow-marine and deep-marine. Continental palaeoenvironments were usually documented by the hiatuses, while rarely by the subaeral deposits. Shallow-marine palaeoenvironments were interpreted by the presence of clastic or carbonate deposits, similar to those usually accumulated at a seashore or on a shelf. Deep-marine palaeoenvironments were traced mostly by the slope deposits (e.g., turbidites). In addition to lithology, also fossils, including plant remains, as well as sedimentological criteria, such as submarine slumps, concretions, etc., were used to determine the palaeoenvironments.

Special attention was paid to three time slices: the Late Toarcian, the Early Bajocian and the Middle Oxfordian, which all correspond to important phases in the evolution of the Caucasus. In the Late Toarcian, all the principal basins of the Caucasus were formed completely. The Early Bajocian and the Middle Oxfordian correspond to the time invervals after something like reorganizations of the Caucasian basins occurred, each following major regressions.

Maps showing the variety of the palaeoenvironments during these time slices were drawn for the Caucasus (Figs. 4A, 5A, 6A). They are attached to the present-day geography of the studied region. Therefore, the next step was to take into consideration the palaeotectonic reconstructions. In this paper, the reconstructions of LORDKIPANIDZE *et al*. (1984) were preferred, because they are based on reliable palaeomagnetic data. Additionally, the results of ERSHOV *et al.* (2003) were considered. Analyzing the composed maps of the palaeoenvironment distribution, attempt were made to recognize palaeogeographic elements (basins, arcs) highlighted by LORDKIPANIDZE *et al*. (1984), and, when necessary, correct their location. Then the verified and corrected information from the Caucasus was incorporated into the reconctructions for the entire Neotethys made by STAMPFLI & BOREL (2002) and GOLONKA (2004). Additionally, reconstructions made for the Pliensbachian by MEISTER & STAMPFLI (2000) became very helpful.

The final result, a set of the palaeogeographic sketches delineates what was the outline of the Caucasus at each of the studied time slices (Figs. 4B, 5B, 6B). They embrace the whole territory of the Caucasus and adjacent regions, including the Pontides, Moesia, Iranian terranes and the southern periphery of the Eurasia continent. Although these sketch-maps remain at a relatively low resolution and the position of landmasses (i.e., continents and islands) is schematic, they may help to fill the gap in our knowledge of the Jurassic palaeogeography of the Caucasus.

environments to the south of it correspond potentially to the Southern Transcaucasian Arc, i.e. another subduction zone. This arc is considered as the eastern edge of the Pontide structure (LORDKIPANIDZE *et al.,* 1984). In our palaeoenvironmental interpretation, there is no evidence to recognize the Lesser Caucasus Strait of the Tethys and the Nakhitchevan' Block, which were shown by LORDKIPANIDZE *et al.* (1984). Another basin, with the proposed name "the Exterior Caucasian Basin", might have been located between the Southern Transcaucasian Arc and the main subduction zone of the Northern Neotethys.

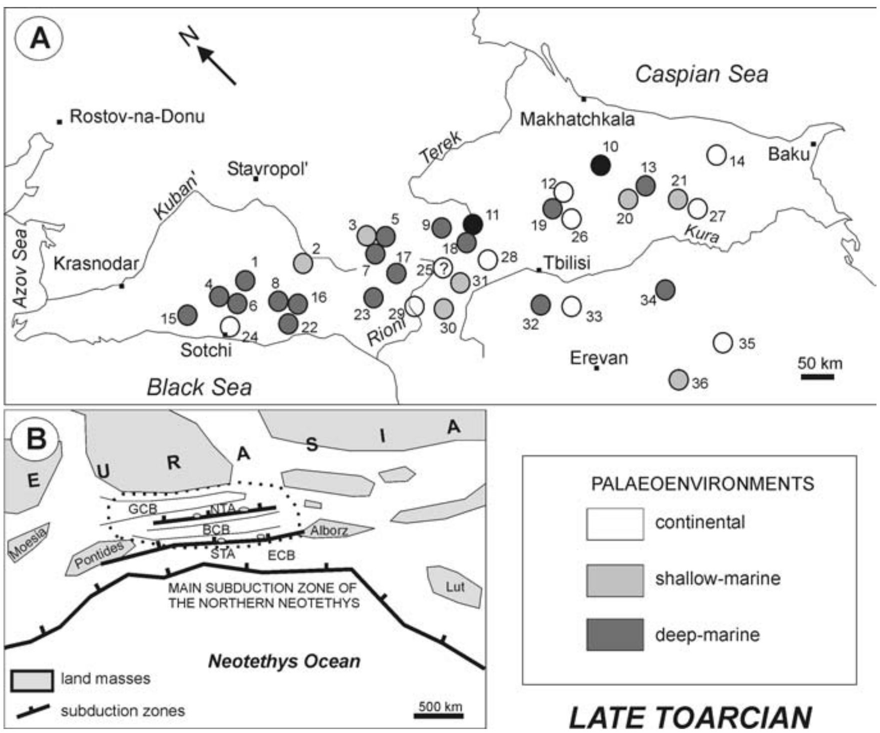

Fig. 4. The Late Toarcian palaeoenvironments (A) and the palaeogeographic outline (B) of the Caucasus (explanation of "zones" – Fig. 3A). "?" marks uncertainty in the interpretation of the continental palaeoenvironments, because of the doubtful establishment of hiatus. GCB, Greater Caucasus Basin, BCB, Black Sea – Caspian Sea Basin, ECB, Exterior Caucasian Basin, NTA, Northern Transcaucasian Arc, STA, Southern Caucasian Arc. The dotted line bounds the Caucasian Sea.

Reconstructions of the Jurassic outlines of the Caucasus

The Late Toarcian (~ 177 Ma)

Marine palaeoenvironments prevailed over most of the Caucasus in the Late Toarcian (Fig. 4A). In its northern part, dominating deep-marine environments trace the elongated basin, which may evidently correspond to the Greater Caucasus Basin of LORDKIPANIDZE *et al.* (1984). Perhaps its western part was the widest and deepest. Sporadic shallow-water environments to the south support the idea of the presence of the Northern Transcaucasian Arc (LORDKIPANIDZE *et al.,* 1984), related to the subduction zone. Moreover, there is no sound evidence for the presence of a large landmass there, as this is usually imagined (e.g., JASAMANOV, 1978). Presumably, only small islands might have been related to this arc.

Another deep basin is weakly delineated southwards, which may be related to the Black Sea – Caspian Sea Basin of LORDKIPANIDZE *et al.* (1984). Shallow-water

In the Late Toarcian outline of the Caucasus (Fig. 4B), a large sea, for which the name Caucasian Sea is proposed, opens towards the Neotethys Ocean. Wide straits between the landmasses to the west and east of this region entered this sea. The Caucasian Sea embraced two sedimentary basins, divided by a submarine mountain range, united perhaps to the west. Possibly, two archipelagoes consisting of very small islands which formed the Northern and Southern Transcaucasian Arcs characterized this sea. The boundary between the Caucasian Sea and the Neotethys Ocean stretched along the Southern Transcaucasian Arc. Our sketch-map suggests that the Exterior Caucasian Basin was embraced by the Neotethys Ocean.

The Early Bajocian (~ 171 Ma)

The Early Bajocian times were characterized by laterally variable palaeoenvironments within the Caucasus (Fig. 5A). Deep-marine environments trace the Greater Caucasus Basin, while shallow-water and continental

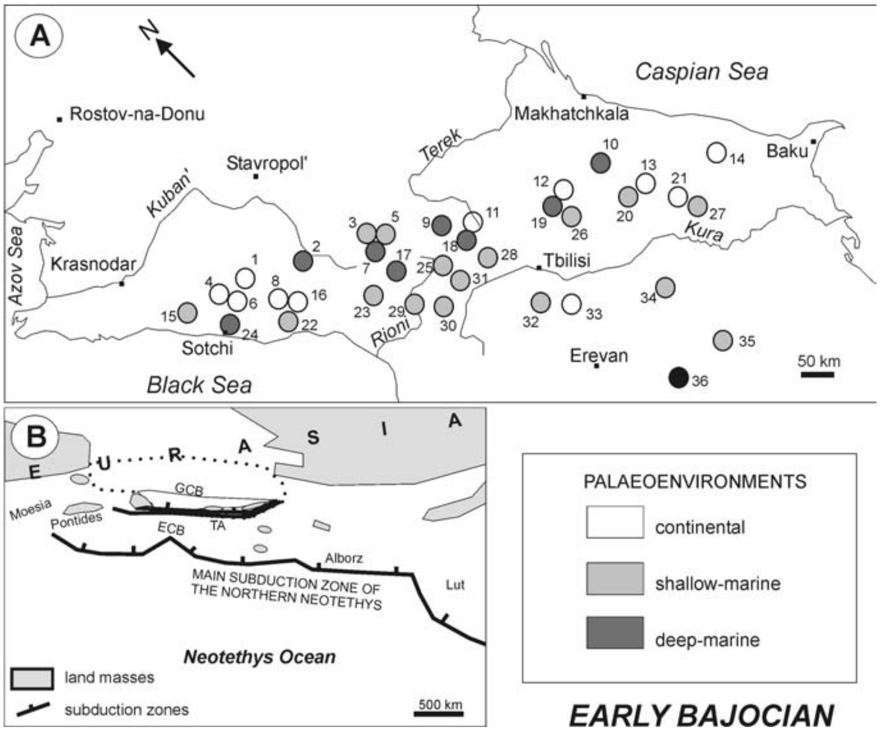

Fig. 5. The Early Bajocian palaeoenvironments (A) and the palaeogeographic outline (B) of the Caucasus (explanation of "zones" – Fig. 3A). GCB, Greater Caucasus Basin; ECB, Exterior Caucasian Basin; TA, Transcaucasian Arc. The dotted line bounds the Caucasian Sea.

environments delineate an island arc to the south, including relatively large islands. Intriguing was the landmass in the western part of the studied territory, where several continental deposits suggest large islands, which appeared as the result of the collision between Northern and Southern Transcaucasian Arcs, which closed the Black Sea – Caspian Sea Basin, generating a single Transcaucasian Arc. Palaeomagnetic data that highlight the presence of the Black Sea – Caspian Sea Basin in the Middle Jurassic appear doubtful (LORDKIPANIDZE *et al*. 1984). The Exterior Caucasian Basin was located between the Transcaucasian Arc and the main subduction zone of the Northern Neotethys. Some islands can be locally evidenced from continental palaeoenvironments.

The Early Bajocian outline of the Caucasus is presented in Fig. 5B. The studied territory was occupied by the Caucasian Sea. It was isolated from the Neotethys Ocean by the island archipelago of the Transcaucasian Arc. Connection between the sea and ocean was realized by straits between these islands, as well as landmasses, located to the west. From the north, the Caucasian Sea was opened to the large, but shallow interior sea, occuping a waste area of the Russian Platform. Only one sedimentary basin was embraced by this sea. The transgression resulted in the appearance of a very large shelf to the north of this basin, and the structure of the sea in the Early Bajocian was characterized by a strong asymmetry. The boundary between the Caucasian Sea and the Neotethys Ocean stretched along the Transcaucasian Arc. Our sketch-map suggests that the Exterior Caucasian Basin was embraced by the Neotethys Ocean. The islands occurring there might have been of volcanic origin and, therefore, related to the wide belt of intense magmatism to the north of the main subduction zone of the Northern Neotethys.

The Middle Oxfordian (~ 158 Ma)

During the Middle Oxfordian, the Caucasus was dominated by shallow-marine palaeoenvironments (Fig. 6A). Marine environments trace the Greater Caucasus Basin. The composed map does not permit the idea of LORDKIPANIDZE *et al*. (1984) about the complete separation of the Western and Eastern Subbasins and the presence of island between them, to be supported. We observed deep-marine environments in the western, central and eastern parts of the Greater Caucasus Basin. Nevertheless, the existence of islands at the western and eastern edges of the latter, hypothesized by LORKIPANIDZE *et al*. (1984) and also by GOLONKA (2004), is confirmed by our results, because continental palaeoenvironments were interpreted for those areas. Another island (or a chain of islands), delineated by the continental environments to the south, may be related to the Transcaucasian Arc. In contrast to LORDKIPANIDZE *et al*. (1984), no evidence for the presence of the Northern and Southern Transcaucasian Arcs, separated by the Black Sea – Caspian Sea Basin, was found. Therefore, it is hypothesized that in the Middle Oxfordian, a unique arc existed, as it was already in the Early Bajocian. However, this arc migrated southwards in comparison with the earlier time slices. Shallow-marine environments in the south of the studied territory are attributed to the Exterior Caucasian Basin.

The Middle Oxfordian outline of the Caucasus is presented in Fig. 6B. The studied territory was oc-

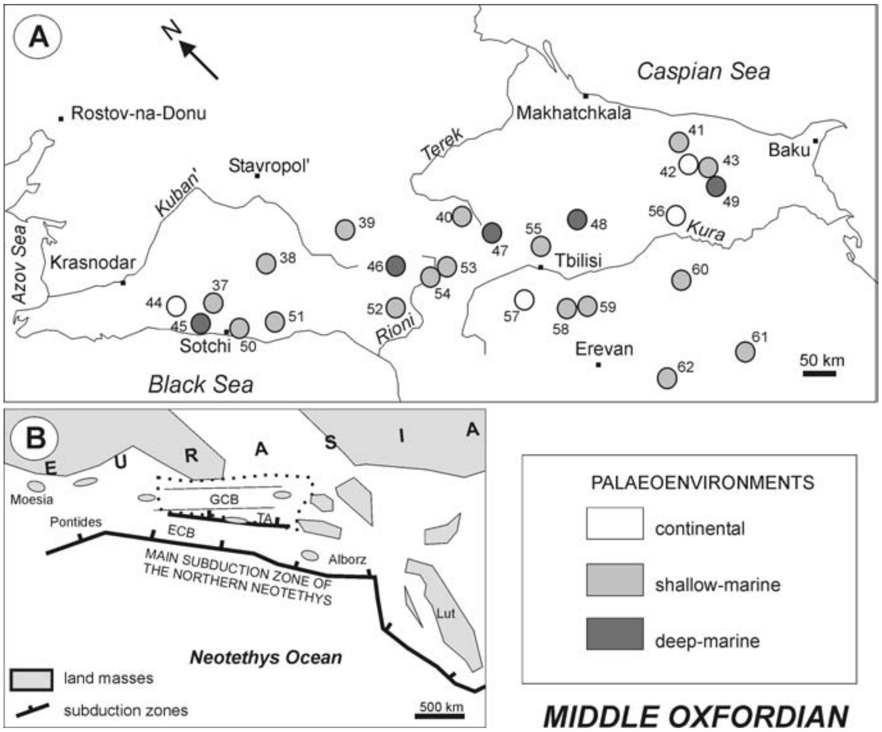

Fig. 6. The Middle Oxfordian palaeoenvironments (A) and the palaeogeographic outline (B) of the Caucasus (for an explanation of the "zones", see Fig. 3B). GCB, Greater Caucasus Basin; ECB, Exterior Caucasian Basin; TA, Transcaucasian Arc. Dotted line bounds the Caucasian Sea.

cupied by the Caucasian Sea. It was only a little isolated from the Neotethys Ocean by the above mentioned island and submarine mountain range of the Transcaucasian Arc. Straits between landmasses to the west and east of this sea also connected it with the Neotethys Ocean. From the north, the Caucasian Sea opened into the interior sea, as in the Early Bajocian, but its area was diminished. Only one sedimentary basin was embraced by this sea. A large shelf existed to the north-east of this basin. Thus, the sea basin in the Middle Oxfordian was characterized by strong asymmetry in its eastern part, but it was quite symmetric in its western part. The boundary between the Caucasian Sea and the Neotethys Ocean stretched along the Transcaucasian Arc. Our sketch-map suggests that the Exterior Caucasian Basin was embraced by the Neotethys Ocean.

A distinctive feature of the Late Jurassic of the Caucasian basins was the wide distribution of carbonate buildups (JASAMANOV, 1978; KHAIN, 1962; LORDKIPANIDZE *et al.*, 1984; KUZNETSOV, 1993; MARTIN-GARIN *et al.*, 2002; ROSTOVTSEV *et al.*, 1992; AKHMEDOV *et al.*, 2003; CECCA *et al.*, 2005; RUBAN, 2005). This coincided with the reef growth documented on the entire northern margin of the Neotethys Ocean (KIESSLING *et al.*, 1999; LEINFELDER *et al.*, 2002; MARTIN-GARIN *et al.*, 2002; OLIVIER *et al.*, 2004; CECCA *et al.*, 2005). The term "carbonate buildups" is preferred to that of "reefs", as they are traditionally called in Russian literature (e.g., JASAMANOV, 1978; KHAIN, 1962; ROSTOVTSEV *et al.*, 1992). SCHMID *et al*. (2001) mentioned the Caucasian buildups as mounds. The carbonate buildups are concentrated around the deepest parts of the Greater Caucasus Basin (Fig. 7). It is suggested that to the north, they developed on the outer shelf periphery, connected to the stable landmass of the Russian Platform, while in the south, they occupied the narrow outer shelf of the Transcaucasian Arc. However, some buildups were also found crossing the basin, suggesting atolls, isolated or in groups, characterizing the Late Jurassic Caucasian Sea and Exterior Caucasian Basin. In general, the distribution of the carbonate buildups was tectonically controlled (KHAIN, 1962; AKHMEDOV *et al.,* 2003).

Discussion

The presented palaeogeographic sketch maps suggest that during the Jurassic, the Caucasian Sea was located between the Eurasian landmass and large and little islands (Figs. 4B, 5B, 6B). A string of large islands located west- and eastwards were the result of accretion of small terranes along the subducted margin of the northern Neotethys. Straits between these small landmasses made a connection with the Caucasian Sea possible. Together they were able to form an important seaway that stretched along the southern periphery of Eurasia. The tectonic origin of this Exterior Caucasian seaway is very different from thopse of the well-known Hispanic Corridor and the Viking Corridor, the results of break-up of continents (HALLAM, 1983; SMITH & TIPPER, 1986; RICCARDI, 1991; WESTERMANN, 1993; ABERHAN, 2001). It also differed from the other seaways, lsuch as the Cretaceous Western Interior Seaway

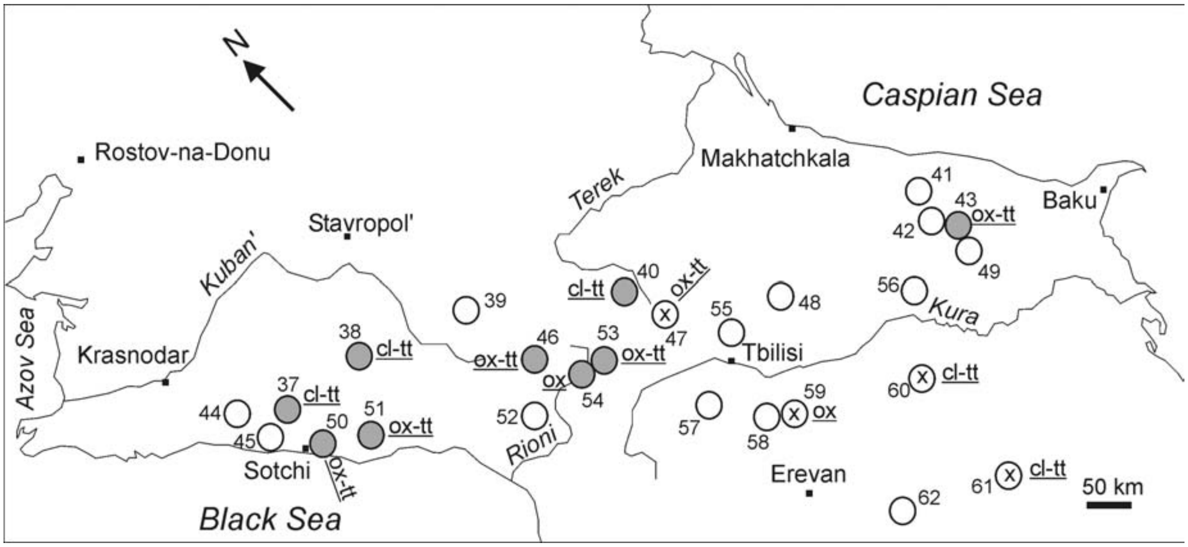

Fig. 7. The location of the Callovian-Tithonian carbonate buildups in the "zones" of the Caucasus (data was extracted from ROSTOVTSEV *et al*. (1992); for the western part of the Caucasus, it was supported by personal field observations) (for an explanation of the "zones", see Fig. 3B). "Zones" where carbonate buildups were evidently documents are highlighted as gray, while "zones" where only coral founds are known are marked by x. The age of buildup- or coral-bearing deposits is indicated.

in North America (REYNOLDS & DOLLY, 1983; SAGEMAN & ARTHUR, 1994; ROBERTS & KIRSCHBAUM, 1995; WHITE *et al.,* 2001, 2002).

The western branches of this seaway included the oceanic basins of the Western Neotethys, such as the Meliata, Maliac, Pindos and Vardar, as well as the Alpine Tethys which opened during the Jurassic (STAMPFLI & BOREL, 2002; BROWN & ROBERTSON, 2004; GOLONKA, 2004). The central part of the seaway consisted of straits separating the blocks of Moesia, Rhodope and Western Pontides. Further east, the seaway communicated with the small Izmir-Ankara Ocean (STAMPFLI & BOREL, 2002). It was directly connected with the Caucasian Sea. The eastern branches of the mentioned seaway extended as straits between the Alborz, South Caspian, Aghdarband, Herat and other terranes of the central part of the northern Neotethyan margin (GOLONKA, 2004). STAMPFLI & BOREL (2002) additionally placed the so-called South Caspian Ocean eastwards of the Caucasus, which seems to be a fragment of the seaway. The latter ended in two branches, as is suggested from the palaeoreconstructions of GOLONKA (2004). Northwards, the seaway connected the basin between the Turan, Herat and Pamirs landmasses, while southwards it led directly to the Neotethys Ocean.

Conclusions

This study of the Jurassic palaeogeography of the Caucasus allows the formulation of some important conclusions:

1) the Caucasian Sea occupied most, although not all, of the studied area during the entire Jurassic;

2) in the Late Toarcian, the Caucasian Sea embraced most of the Caucasus, including the Greater Caucasus Basin and the Black Sea – Caspian Sea Basin, and was opened to the Neotethys Ocean, which covered the Exterior Caucasian Basin;

3) in the Early Bajocian, the Caucasian Sea comprised the Greater Caucasus Basin, it opened to the epicontinental seas of the Russian Platform, and it was connected with the Neotethys Ocean by the straits between islands of the Transcaucasian Arc;

4) in the Middle Oxfordian, the Caucasian Sea also covered the Greater Caucasus Basin and was open to both the epicontinental sea of the Russian Platform and the Neotethys Ocean;

5) during the Jurassic, the Caucasus was included in the long seaway, which stretched along the northern margin of the Neotethys.

Further studies are necessary to verify and detalize the very simple palaeogeographic reconstructions proposed in this paper. A significant task is the collection of data on the carbonate buildups, which has already been made for the Azerbaijanian part of the Caucasus (AKHMEDOV *et al*., 2003). These data will help to delineate the Late Jurassic carbonate platform. Special attention should also be paid to the high-resolution palaeotectonic interpretations.

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Резиме

Палеогеографски оквири Кавказа у Јури: Кавкаско море и Неотетиски океан

Кавказ представља пространу издужену област између Црног мора и Каспијског језера, која обухвата југоисточну Русију и целу Грузију, Јерменију и Азербејџан. Ова област се за време јуре налазила на северном ободу Неотетиског океана и представљала је "главни" прелаз између западног и средњег дела северног Неотетиса. Ранија тумачења њене палеогеографије су застарела и често засnована на погрешним схватањима. Овај рад је покушај да се реконструишу палеогеографски оквири Кавказа у три временска раздобља – горњи тоар, доњи бајес и средњи оксфорд. Територија Кавказа је подељена на 62 посебне области, које се традиционално називају "зонама". За сваку зону је дато тумачење палеосредине свих формација и то континентална, плитководна и дубоководна палеосредина за поменута временска раздобља. Анализом карата распореда палеосредина утврђени су палеогеографски елементи података за Кавказ у реконструкције читавог Неотетиса. Као коначни резултат добијен је скуп палеогеографских скица које дају контуру Кавказа из свих проучаваних раздобља.

У горњем тоару (око 177 Ма), пространо море, за које се предлаже назив Кавкаско море, отварало се према Неотетиском океану. У ово море су залазили широки мореузи између копна са западне и источне стране ове области. Кавкаско море је обухватало два седиментациона басена, раздвојена подводним планинским ланцем, који су се можда спајали на западу. То море су вероватно карактерисала два архипелага врло малих острва која су образовала северни и јужни транскавкаски лук. Граница између Кавкаског мора и Неотетиског океана протезала се дуж јужног транскавкаског лука. Спољашњи, јужни кавкаски басен био је опкољен Неотетиским океаном.

У доњем бајесу (око 171 Ма) проучавану територију је заузимало Кавкаско море. Оно је било одвојено од Неотетиског океана архипелагом транскавкаског лука. Веза између мора и океана остваривала се мореузима између острва и копна на западу.

На северу се Кавкаско море отварало према великом али плитком унутрашњем мору које је заузимало пространу област руске платформе. То унутрашње море је обухватало само један седиментациони басен. Резултат трансгресије је формирање великог шелфа на северу басена, а структура мора се у доњем бајесу карактерисала великом асиметријом. Граница између Кавкаског мора и Неотетиског океана, као и у претходном случају, протезала се дуж транскавкаског лука. Спољни басен је био обухваћен Неотетиским океаном. Острва која су тамо постојала могла су бити вулканског порекла, па су према томе у вези са широким појасом интензивног магматизма северно од главне зоне подвлачења северног Неотетиса.

У средњем оксфорду (око 158 Ма) је проучавана територија још увек била под Кавкаским морем. Била је само мало изолована од Тетиског океана поменутим подморским планинским ланцем транскавкаског лука. Мореузи између копна западно и источно од овог мора такође су га повезивала са Неотетиским океаном. Са севера се Кавкаско море отварало према унутрашњем мору као и у доњем бајесу, али се његова површина смањила. Море је обухватало само један седиментациони басен. Велики шелф је постојао на североистоку басена. Тако се морски басен у средњем оксфорду карактерисао великом асиметријом у источном делу, али му је западни део био доста симетричан. Граница између Кавкаског мора и Неотетиског океана протезала се дуж транскавкаског лука. Схематска карта указује да је спољашњи кавкаски басен био обухваћен Неотетиским океаном.

Широка распрострањеност карбонатних наслага представља значајну карактеристику кавкаских басена горње јуре. Током јуре је створен морски пролаз дуж обода Неотетиса, а Кавкаско море је постало његов значајни део. Западни огранци овог морског пролаза обухватили су океанске басене западног Неотетиса као што су Мелиата, Малиак, Пинд и Вардар као и алпски Тетис. Средњи део морског пролаза састојао се од мореуза који су раздвајали блокове Мезије, Родопа и западних Понтида. Даље на исток морски пролаз је био у вези са малим Измирско-анкарским океаном, који је био директно повезан са Кавкаским морем. Источни огранци морског пролаза настављали су се у мореузе између Алборза, јужног Каспија, Агдарбанда, Херата и других терана средњег дела северног обода Неотетиса. Такозвани Јужни каспијски океан источно од Кавказа је по свој прилици представљао део басена између туранског, хератског и памирског копна, док је на југу водио директно у Неотетиски океан.

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Trans-border (east Serbia/west Bulgaria) correlation of the Jurassic sediments: main Jurassic paleogeographic units

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Abstract. In the region across the Serbian/Bulgarian state border, there are individualized 5 Jurassic paleogeographic units (from West to East): (1) the Thracian Massif Unit without Jurassic sediments; (2) the Lužnica-Koniavo Unit – partially with Liassic in Grsten facies and with deep water Middle Callovian–Kimmeridgian (*p. p.*) sediments of the type "*ammonitico rosso*", and Upper Kimmeridgian–Tithonian siliciclastics flysch; (3) The Getic Unit subdivided into two subunits – the Western Getic Sub-Uni – without Lower Jurassic sediments and the Eastern Getic Sub-Unit with Lower Jurassic continental and marine sediments, which are followed in both sub-units by carbonate platform limestones (type Stramberk); (4) the Infra (Sub)-Getic Unit – with relatively deep water Liassic and Dogger sediments (the Dogger – of type "black shales with *Bossitra alpina*") and Middle Callovian–Tithonian – of type "*ammonitico rosso*"; (5) the Danubian Unit – with shallow water Liassic, Dogger and Malm (Miroč–Vrška Čuka Zone, deep water Dogger and Malm (Donjomilanovačko–Novokoritska Zone).

Key Words: Jurassic, paleogeographic units, south-eastern Serbia, western Bulgaria.

Апстракт: У подручју српско-бугарске државне границе издвојено је пет јурских палеогеографских јединица (од запада ка истоку): 1. Тракијски масив без јурских седимената; 2. Лужница–Кониаво – делимично са лијасом развијеним у грестенској фацији и са дубоководним седиментима средњег каловеја–кимерица (*p. p.*) типа "*ammonitico rosso*" и силикокластичним флишом горњег кимерица–титона; 3. Гетикум, подељен на Западногетску подјединицу без доњојурских седимената и Источногетску подјединицу са доњојурским континенталним и маринским седиментима после којих у обе подјединице следе кречњаци карбонатске платформе (типа Stramberk); 4. Инфра(суб)гетикум са релативно дубоководним седиментима лијаса и догера (догер типа "црних глинаца са *Bossitra alpina*") и средњег каловеја–титона (типа "*ammonitico rosso*"); 5. Данубијска јединица са плитководним лијасом, догером и малмом (зона Мироч–Вршка Чука), дубоководним догером и малмом (Доњомилановачка–новокоритска зона).

Кључне речи: јура, палеогеографске јединице, југоисточна Србија, западна Бугарска.

Introduction

During the Springer of 2005, a Serbian–Bulgarian team commenced bilateral research with the aim of making an effort to unify the views of Bulgarian and the Serbian geologists concerning the geology of the Jurassic on both sides of the Bulgarian/Serbian border. For the beginning, an attempt will be made to unify our opinions on the main paleogeographic units and subsequently new research on the lithostratigraphy and the correlation of Jurassic sediments from both side of the border will be performed.

During the Jurassic, from the Romanian Carpathians, the following main paleogeographic units can be prolonged in eastern Serbia: Thracian Massif Unit, Lužnica–Koniavo Unit, Getic, Infra (Sub)-Getic, Danubian. They

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are more or less accepted by the Serbian geologists, but are not used in Bulgaria. These units, which are strictly paleogeographic and differ from the present day tectonic units, have a bipartite structure, built of two ensembles of beds – lower (the Lower Jurassic up to the Lower Callovian) and upper (the Middle Callovian–Tithonian). From the differences in these two parts, the main paleogeographic units in the studied region were reconstructed.

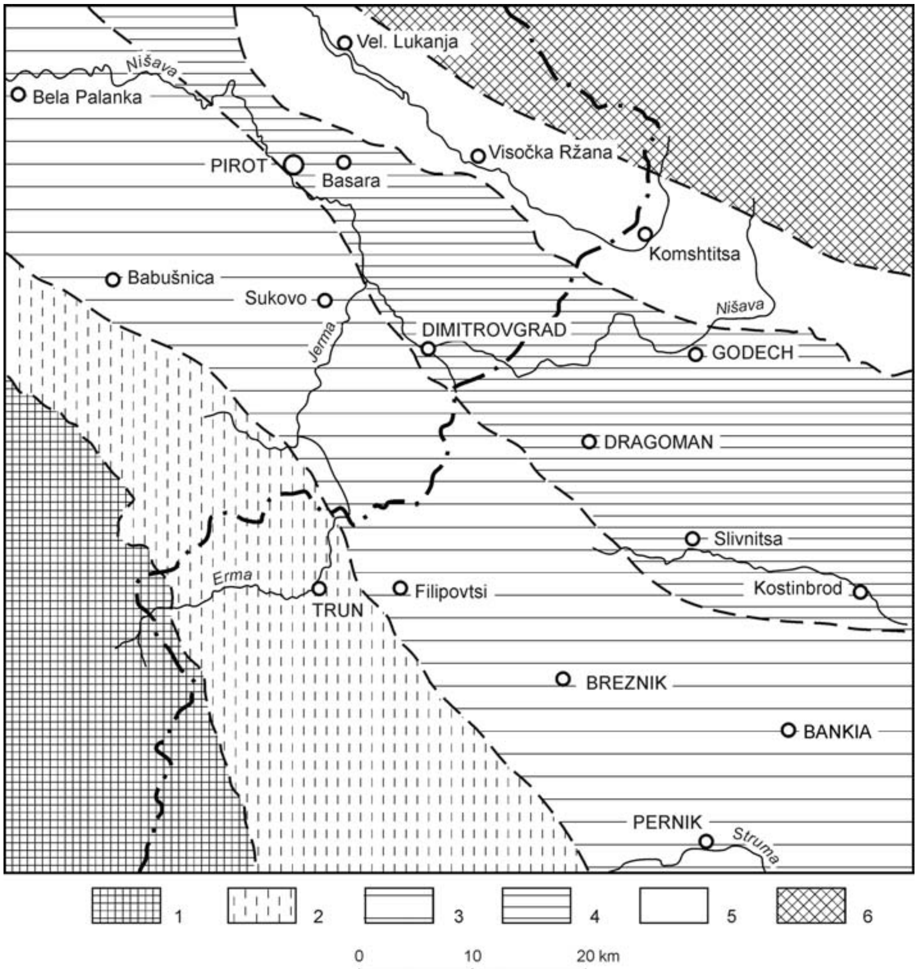

Fig. 1. Main Jurassic paleogeographic units in south-eastern Serbia and western Bulgaria. **1**, Thracian Massif Unit; **2**, Lužnica–Koniavo Unit; Getic Unit: **3**, Western Getic Sub-Unit; **4**, Eastern Getic Sub-Unit; **5**, Infra (Sub)-Getic Unit; **6**, Danubian Unit.

The Thracian Massif Unit (Fig. 1)

The name Thracian Massif Unit is used for the paleogeographic unit which unifies the Rhodope Massif, the Serbo-Macedonian Massif and the Srbsko-Makedonska Masa (DIMITRIJEVIĆ, 1992), etc. During the Jurassic, the Thracian Massif Unit played the role of source area and was never covered by sea water, and hence there are not marine sediments on it. For this unit (ANDJELKOVIĆ *et al*., 1996) used the name of Moravska Zone.

The Lužnica–Koniavo Unit (Figs. 1, 2)

A characteristic for the Jurassic of this paleogeographic unit is the almost complete lack of Lower Jurassic sediments and the presence of Upper Jurassic deep water deposits. Lower Jurassic deposits exist only in the Svetlya paleograben in western Bulgaria. They are represented (Fig. 2) in the base by continental clays and sandstones (of Gresten facies), covered by Middle and Upper Liassic bioclastic and sandy limestones (of type Gresten – *sensu lato*). Apart from the territory of the Svetlya graben, during the Early Jurassic, the terrain of the Lužnica–Koniavo Unit represented dry land. During the Middle Jurassic (DODEKOVA *et al*., 1984), the whole area was covered by shallow marine waters, and sandstones and higher bio- and lithoclastic limestones were sedimented. Only in the western part of the territory of Bulgaria were black shales deposited. With the Middle Callovian started a relative subsidence of the terrain and the formation of "*ammonitico rosso*" type sediments, and since the Late Kimmeridgian, the deposition of flysch type alternation of argillites/marls and graded bedding sandstones – Niš-Troyan Flysch Trough (Basin) (NACHEV, 1976), Lužnica Flysch, or Ruj Flysch (DIMITRIJEVIĆ & DIMITRIJEVIĆ, 1987) started. As a whole, the terrain is noted as Supra Getikum (DIMITRIJEVIĆ, 1992), or Supragetic units (SANDULESCU & DIMITRESCU, 2004). This unit is noted (ANDJELKOVIĆ *et al*., 1996) as the tectonic structure Lužnička nappe (K-I) of the Karpatikum. In Bulgaria (TCHOUMATCHENCO, 2002) the name Jurassic Kraishtides is used for this unit. To avoid discordance between the meaning included by the different authors, the most neutral term of Lužnica–Koniavo Unit is used here.

The Getic Unit (Figs. 1, 2)

The paleogeographic unit with the same name is well known in the Romanian East and South Carpathian (SANDULESCU & DIMITRESCU, 2004; etc.), as well as in Serbia (DIMITRIJEVIĆ, 1992; KRAÜTNER &

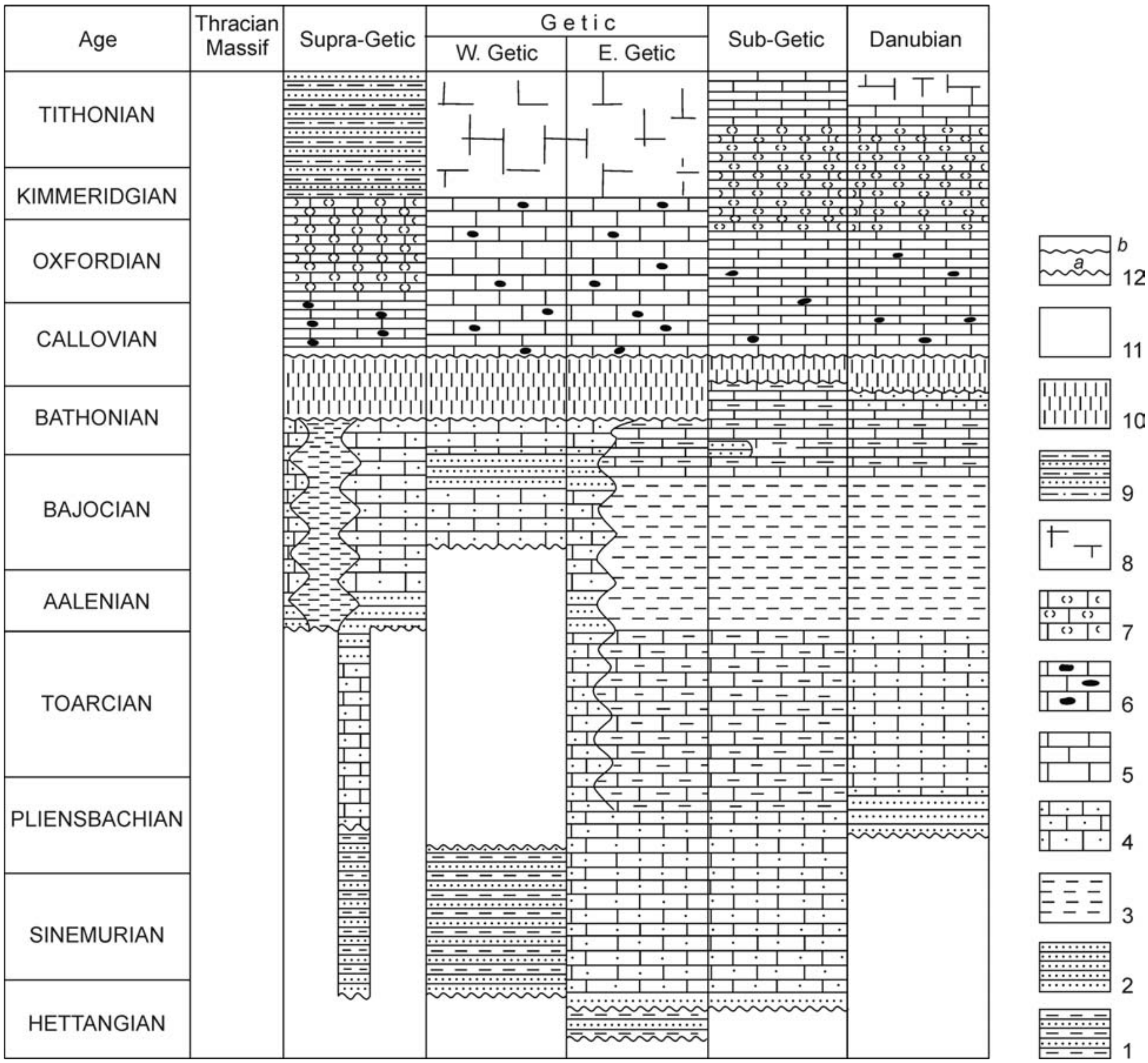

Fig. 2. Stratigraphical section across the main Jurassic paleogeographic units in south-eastern Serbia and western Bulgaria. **1**, Continental clays and sandstones (Gresten facies); **2**, sandstones; **3**, black shales; **4**, sandy and bioclastic limestones; **5**, micritic limestones; **6**, micritic limestones with chert concretions; **7**, nodular and lithoclastic limestones (type "*ammonitico rosso*"); **8**, thick bedded limestones (type "*Stramberk*"); **9**, flysch type alternation of sandstone and clay; **10**, interval with submarine break in the sedimentation; **11**, interval with aerial break in the sedimentation (dry land conditions); **12**, stratigraphic boundaries: a, transgressive; b, connected with submarine break in the sedimentation.

KRSTIĆ, 2003). In the Bulgarian literature, this paleogeographic unit is known as Dragoman Jurassic Horst (SAPUNOV *et al.*, 1985). As a Jurassic paleogegraphic unit, the Getic finished in the region south of the town of Pernik on Bulgarian territory, where it is "cut" by the Thracian Massif Unit (its Rhodope part).

More uniform for the Getic Unit is the upper part (beds), which consist of Callovian–Upper Jurassic–Lower Cretaceous thick bedded carbonate platform limestones, in many places with coral reefs. However the lower part – the Jurassic sediments lying below these thick bedded bioclastic limestones is different in different parts of the Getic Unit. This permited the division of the Getic Unit into two sub-units: the Western Getic Sub-Unit with Middle Jurassic marine sediments and the Eastern Getic Sub-Unit with Lower and Middle Jurassic in the lower part.

The Western Getic Sub-Unit (Figs. 1, 2)

The Western-Getic Sub-Unit is situated to the East of the Lužnica–Koniavo Unit. It is structured by two parts. The lower part is built up of Middle Jurassic shallow water sandstones and sandy and bioclastic limestones, which lie locally on continental Lower Jurassic clays and sandstones of Gresten facies. The upper part is built up of relatively thick bedded carbonate platform limestones, in the lower part with concretions of white chert and in the upper part by chert-free thick bedded shallow water bioclastic limestones.

The Western Getic Sub-Unit represents the Karpatikum in the territory of Serbia and enters into the following tectonic units (ANDJELKOVIĆ *et al.*, 1996): K-II – Gornjačko-Suvoplaninska nappe, K-IV – Kučajsko-Svrljiška nappe.

The Eastern Getic Sub-Unit (Figs. 1, 2)

The characteristic for this paleogeographic unit (e.g. the section of Berende Izvor in western Bulgaria) is the presence of Lower Jurassic sediments upwards from the base: continental clay and sandstones, marine sandstones, bioclastic limestones and marls, interbedded by clayey limestones, and of Middle Jurassic black shales with *Bositra alpina* (facies well known in the Alps), followed by clayey limestones and marls, caped by a thin bed of sandy, crinoidal limestones. To West (e.g. near the town Slivnitsa), the Liassic is represented by irony red limestones, and the Dogger by sandstones and bioclastic limestones, similar to those in the Western Getic Sub-Unit. The upper parts are also similar to those of the Western Getic Sub-Unit – thick bedded limestones, in the base with concretions of white chert, and capped by chert free limestones. These sediments build the Vidlič Mountain in Serbia and are individualized as Vidlič Scale (KRAÜTNER & KRSTIĆ, 2003), or Vidlička nappe (K-VII) (ANDJELKOVIĆ *et al.*, 1996). In Bulgaria it is part of the Dragoman paleo-horst (SAPUNOV *et al.*, 1985).

The Infra (Sub)-Getic Unit (Figs. 1, 2)

The Infra (Sub)-Getic Unit, with relatively deeper water sediments is situated to the east of the Getic Unit. It is built also built up of two parts: lower and upper. The sedimentation (Fig. 2) of the lower part started during the Late Hettangian with marine sandstones, continued with bioclastic limestones, followed by marls, intercalated by clayey limestones. The Middle Jurassic is represented by black shales with *Bossitra alpina*, followed by marls and clayey limestones, similar to those in the lower part of the Eastern Getic Sub-Unit. The Middle Callovian–Tithonian sediments are represented by lithoclastic and nodular grey and red limestones, similar to the facies "*ammonitico rosso superiore*", well-known in the Alps. In Bulgaria, the Infra-Getic paleogeographic Unit is known as Izdremets Paleograben (SAPUNOV *et al.*, 1985). In the Serbian literature it is known as Infra Getikum (DIMITRIJEVIĆ, 1992), Dobrodolsko-Grliška nappe (K-VIII) of the Karpatikum and the Staroplaninsko-Porečka Unit (ANDJELKOVIĆ *et al.*, 1996), or Upper Danubian (KRAÜTNER & KRSTIĆ, 2003).

The Danubian Unit (Figs. 1, 2)

The terrain of the Danubian Unit is situated to the East of the Infra (Sub)-Getic Unit. The Lower Jurassic is represented by shallow water brecco-conglomerates, sandstones, clays, clayey limestones with bivalves and sparite limestones with crinoids. The Middle Jurassic in the region of Danubian Unit is represented by two facies: (a) the Klaus facies (red nodular and ferruginous limestones of Upper Bajocian, Bathonian and Lower Callovian age – stratigrapical condensation; (b) laterally it passed to black shales with *Bositra alpina*. The Callovian–Upper Kimeridgian is developed in the facies "*ammonitico rosso*" (Donjomilanovačko–Novokoritska region in Serbia and Mihaylovgrad Paleo-Graben in Bulgaria). The Oxfordian–Berriasian in Serbia is built of deep water sediments: radiolarites and limestones with cherts.

In the Bulgarian literature (SAPUNOV *et al.*, 1988), this Unit is known as the Vratsa Jurassic Horst; in the Serbian literature it is individualized as Milanovačko-Novokoritska Unit (ANDJELKOVIĆ *et al.*, 1996), the Danubikum (DIMITRIJEVIĆ, 1992), the Lower Danubian Units (KRAÜTNER & KRSTIĆ, 2003), etc.

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Резиме

Упоређење седмената главних јурских палеогеографских јединица у граничној области источне Србије и западне Бугарске

На бугарским и српским геолошким картама (нпр. геолошке карте Србије и Бугарске у размери 1:100000, недавно објављене у обе земље) "нормално" се види да захватају терене само до државне границе. Са обе стране границе геолошке карте су потпуно различите и веома је тешко утврдити односе геолошких јединица. Због тога је једна мешовито српско-бугарска екипа геолога у пролеће 2005. године започела истраживања у области државне границе у циљу усаглашавања гледишта о геологији јуре са обе стране бугарско-српске границе. За почетак покушавамо да усагласимо наша мишљења о главним палеогеографским јединицама, а затим да упоредимо јурске седименте на обе стране границе.

Главне палеогеографске јединице из времена јуре које се протежу од румунских Карпата у источној Србији су: Тракијски масив, Лужница–Кониаво, Гетикум, Инфра(суб)гетикум и Данубијска јединица. Њих мање или више прихватају српски геолози, али се та подела не примењује у Бугарској. Највећа разлика је у појму "јужни Карпати". У Бугарској, према BONCHEV-у (1936, 1938) до новијих радова DABOVSKI *et al*. (2002) и NACHEV & NACHEV (2003), "јужним Карпатима" су се називали само доњокредни и горњокредни седименти северозападе Бугарске на Крајинским висовима западно од вароши Кула – зона простирања синајског флиша. За друге седименте који прелазе српско-бугарску границу, а који се настављају на јурске јединице румунских Карпата, користе се бугарски термини само до државне границе. Настојаћемо да пратимо палеогеографске јединице које су откривене са обе стране границе и назваћемо их по предности њиховог обележавања.

Те јединице су строго палеогеографске, али палеогеографија је предодређена јурском тектоником у овом делу Балканског полуострва. Ове палеогеографске јединице имају двоструку структуру, односно изграђене су од две групе слојева – доња (доња јура до доњег каловеја) и горња (средњи каловеј–титон). На основу разлика ова два дела реконструисали смо главне палеогеографске јединице у проучаваној области. Шта је карактеристично за јуру ових јединица? Јединица Тракијског масива је без јурских седимената; јединица Лужница–Кониаво делимично садржи лијас у грестенској фацији и дубоководне средњокеловејске–кимерицске (*p. p.*) седименте типа "*ammonitico rosso*" и горњокимерицско–титонски силикокластични флиш; Гетска јединица је подељена на Западногетску подјединицу са доњојурским седиментима и Источногетску подјединицу са доњојурским континенталним и морским седиментима, праћена у обе подјединице кречњацима карбонатне платформе (типа Страмберк); Инфра(суб)гетска јединица садржи релативно дубоководне лијаске и догерске седименте (догер типа "црних глинаца са *Bossitra alpina*") и средњокеловејско–титонске типа "*ammonitico rosso*"; Данубијска јединица садржи плитководни лијас, догер и малм (зона Мироч–Вршка Чука) и дубоководни догер и малм у Доњомилановачко–новокоритској зони.

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Tran-sborder (south-east Serbia/west Bulgaria) correlations of the Jurassic sediments: Infra-Getic Unit

Platon Tchoumatchenco[1], Dragoman Rabrenović[2], Barbara Radulović[3] & Vladan Radulović[4]

Abstract. The Infra-Getic Unit is a palaeogeographic unit, predestined by palaeotectonics. From the point of view of geological heritage, it represents a geosites framework. For the purpose of the correlation, the Serbian sections of Lukanja, Bogorodica Monastery, Rosomač and Senokos, as well as the Bulgarian sections of Komshtitsa, Gintsi, and Stanyantsi were used. The Jurassic sediments of the Infra-Getic Unit crop out on the southern slops of the Stara Planina Mountain in east Serbia and west Bulgaria. The Lower Jurassic started with continental and continental-marine sediments (clays and sandstones) (Lukanja clastics and Lukanja coal beds in Serbia and the Tuden Formation in Bulgaria) and continue with Lukanja quartz sandstones (Serbia) and the Kostina Formation (Bulgaria). These sediments are covered by Lukanja brachiopod beds and Lukanja limestones (Serbia) and the Romanov Dol, Ravna and Dolni Loukovit Members of the Ozirovo Formation (Bulgaria) predominantly consist of bioclastic limestones. The sedimentations follow with Lukanja belemnites-gryphaea beds (marls and clayey limestones), which in Bulgaria correspond to the Bukorovtsi Member (also marls and clayey limestones) of the Ozirovo Formation. The Middle Jurassic sedimentation started with black shales with *Bossitra alpine*. These sediments are individualized in Serbia as Senokos aleurolites and clays and in Bulgaria they are known as the Etropole Formation. In Serbia the section continues with sandstones called Vodenički sandstones of Bajocian age, known in Bulgaria as the Dobrogled Member of the Polaten Formation. However, in Bulgaria, the age is Upper Bajocian–Lower Bathonian, and it cover the marls of the lower member (Gornobelotintsi Member) of the Bov Formation and is covered by the upper member – alternation of marls and clayey limestones – the Verenitsa Member of the Bov Formation. The Vodenički sandstones–Dobrogled Member which ended their distribution in the section of Komshtitsa, to the east (in the Gintsi section), they are not represented – build a body of sandstones, a prodelta coming from the west to the east. The Bov Formation corresponds to the Senokos ammonite beds in east Serbia. The upper boundary of the Senokos ammonite beds and of the Bov Formation is sharp. It is covered by grey limestones of the Yavorec Formation in Bulgaria and by the Kamenica limestones in eastern Serbia. They are covered by grey or red nodular/lithoclastic limestones ("*ammonitico rosso*" type) of the Gintsi Formation in Bulgaria and the Pokrovenik ammonitic (*acanthicum*) limestones in Serbia. The Jurassic section in the Infra-Getic ended with grey micritic and lithoclastic limestones, which belong to the Rosomač and Rsovci limestones in east Serbia and to the Glozhene Formation in Bulgaria.

Key words: Jurassic, Infra-Getic, correlations, lithostratigraphic units, south-eastern Serbia, western Bulgaria.

Апстракт. Инфрагетска јединица је палеотектонски условљена палеоеографска јединица а са становишта геолошког наслеђа представља подручје геолошких објеката. У циљу упоређења анализирани су профили Лукање, Манастира Богородице, Росомача и Сенокоса у Србији и профили Комштице, Гинци и Стањанци у Бугарској. Јурски седименти Инфрагетске јединице су откривени на јужним падинама Старе Планине у источној Србији и западној Бугарској. Доња јура почиње са континенталним и континентално-маринским седиментима (глинци и пешчари) (Лукањски кластити и лукањски слојеви угља у Србији

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и Туден формација у Бугарској) и наставља се Лукањским кварцним пешчарима (Србија) и Костином формацијом (Бугарска). Ови седименти су прекривени Лукањским брахиоподским слојевима и Лукањским кречњацима (Србија) и члановима Романов Дол, Равна и Долни Луковит Озировске формације (Бугарска) ицграђени претежно од биокластичних кречњака. Седиментација се наставља Лукањским белемнитско-грифејским слојевима (лапорци и глиновити пешчари) којима у Бугарској одговара Букуровачки члан (такође лапорци и глиновити пешчари) Озировске формације. Средњојурска седиментација почиње црним глинцима са *Bossitra alpina*, седиментима који су у Србији познати као Сенокоски алевролити и глине, а у Бугарској као Етрополска формација. У Србији се профил наставља Воденичким пешчарима бајеске старости, који су у Бугарској познати као Доброгледски члан Полатенске формације где су горњобајеске–доњобатске старости. Ови пешчари прекривају лапорце члана Бов формације (Горњобелотиначки члан), а преко њих лежи горњи члан исте формације (Веренички члан) изграђен од смене лапораца и глиновитих кречњака. Воденички пешчари, односно Доброгледски члан, завршава се у профилу Комштице, даље према истоку (у профилу Гинци) они нису развијени. Бовска формација одговара Сенокосним амонитским слојевима у источној Србији. Горња граница Сенокосних амонитских слојева и Бовске формације је оштра; прекривена је сивим кречњацима Јаворечке формације у Бугарској, односно Каменичким кречњацима у источној Србији. Преко њих леже сиви и црвени квргави или литокластични кречњаци (типа *ammonitico rosso*) Гинци формације у Бугарској и Покровенички акантички кречњаци у источној Србији. Јурски профил у Инфра-генетикуму завршава се сивим микритским и литокластичним кречњацима Росомача и Рсоваца у источној Србији и Гложенској формацији у Бугарској.

Кључне речи: Јура, Инфра-гетик, упоређење, литостратиграфске јединице, југоисточна Србија, западна Бугарска.

Introduction

In this paper we expose our essay to make correlations accross the Serbian/Bulgarian state border of the existing in the published literature Jurassic formal lithostratigraphic units in the framework of the Infra-Getic paleotectonic and paleogeographic unit (Fig. 1). This unit is known in the Serbian literature presumably as the Staroplaninska–Porečka units (ANDJELKOVIĆ *et al*., 1996) and as the Izdremets Jurassic paleograben (SAPUNOV *et al*., 1986, etc.).

Substratum

The substratum of the Jurassic sediments in the studied area of the Infra (Sub)-Getic consists of Triassic rocks. In the Serbian Bogorodica, Rosomač and Senokos sections, the substratum consists of redish aleurolites, marls to argillites with concretions of sphaero-siderites, inter-bedded by sandstones, from 5 up to 100 m thick. They are called the Senokos red series (ANDJELKOVIĆ, 1996, p. 78) (Pl. 1, Fig. 2). These sediments cross the state border near the village Komshtitsa and continue to the east up to the Gintsi village. They are the Bulgaria Komshtitsa Formation in the Bulgaria (TRONKOV, 1969). The problem of the age is controversial because of the lack of characteristic fossils: in Serbia two opinions exist: (1) that of ANDJELKOVIĆ *et al*. (1996, p. 78, etc.), after which the Senokos red series is with the Late Triassic age; (2) this of UROŠEVIĆ & RADULOVIĆ (1990), after which they are Rhaeto–Liassic. ANDJELKOVIĆ (1996, p. 78) considered the Senokos Formation as Upper Rhaetian because they were formed under a dry and hot climate, while Jurassic sediments were formed under humid conditions. In Bulgaria, the Komshtitsa Formation, after TRONKOV (1993, p. 170) is connected by a progressive lithologic passage with the Carnian Russinovdol Formation and for that reason it is considered as Carnian–Norian.

In the section of Velika Lukanja, the Jurassic substratum is represented by 2 m of thick red breccia limestones – the Jelovica limestones (Pl. 1, Fig. 1), of Late Raetian age (ANDJELKOVIĆ *et al*., 1996, p. 78).

In the out crops near the villages Stanyantsi, Berende Izvor, Tuden, etc. in Bulgaria, the Jurassic substratum is built up of grey Middle Triassic limestones of the Iskar Carbonate Group.

Lower Jurassic (Figs. 2, 3)

In the vicinities of the villages of Velika Lukanja (Serbia) and Stanyantsi (Bulgaria), the Lower Jurassic sedimentation started by a continental sedimentation (Fig. 2). These sediments are called, in Serbia, the Lukanja clastics and Lukanja coal beds (ANDJELKOVIĆ, 1996, p. 84–86) and, in Bulgaria, the Tuden Formation (SAPUNOV *et al*., 1990). They are covered by marine sandstones.

The Lukanja clastics, (2–120 m thick), (known also as „podinski nivo", ANDJELKOVIĆ, 1958, pp. 13–14) lie with discordance on different Triassic rocks. The Lukanja clastics are built up of conglomerates and sandstones. The conglomerates are with quartz pebbles and cement of silica, rarely of clay. The sandstones predominantly consist of quartz and silica or clayey cement. (Pl. 1, Fig. 4).

The Lukanja coal beds (8–150 m thick) started with fine grained quartz sandstones are gradually intercalated by clay and clayey sandstones with coal beds (Pl. 1, Fig. 3).

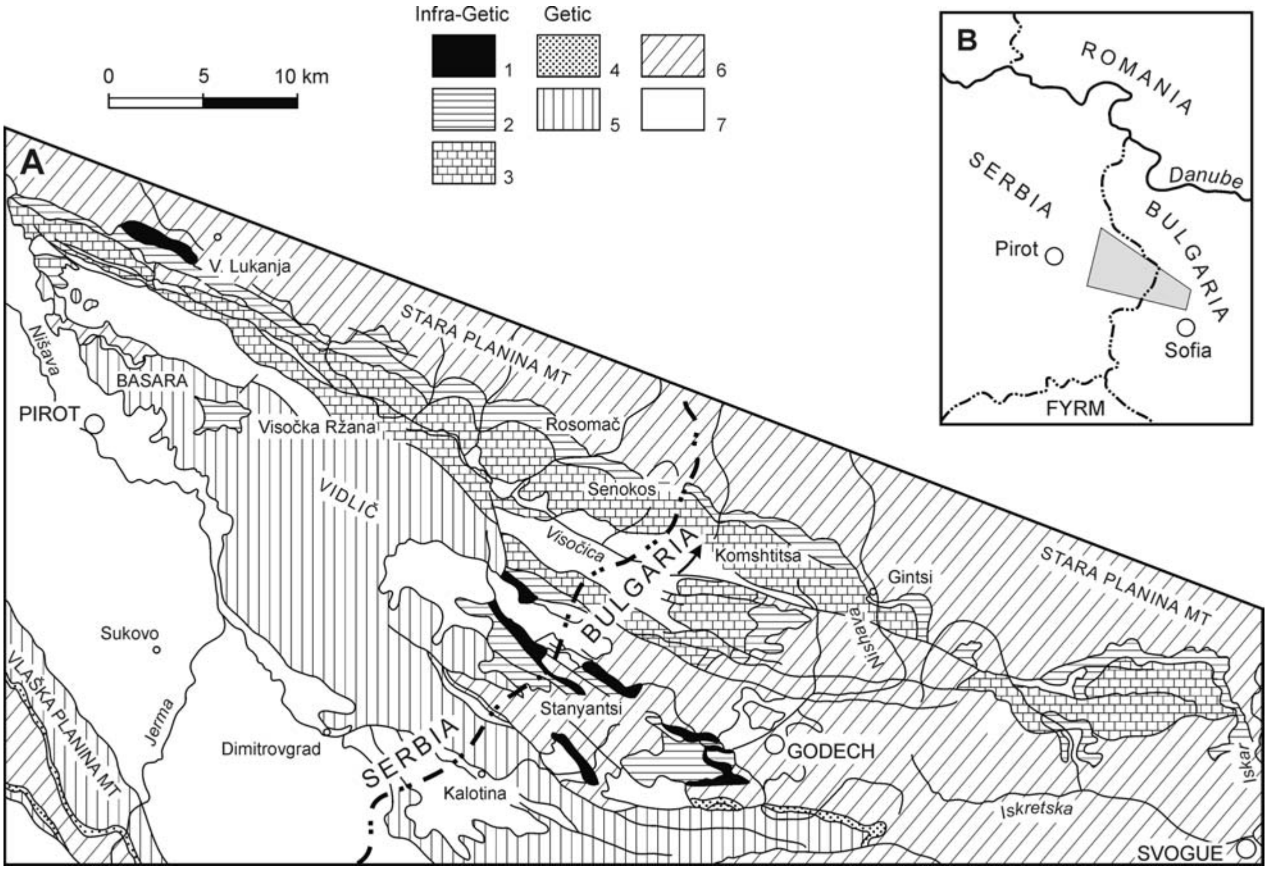

Fig. 1. Geological map of the studied region (simplified, after KRAÜTNER & KRSTIĆ, 1993) with the location of the studied sections. **A**. Infra-Getic: 1, Lower Jurassic continental and continental/marine: sandstones and clays; 2, Lower and Middle Jurassic marine sandstones, bioclastic limestones, marls, black shales with *Bossitra alpina*, clayey limestones and marls; 3, Middle Callovian–Tithonian micritic, nodular and/or lithoclastic limestones; Getic: 4, Middle Jurassic sandstones, sandy and bioclastic limestones; 5, Middle Callovian–Tithonian reef and subreef limestones; 6, substratum; 7, cover; **B**. Location of the studied region.

The Tuden Formation (about 30 m thick) consists predominantly of clays, intercalated with sandstones. The sections started with grey to black clays and coal shales; the higher sections are intercalated with fine grained sandstones, often laminated (Pl. 3, Fig. 1).

Marine sandstones (Fig. 3) also lie on continental Lukanja coal beds and the Tuden Formation, as well as directly on Triassic sediments. In East Serbia, they are known as Lukanja quartzy sandstones (ANDJELKOVIĆ *et al*., 1996, pp. 86–87) and in Bulgaria as the Kostina Formation (SAPUNOV *in* SAPUNOV *et al*., 1967) (Pl. 3, Fig. 2)

The Lukanja quartzy sandstones (Pl. 1, Fig. 5) (2.8 m thick in Rosomač, 8 m in Senokos and up to 120 m in the Mala Lukanja River) are built of coarse to middle

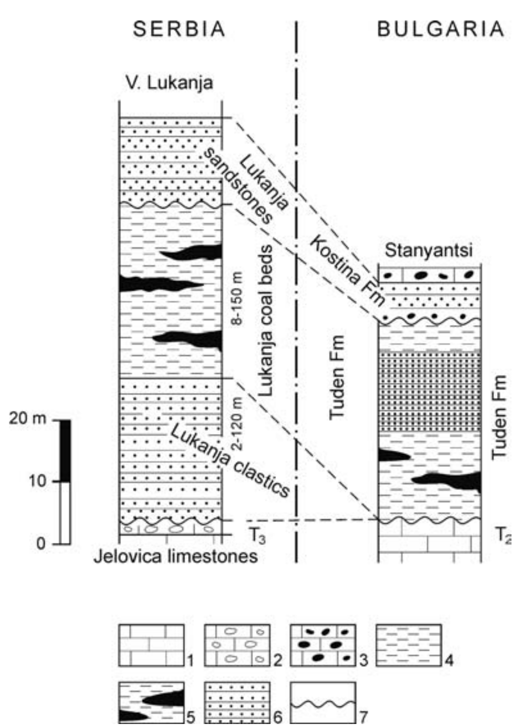

Fig. 2. Simplified columnar sections of the continental and continental-marine Lower Jurassic sediments of the Infra-Getic domain: Velika Lukanja (Pirot)–Stanyantsi (Godech) area. 1, micritic limestones (Middle Triassic); 2, red brecciated limestones = Senokos red series (Upper Rhaetian); Lower Jurassic: 3, black to grey limestones with quartz pebbles; 4, clays; 5, clays with coal beds and/or coal clays; 6, sandstones; 7, transgressive boundary.

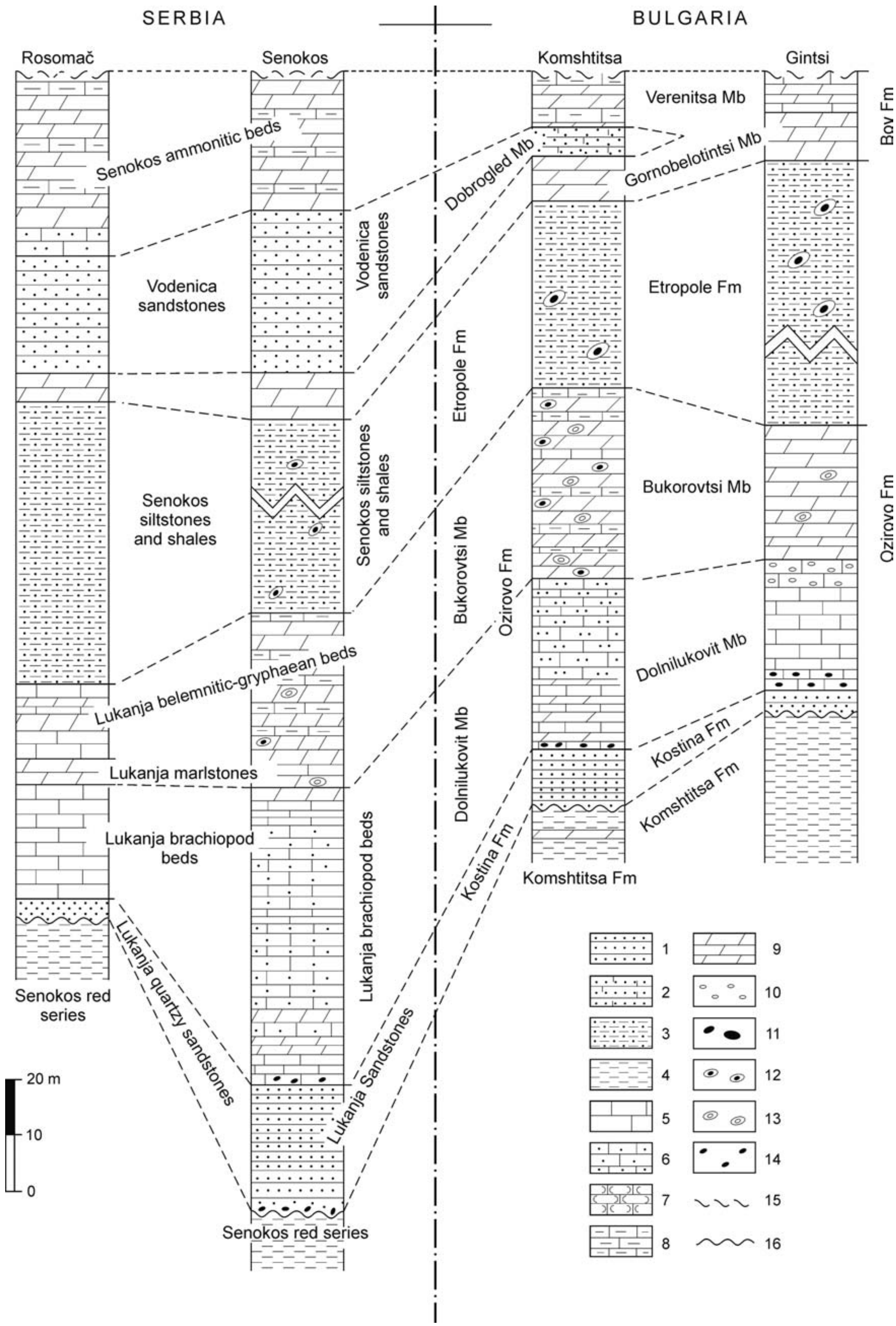

Fig. 3. Simplified columnar sections of the Lower and Middle Jurassic sediments of the Infra-Getic domain in the Pirot-Godech area. **1**, sandstones; **2**, calcareous sandstones; **3**, black shales and aleurolites with *Bossitra alpina*; **4**, clays; **5**, micritic limestones; **6**, sandy and/or bioclastic limestones; **7**, lithoclastic and/or nodular limestones (type "*ammonitico rosso*"); **8**, clayey limestones; **9**, marls; **10**, leptochloritic ooids; **11**, chert nodules; **12**, sideritic concretions; **13**, phosphoritic concretions; **14**, conglomeratic pebbles; **15**, transgressive boundary; **16**, boundary, connectected with submarine gap in the sedimentation.

grained quartz with silica cement and a transition to quartzite of Early Liassic age.

The Kostina Formation (Pl. 3, Fig. 3) lies directly on the Komshtitsa Formation in the vicinities of the villages Komshtitsa and Gintsi and on the Tuden Formation near the village of Stanyantsi. It consists of coarse to middle grained sandstones, from 3.5 m (near Stanyantsi village) up to 12 m thick (near Komshtitsa village). Its age is Middle Hettangian.

The Lower Jurassic sections continue with calcareous sedimentation. In east Serbia, the Lukanja brachiopod beds developed, which, in western Bulgaria, correspond to the Dolniloukovit Member of the Ozirovo Formation (Pl. 3, Figs. 4, 5).

The Lukanja brachiopod beds (ANDJELKOVIĆ, 1958, p. 15) near Senokos village started with dark grey to black crinoidal limestones (1.5 m thick), which contain many well-rounded quartz pebbles (Pl. 1, Fig. 6), as well as many brachiopods and bivalves. The same limestones with quartz pebbles and fossils also crop out in the Bulgarian section of Komshtitsa. In Senokos above them crop out marls (4–5 m) with rare interbeds of clayey limestones (Pl. 1, Fig. 7) (of Hettangian–Sinemurian age). Analogous sediments are individualized in Bulgaria as the Ravna Member of the Ozirovo Formation. The largest part of the Lukanja brachiopod beds is structured by sandy and bioclastic dark grey bituminous limestones, with many brachiopods, bivalves and belemnites (Pl. 1, Fig. 8). Near Senokos village, they were separated by ANDJELKOVĆ & MITROVIĆ-PETROVIĆ (1992) as the Senokos beds. The thickness of the Lukanja brachiopod beds is 40–45 m.

The Bulgarian Dolni Lukovit Member of the Ozirovo Formation (SAPUNOV, 1983) is presented by sandy and/or bioclastic (predominantly crinoidal) dark grey limestones (Pl. 3, Figs. 4, 5), containing many brachiopods, bivalves and belemnites. They are between 20–40 m thick and are of Carixian–Domerian (*p. p.*) age.

The Lower Jurassic sedimentation finished with rocks, individualized in east Serbia as the Lukanja marlstones and Lukanja belemnitic-gryphaean beds and in Bulgaria as the Bukorovtsi Member of the Ozirovo Formation.

The Lukanja marlstones (Upper Pliensbachian) consist of grey, laminated marls, clays, aleurolites and thin bedded clayey sandstones, with many small belemnites. They are covered by the Lukanja belemnitic-gryphaean beds (Upper Pliensbachian–Toarcian) (ANDJELKOVIĆ, 1958), built up of thin bedded sandy marls and clays. Within them, two parts are individualized: lower – belemnitic-brachiopod (with a predominance of small belemnites and brachiopods) and upper – belemnitic-gryphaean parts (with many large belemnites and *Gryphaea*). They contain many sideritic and phosphoritic concretions.

The Bulgarian Bukorovtsi Member is represented by grey silty marls, interbedded by thin (10–15 cm thick) beds of clayey limestones with many sideritic and phosphoritic concretions (Pl. 3, Fig. 6). They contain many belemnites and large bivalves (aequipectens and gryphaeas). They are not subdivided into different parts and encompass the Domerian and the Toarcian.

Middle Jurassic (Fig. 3)

The Middle Jurassic sediments, in south-east Serbia, are subdivided into the following lithostratigraphic units: Senokos siltstones and shales (Aalenian), Vodenica sandstones (Middle Bajocian) and Senokos ammonitic beds (Upper Bajocian, Bathonian and Lower Callovian), and in western Bulgaria into: the Etropole Formation (Aalenian–Bajocian) and the Bov Formation (Upper Bajocian–Upper Bathonian), intercalated by the Dobrogled Member of the Polaten Formation (Bathonian, lower part). The Senokos ammonitic beds and the Etropole Formation are similar to the "black shales with *Bossitra alpine*" from the Alpes.

The Senokos silstones and shales (ANDJELKOVIĆ, 1958) are structured by dark grey to black aleurolitic argillites and marly sandstones with phosphoritic, sideritic and calcareous concretions (Pl. 2, Fig. 1). Near Senokos and Rosomač villages, they are 50–70 m thick. The upper boundary with the Senokos ammonitic beds represents a transition. In Bulgaria, the Etropole Formation is analogous (SAPUNOV *in* SAPUNOV *et al.*, 1967). It is built up of dark grey to black shales, generally aleurolitic with sideritic and rare phosphoritic concretions (Pl. 3, Figs. 7, 8). Near Komshtitsa village it is about 30 m thick and encompasses the Aalenian up to the lower part of the Upper Bajocian.

The Vodenica sandstones (ANDJELKOVIĆ, 1958, p. 20, 21), about 40 m thick, encompasses coarse grained quartz sandstones of red and reddish colour, thick bedded in the base, upwards becoming thin bedded (Pl. 2, Fig. 2); they also contain intercalations of microconglomerates.

The Dobrogled Member of the Polaten Formation (SAPUNOV *et al.*, 1993) is about 4 m thick in the section of Komshtitsa (Bulgaria). This lithostratigraphic unit is represented by yellow to brown thick bedded limy sandstones in alternation with thin bedded calcareous limestones (Pl. 4, Fig. 1). Its age is Lower Bathonian.

Between the Senokos siltstones and shales and the Vodenica sandstones, as well as between the Etropole and the Bov Formation, the boundary is connected with a progressive transition. In the section of Komshtitsa (Bulgaria), between them grey-greenish silty marls with rare sideritic concretions, greenish marls developed, which are the horizontal prolongation of the lower member – Gornobelotintsi Member (Pl. 3, Fig. 8) of the Bov Formation. Such a lithostratigraphic unit is not individualized in the sections of south-east Serbia.

Above the Vodenica sandstones, in the vicinities of the villages Senokos and Rosomač, lies the Senokos ammonitic beds (ANDJELKOVIĆ *et al.*, 1996, pp. 124–125), represented by grey-greenish sandy marls and clayey marls, rich in ammonites, which in the upper part become an alternation between grey-greenish aleuritic marls and clayey limestones with *Zoophycos,* about 30–40 m thick (Pl. 2, Figs. 3, 4). The lower boundary represents a passage effectuated by 3–4 m thick aleuritic limestones with many muscovite flakes. From the upper part, in marls and clayey limestones, ANDJELKOVIĆ *et al*. (1996, p. 128) cited *Macrocephalites macrocephalus*, *Oxycerites neumayeri* and *Hecticoceras haugi*. From the Lower Callovian (thickness 0.75 m); higher, also in marls and clayey limestones (thickness 0.50 m) were found the Middle Callovian ammonites *Hecticoceras haugi*, *Oxycerites tilli, Hecticoceras pompecki*, etc.

In Bulgaria, this unit corresponds to the Verenitsa Member of the Bov Formation (TCHOUMATCHENCO, 1978), represented by an alternation between clayey-silty limestones and thin beds of silty marls, about 8 m thick containing *Zoophycos* sp. indet of Late Bathonian age (Pl. 4, Fig. 2). From the uppermost part were collected *Rhopaloteuthis gillieroni* and *Homoeoplanulites homoemorphus*, which prove the middle part of the Upper Bathonian (*Oppelia (Oxycerites) aspidoides* Zone).

To west of Rosomača, in the valley of Jelovica River, Middle–Upper Callovian sandy limestones and sandstones crop out.

Middle Callovian–Tithonian (Fig. 4)

In the base, near the villages of Senokos and Rosomač, crop out the Kamenica limestones (ANDJELKOVIĆ *et al*., 1996, p. 133) represented in the base by brecciated limestones, which are covered by micritic, well bedded limestones, on the beds surfaces of which there are lumachelles of ammonites. These limestones are Lower and Upper (*p. p.*) Oxfordian.

To west of Rosomač village crop out sub reef sediments known as the Ržana limestones. They are represented by grey, well bedded limestones, 10 m thick, which contain many bivalves, gastropods, bryozoans, brachiopods, sponges, etc.

To the Kamenica limestones, in the vicinities of the villages of Komshtitsa, Gintsi, etc. in western Bulgaria, correspond the micritic limestones of the Late Callovian–Oxfordian–Middle Kimmeridgian (*p. p.*) Javorets Formation (Pl. 4, Figs. 3, 4) (NIKOLOV & SAPUNOV, 1970; TCHOUMATCHENCO *et al*., 2001) which consists of grey, predominantly micritic, medium to thin bedded limestones with concretions of black to dark grey chert. The hickness is about 20 m.

The Late Jurassic section continues with the Pokrovenik acanthicum limestones (Pl. 2, Figs. 5–7) in Serbia and the Gintsi Formation (Pl. 4, Figs. 5, 6) in Bulgaria.

The Pokrovenik acanthicum limestones (ANDJELKOVIĆ, 1958; ANDJELKOVIĆ *et al*., 1996, p. 139–142) (of "*ammonitico rosso*" type) consist of red, redish to grey, thin bedded limestones, which contain many lithoclasts and bioclasts (ammonites). On the basis of the ammonites, the Pokrovenik limestones are subdivided in three parts: Lower acanthicum limestones with red to reddish

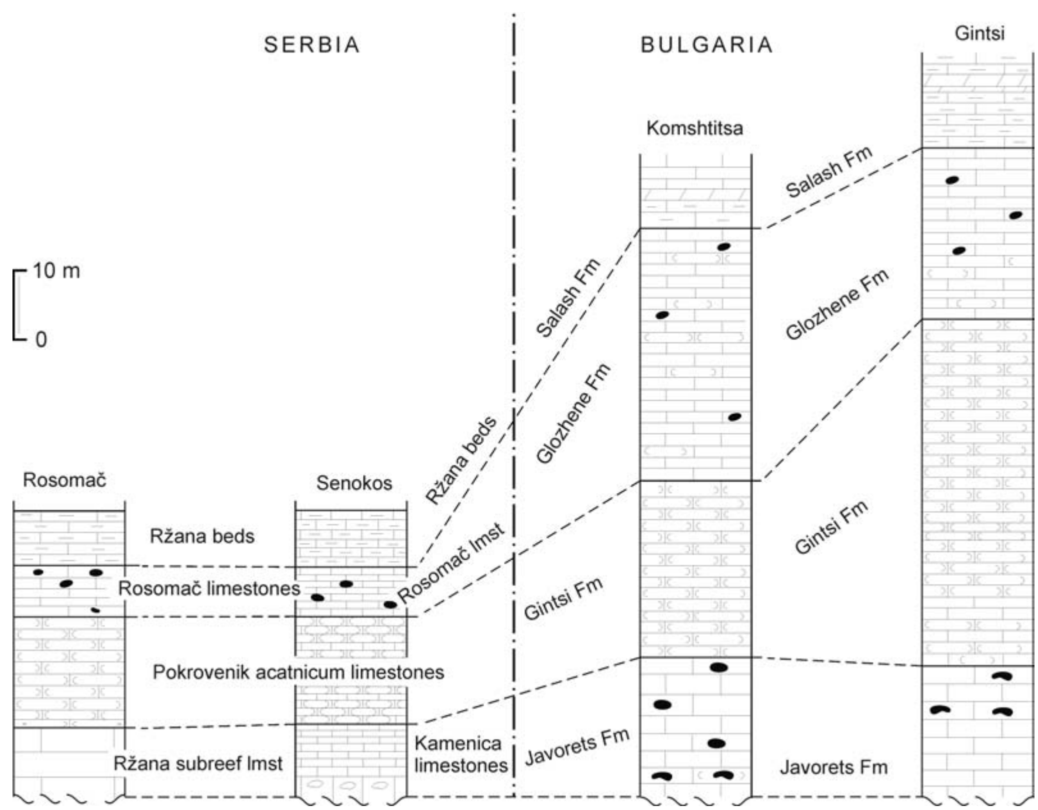

Fig. 4. Simplified columnar sections of the Middle Callovian–Upper Jurassic sediments of the Infra-Getic domain in the Pirot-Godech area. Legend as for Fig. 3.

nodular limestones, 3–5 m thick; Middle acanthicum limestones (7–20 m thick) with reddish limestones, intercalated by grey limestones, with ammonite fossils; Upper acanthicum limestones (3–10 m) with well bedded clayey, nodular and/or lithoclastic limestones, greyredish to red, rich in ammonites.

The Pokrovenik acanthicum limestones are of Kimmeridgian–Early Tithonian age.

The Gintsi Formation in Bulgaria is analogous to the Pokrovenik limestones in Serbia. They are lithoclastic and/or nodular, red or grey limestones, with marly cement, of Middle Kimmeridgian (upper part)–Middle Tithonian (upper part) age, in the Komshtitsa section 29.15 m thick and in Gintsi section about 40 m.

The Rosomač limestones cover the reddish Lower Tithonian Pokrovenik limestones. The Rosomač limestones are represented by grey well stratificated limestones, containing dark grey to black interbeds of chert. They are Middle Tithonian–Berriasian (*p. p.*) (Pl. 2, Fig. 8). These limestones are known in Bulgaria as the Glozhene Formation (Pl. 4, Fig. 7).

The Jurassic sediments in east Serbia are covered by the Berriasian–Lower Barremian Ržana beds, consisting of slaty, grey biomicritic limestones with intercalations of chert nodules, situated in the Berriasian parts in 5 levels. Their analogous in Bulgaria are the clayey limestones of the Salash Formation (NIKOLOV & TZANKOV, 1971) (Pl. 4, Fig. 8).

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Резиме

Упоређење јурских седимената Инфра-гетске јединице у граничној области југоисточне Србије и западне Бугарске

Инфра-гетска палеогеографска јединица условљена палеотектоником налази се између Данубијске и Гетске палеогеографске јединице. У српској литератури је позната као Инфра-гетикум, а у бугарској као јурски Издремечки палеоров. Циљ овог рада је упоређење односа јурских седимената са обе стране српско–бугарске границе. У том циљу су коришћени профили Лукање, Богородичиног манастира, села Росомач и Сенокос (околина Пирота, југоистоисточна Србија) и профили у атарима села Комштица, Гинци и Стањанци (Годечки срез у западној Бугарској). Јурски седименти у Инфра-гетској јединици су откривени на јужним падинама Старе Планине. Леже трансгресивно преко тријаске подине црвенкастих алевролита, лапораца и аргилита са прослојцима пешчара. Називају се Сенокосна црвена серија у Србији, а у западној Бугарској формација Комштица. Јурске наслаге почињу континенталним и континентално-маринским седиментима (глинци и пешчари) (Лукањски кластити и лукањски угљени слојеви у Србији и Туденска формација у Бугарској), настављају се лукањским кварцним пешчарима (Србија) и кварцним пешчарима Костинске формације (Бугарска). Ове седименте покривају Лукањски брахиоподски слојеви (биокластични кречњаци) и Лукањски кречњаци (Србија) и чланови Озировске формације: Романов Дол (кречњаци са кварцним шљунком), Равна (кречњаци и глинци до лапорци) и Долни Луковит (биокластични кречњаци) у којима преовлађују биокластични кречњаци (Бугарска). Седиментација се наставља Лукањским белемнитско-грифејским слојевима (лапорци и глиновити пешчари) којима у Бугарској одговара Букоровачки члан (такође од лапораца и глиновитих кречњака са квргама фосфорита и сидерита) Озировске формације. Средњојурска седиментација је почела црним алевритским глинцима са ситним шкољкама (*Bossitra alpina*) и крупним белемнитима. Ови седименти су утврђени у Србији као Сенокосни алевролити и глинци, а у Бугарској као Етрополска формација. Ова фација је у Алпима позната као “црни глинац са *Bossitra alpina*”. У Србији се профил наставља Воденичким пешчарима бајеске старости, а у Бугарској Доброгледским чланом Полатенске формације. У Бугарској, они су горњобајеске–доњобатске старости, прекривају лапорце доњег члана (Горњобелотиначки члан) Бовске формације, а леже испод горњег Верeничког члана, представљених сменом лапораца и глиновитих кречњака, Бовске формације. Воденички пешчари, односно Доброгледски члан, завршавају у профилу Комштице. Бугарска Бовска формација одговара Сенокосним амонитским слојевима у источној Србији. Горња граница амонитских слојева Сенокоса и Бовске формације је оштра, местимично ерозиона (неправилна), прекривена амонитском бречом са мноштвом *Macrocephalites*–а. У Бугарској, навише следе сиви кречњаци са рожначким квргама Јаворечке формације, а у источној Србији Каменички кречњаци. Изнад њих су сиви или црвени квргави, односно литокластични кречњаци (тип “*ammonitico rosso*”) Гинци формације у Бугарској и Покровенички амонитски (акантикум) кречњаци у Србији. Јурски профил Инфра-гетикума се завршава сивим микритским и литокластичним кречњацима који у источној Србији припадају Росомачким и Рсовачким кречњацима, а у Бугарској – Гложен формацији. Закључак је да се литостратиграфске јединице, које су посебно издвојили разни аутори у источној Србији и западној Бугарској, могу поредити и њихов однос доводити у везу са обе стране државне границе.

PLATE 1

Serbia

Fig. 1. Jelovica limestones, Triassic, Velika Lukanja.
Fig. 2. Senokos red series, Upper Triassic, Senokos.
Fig. 3. Lukanja coal beds, Lower Jurassic, Velika Lukanja.
Fig. 4. Lukanja clastics, Lower Jurassic, Velika Lukanja.
Fig. 5. Lukanja Quartz sandstones, Lower Jurassic, Senokos.
Fig. 6. Base of the Lukanja brachiopod beds, Lower Jurassic, Senokos.
Fig. 7. Lukanja brachiopod beds, detail, Lower Jurassic, Senokos.
Fig. 8. Lukanja brachiopod beds, general view, Lower Jurassic, Senokos.

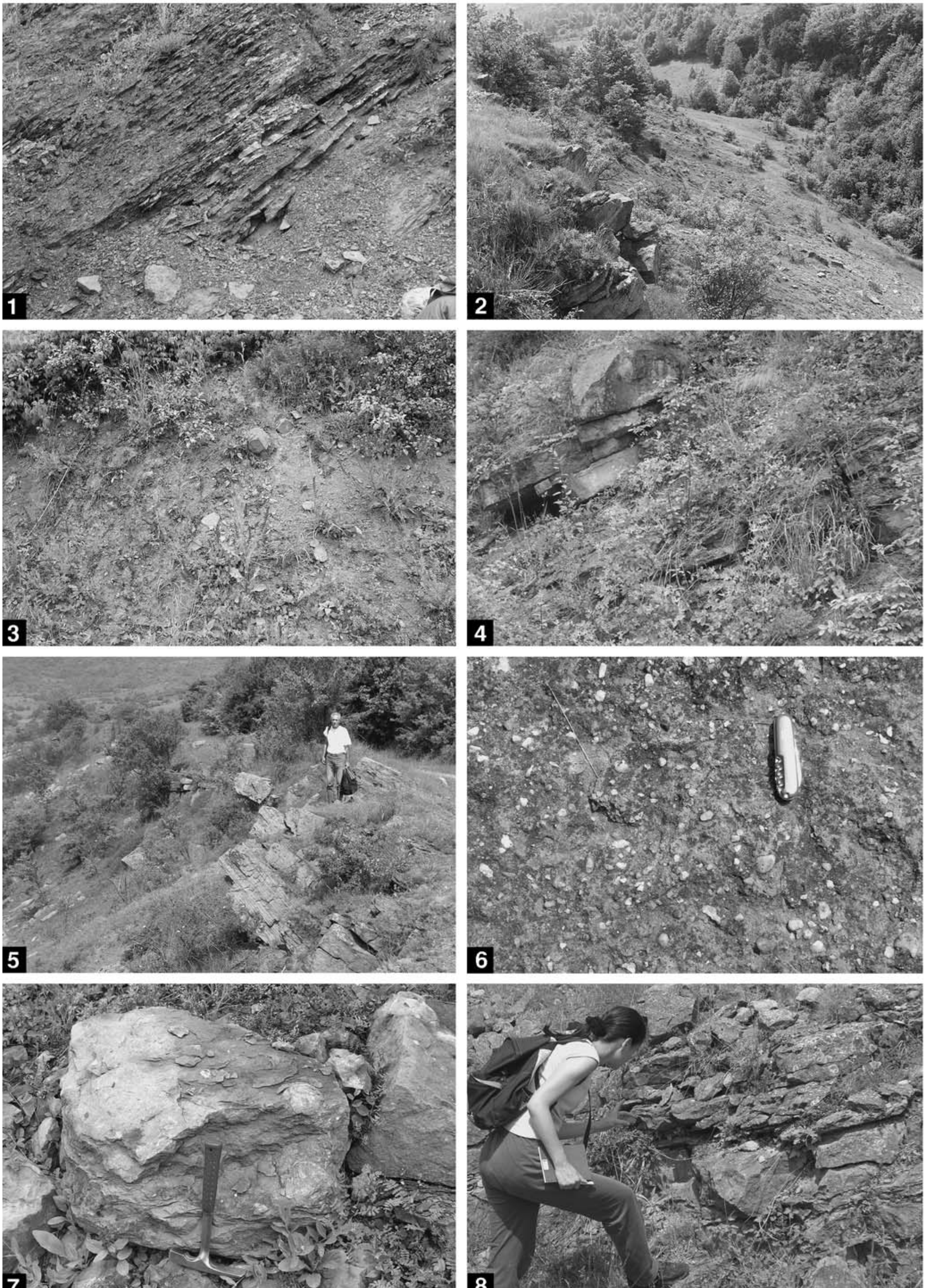
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PLATE 2

Serbia

Fig. 1. Senokos siltstones and shales, Middle Jurassic, Senokos.
Fig. 2. Vodenica sandstones, Middle Jurassic, Senokos.
Fig. 3. Senokos ammonitic beds, Middle Jurassic, Senokos.
Fig. 4. Senokos ammonitic beds, Middle Jurassic, Senokos.
Fig. 5. Pokrovenik acanthicum limestones, Upper Jurassic, Rosomač.
Fig. 6. Pokrovenik acanthicum limestones, detail, Upper Jurassic, Rosomač.
Fig. 7. Pokrovenik acanthicum limestones, Upper Jurassic, Rosomač.
Fig. 8. Rosomač limestones, Upper Jurassic, Rosomač.

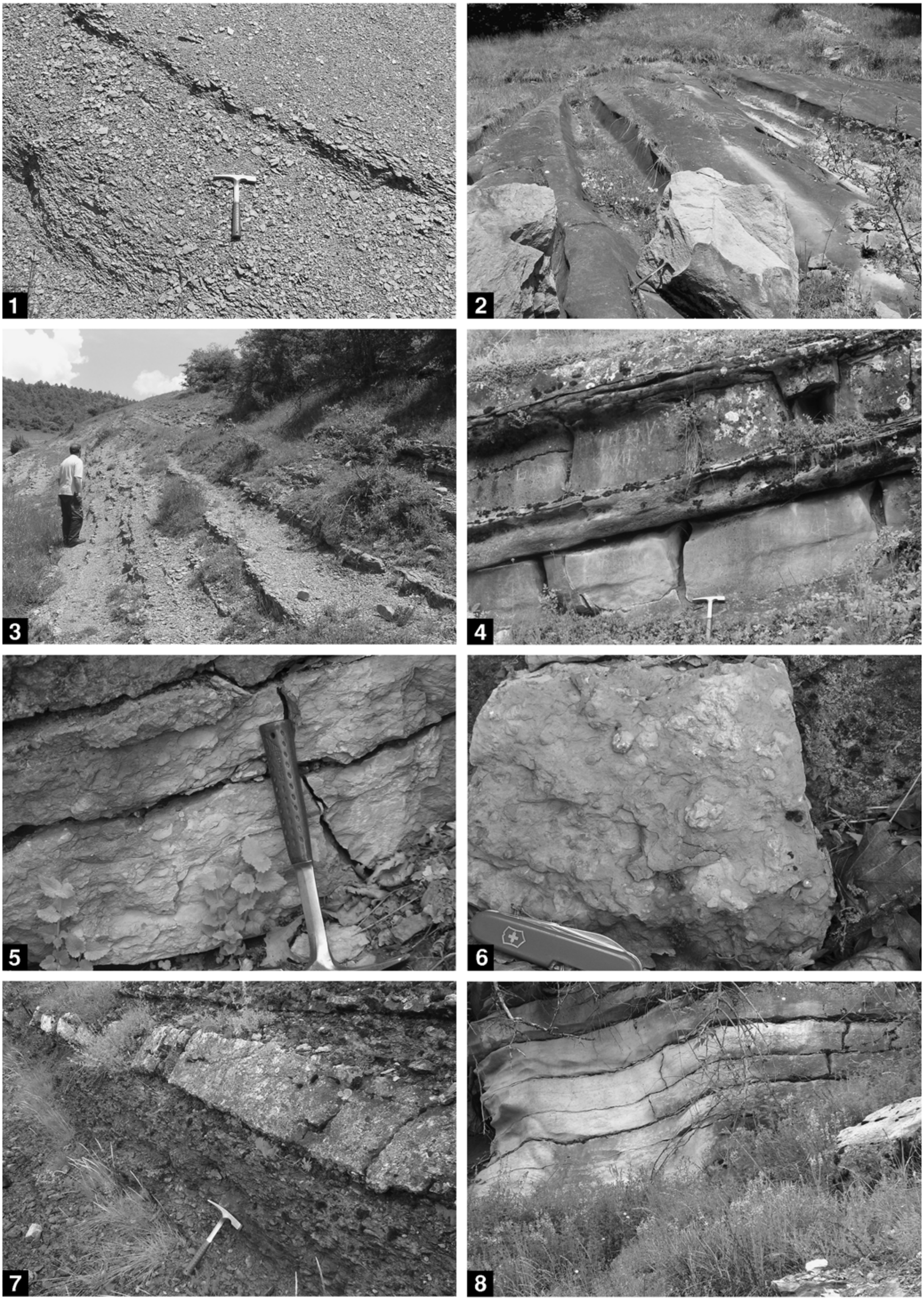
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PLATE 3

Bulgaria

Fig. 1. Touden Formation (Lower Jurassic) and the boundary with the Middle Triassic limestones, Stanyantsi.
Fig. 2. Boundary between the Komshtitsa Formation (Upper Triassic) and the Kostina Formation (Lower Jurassic), Komshtitsa.
Fig. 3. Kostina Formation, Lower Jurassic, Visochica River, Komshtitsa.
Fig. 4. Dolni Loukovit Member, Ozirovo Formation, Lower Jurassic, Komshtitsa.
Fig. 5. Dolni Loukovit Member (detail), Ozirovo Formatin, Lower Jurassic, Komshtitsa.
Fig. 6. Bukorovtsi Member, Ozirovo Formation, Lower Jurassic, Komshtitsa.
Fig. 7. Etropole Formation, Middle Jurassic, Barlya.
Fig. 8. The boundary between the Etropole Formation and the Bov Formation (Gornobelotintsi Member), Middle Jurassic, Barlya.

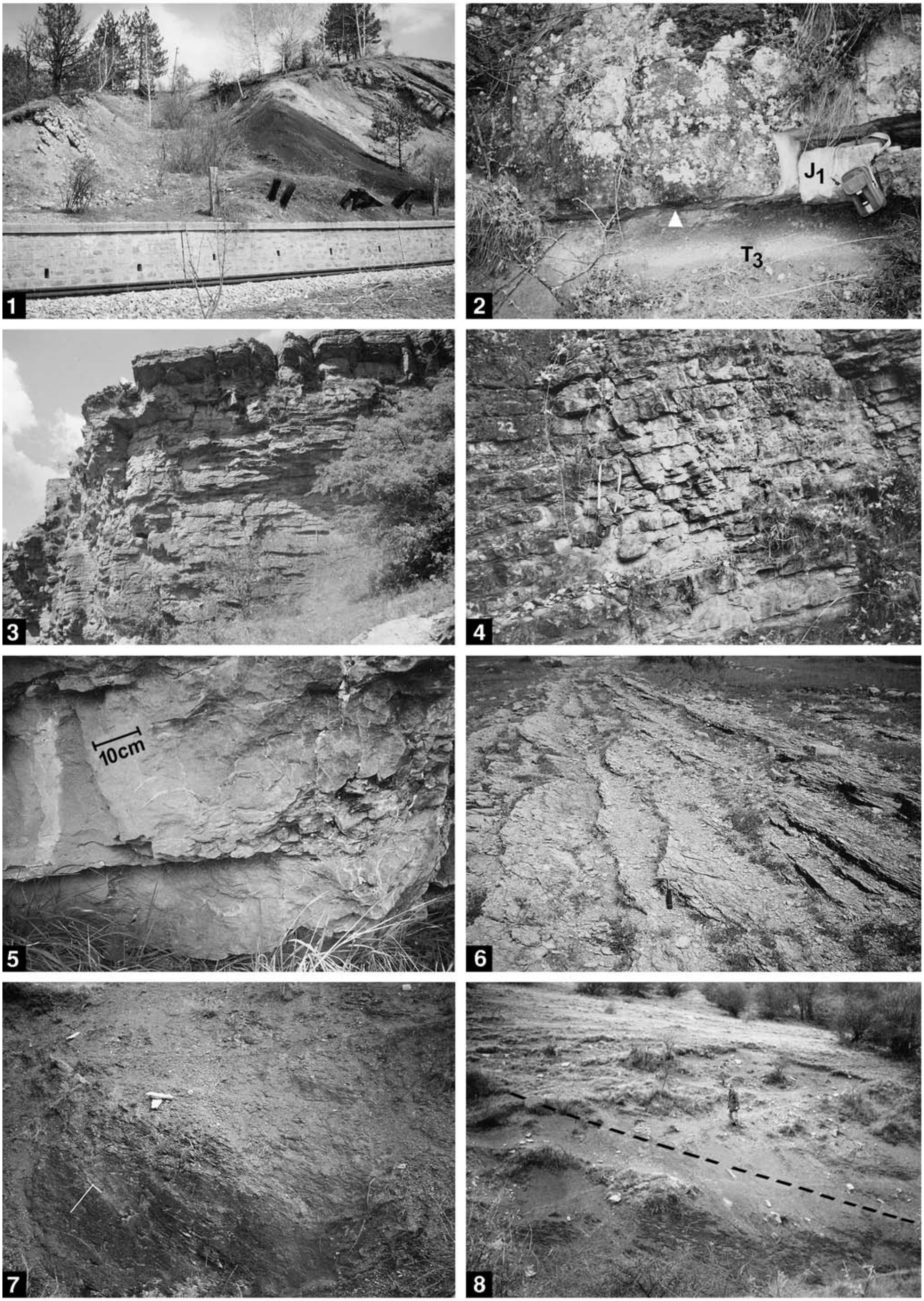
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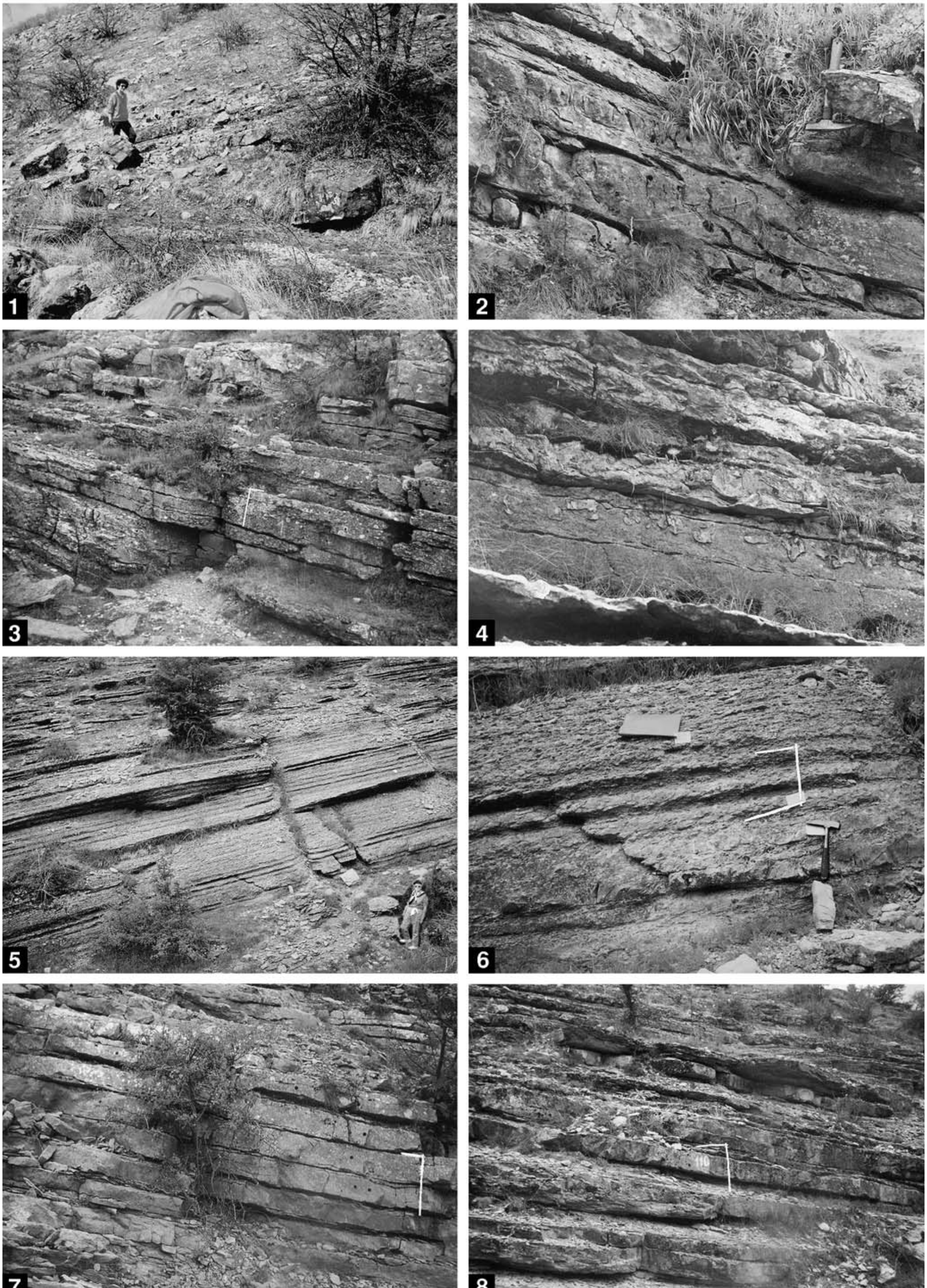
PLATE 4

Bulgaria

Fig. 1. Dobrogled Member, Polaten Formation, Lower Bathonian, Barlya.
Fig. 2. Verenitsa Member, Bov Formation, Middle Jurassic, Barlya.
Fig. 3. Yavorets Formation, Callovian–Oxfordian, Barlya.
Fig. 4. Yavorets Formation, Callovian–Oxfordian, Barlya.
Fig. 5. Gintsi Formation, Upper Jurassic, Barlya.
Fig. 6. Gintsi Formation (detail), Upper Jurassic, Barlya.
Fig. 7. Glozhene Formation, Upper Jurassic, Barlya.
Fig. 8. Salash Formation, Lower Cretaceous, Barlya.



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A storm event during the Maastrichtian in the Cauvery basin, south India

Mu. Ramkumar

Abstract. Sedimentary structures in the Kallankurichchi Formation of the Ariyalur Group, South India have been examined with a view of assessing the depositional setting of these rocks. Of the different sedimentary structures, such as cross bedding, cut and fill, etc., hummocky cross stratification is significant as it resulted from a major storm event. This paper deals with the recognized sedimentary structures, their genesis and environmental implications.

Key words: storm event, Maastrichtian, Kallankurichchi Formation, Ariyalur Group, South India.

Апстракт. Седиментне структуре формације Каланкуричи, Аријалур група, јужна Индија, проучаване су ради утврђивања депозиционог простора тих стена. Међу различитим седиментним структурама, као што су укрштена слојевитост, структура спирања итд., брежуљкаста коса слојевитост је значајна као последица деловања снажне олује. У овом раду се говори о утврђеним седиментним структурама, њиховом пореклу и утицајима на депозициону средину.

Кључне речи: утицај олуја, мастрихт, Каланкуричи формација, Аријалар група, јужна Индија.

Introduction

Sedimentary structures play a vital role in the interpretation of depositional conditions and hence an attempt was made to understand the depositional environment of the Kallankurichchi Formation of the Ariyalur Group, Tamil Nadu based on its sedimentary structures. The study area is situated east of the town Ariyalur and forms a part of the Kallankurichchi Formation (Fig. 1). The general stratigraphic setup is as follows (after Sastry *et al*., 1968; Chandrasekaran & Ramkumar, 1995).

	Age	Formation	Gross Lithology
Ariyalur Group	Maastrichtian	Kallamedu Formation	Sandstone
		Ottakoil Formation	Sandstone
		Kallankurichchi Formation	Limestone
		----- *Unconformity* ----	
	Campanian	Sillakkudi Formation	Sandstone
		----- *Unconformity* ----	
		Trichinopoly Group	

In the study area, the Kallankurichchi Formation is a prominent carbonate unit and is exposed as isolated outcrops (Guha & Senthilnathan, 1990). The formation is 40 m thick and has N–S extension of 35 kilometers with a width varying from 500–3500 m. Based on the faunal composition, Maastrichtian age has been assigned by Sastry *et al*. (1972) and later refined to Lower Maastrichtian by Ramamoorthy (1991) & Radulović and Ramamoorthy (1992). Hart *et al*. (2000) speculated the commencement of the deposition of this formation during the late Campanian–Earliest Maastrichtian. The generalized lithological succession of this formation was provided by Ramkumar (1999) and is presented herein.

Member	Lithology	Formation	Group
	Kallamedu Formation		
	Ottakoil Formation		ARIYALUR GROUP
	----- *Unconformity* -----		ARIYALUR GROUP
Gryphaean lst Mb (18 m)	Gryphean fragmental shell lst Gryphean lst	Kallankurichchi Formation	ARIYALUR GROUP
Fragmental shell lst Mb (8 m)	Gryphean fragmental shell lst Bedded fragmental shell lst HCS shell hash Cross bedded fragmental shell lst Bedded fragmental shell lst	Kallankurichchi Formation	ARIYALUR GROUP
Inoceramus lst Mb (8 m)	Inoceramus lst	Kallankurichchi Formation	ARIYALUR GROUP
Arenaceous Mb (6 m)	Arenaceous gryphean lst Silicious and limy conglomerate	Kallankurichchi Formation	ARIYALUR GROUP
	----- *Unconformity* -----		ARIYALUR GROUP
	Sillakkudi Formation		ARIYALUR GROUP

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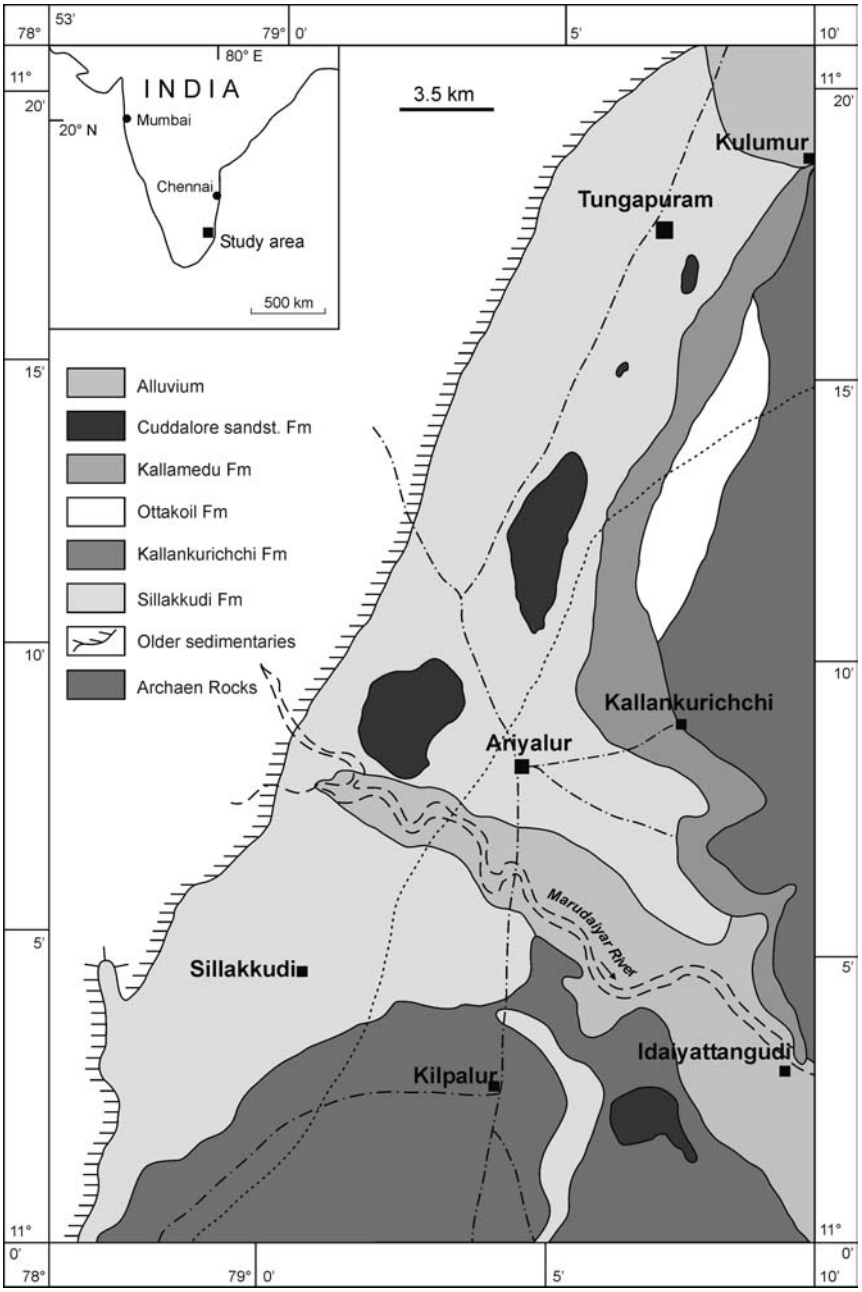

Fig. 1. Location map of the study area

The rocks of this formation consist predominantly of skeletal limestones and fragmental limestones analogous to the bank and bank-derived materials of NELSON *et al*. (1962). They contain whole shells and bioclasts of mollusca, bryozoa, foraminifera, brachiopoda, echinodermata, ostracoda and algae. Minor to significant amounts of peloid, quartz, lithoclasts and intraclasts are also observed. The six standard types of microfacies of WILSON (1975) are recognized from this formation (RAMKUMAR, 1995) and interpreted to have been deposited in a distally steepened carbonate ramp setting (RAMKUMAR, 1999). The depositional history of this formation was elucidated by RAMKUMAR (1995, 1999) and a brief note of it is presented herein.

The Kallankurichchi Formation commenced with a transgression during the Latest Campanian–Early Maastrichtian (HART *et al*., 2000). Towards the top, the conglomeratic deposits show a reduction in proportion and size of siliciclastics which were increasingly replaced by gryphean colonies. In due course, the gryphean bank shifted towards shallower regions and the locations previously occupied by coastal conglomerate become middle shelf, wherein typical inoceramus limestone started developing. The break in the sedimentation of inoceramus limestone was associated with a regression of the sea level, resulting in the erosion of shell banks and middle shelf deposits and their redeposition into biostromal deposits. Again the sea level rose to create a marine flooding surface, as a result of which gryphaean shell banks started developing more widely than before. Towards the top, shell fragments and minor amounts of siliciclastics are observed, indicating the onset of regression and higher energy conditions. The occurrence of a non-depositional surface at the top of this formation and the deposition of shallow marine siliciclastics (Ottakoil Formation) immediately over the carbonates and a conformable offlap of much younger fluvial sand deposits (Kallamedu Formation) are all suggestive of a gradual regression associated with the establishment of a fluvial system during the end of the Cretaceous.

Sedimentary structures

Cross Bedding

Tabular cross bedding is a common in fragmental limestone. The maximum thickness of the cross bedded unit is of the order of 1.8 meters. Due to the presence of shell fragments, the foreset beds do not exhibit well defined layers in the vertical section. However, they do appear as uniform layers on the surface (Fig. 2A). The cross bedding structure is found in a limited region within finely fragmented limestone and can be seen in the southwest wall of mine pit I of the Tancem mine (located west of Kallankurichchi Village and north of the Ariyalur–Kallankurichchi road – Fig. 1). This cross bedded unit can be termed as large scale cross bedding (REINECK & SINGH, 1986). The individual laminae have a more or less uniform thickness varying from 1.5–2.3 cm. The bounding surfaces of the foresets are sharp. The individual laminae can be traced throughout the length. The grains are well sorted irrespective of the nature of the clasts. High roundness is observed in both the bioclasts and peloids. Since this unit is bounded by bank deposits, the cross bedded deposits can be described as large underwater sand dunes developed in the shelf region which might have originated by shoaling waves (Chakraborty, personal communication). Like the carbonate sequence of the Middle Eocene of Peninsular Florida, described by RANDAZZO *et al*. (1990), this cross bedded unit also has abundant burrows.

Cut-and-Fill Structure

Cut-and-fill structures characterized by a shallow concave base and a flat top are common. These are observed in the Tancem mine I along the SW wall of bench I (located west of Kallankurichchi Village and north of the Ariyalur–Kallankurichchi road – Fig. 1). These have a maximum length of 150 cm and a height of 20 cm. These structures occur above the cross bedded strata and form the base of the hummocky cross bedding. The channel fill material does not show any cross bedding and the channels are filled up with fining upwards coarse grained carbonate sand. This carbonate sand consists of minor amounts of intraclasts, ferruginous matrix and fine quartz sand. These channel-fill structures gradually merge into hummocky cross stratification (HCS).

Hummocky Cross Stratification

Hummocky cross bedding is found near the location where cut-and-fill structures predominate. Its characteristics are described herein.

a. The laminae are curved both in hummocks (convex up) and swales (concave up) sectors.
b. The laminations dip at 12°; but the bed sets appear to meet at very low angles in such a way that, at times, they are parallel to the lower bounding surface.
c. Individual laminae have a maximum thickness of 4 cm at swales and 1.8 cm at hummocks, reflective of a thickening (at swales) and a thinning (at hummocks) nature. Maximum wave height is 97 cm and wave length 6 meters.
d. The laminations show no preferred orientation.
e. The rocks showing HCS structures are composed of polished fragmental shells (Fig. 2B, C). These are sandwiched between normal bedded and cross bedded carbonate sand. The upper contact of the hummocky cross stratification unit is also sharp.

Hummocky cross stratification is commonly associated with storm deposits ("Tempstites" of AGER, 1973; KREISA & BAMBACH, 1982; LOOPE & WATKINS, 1989; MENG *et al*., 1997). It is observed on the continental shelf of the northwest Atlantic Ocean in water depths of 10–40 meters. It is also found in tidal flats (MUKHERJEE *et al.,* 1987; WEIDONG *et al.,* 1997). It has been reported from clastic sediments (Bose *et al.,* 1997), as well as from carbonate skeletal deposits (MENG *et al*., 1997; WEIDONG *et al*., 1997). The HCS is interpreted as being due to a combination of storm generated and geostrophic currents (SWIFT *et al*., 1983).

In the present area, reworked autochtonous fauna in the HCS with little lateral variation of texture and structures are found to occur. This suggests that this particular unit of the Kallankurichchi Formation did not receive material from distant sources during the storm. The absence of whole unabraded, well marked layering, edge-polished shell fragments of fossils (Fig. 2B, C), in addition to the occurrence of storm deposits as a single thick unit, etc., suggest that the prevalent major storm might have mobilized already deposited sediments on the bottoms (MENG *et al*., 1997; KROH & NEBELSICK, 2003). According to the descriptions of AIGNER (1982) and AIGNER & REINECK (1982), the exposures of HCS at Tancem mine I SW wall bench I represent a proximal storm bed in view of the following characteristics.

a. This storm depositional unit is a very thick bed.
b. The beds are composite and intermixed with various bedforms and materials.
c. It is composed of bioclasts which are coarse grained (Gravel to coarse sand).

These characteristics of this sequence are spread over short distances and die out towards the east where the size of the bioclasts decreases. Further east, thinly bedded, mud dominated rocks with unabraded fossils are observed, which may represent the distal end of storm beds (TUCKER & WRIGHT, 1990). BOUOUGRI & PORADA (2002) and MENG *et al*. (1997) also observed the deposition of mud and finer grain rich deposits after major storm event in the Neoproterozoic deposits of Morocco. As has been observed in storm associated deposits elsewhere (MENG *et al*., 1997; SAVRDA & NANSON, 2004), due to the reduction of intensity of the storm, the finer grade materials also started to settle and hence, this sequence shows fining upward gradation from gravel to sand. The grains were carried and settled from a suspension cloud. These interpretations are supported by the horizontality of platy shell material with reference to the original sedimentation surfaces. Comparison of these characteristics based on the criteria enlisted by GOFF *et al*. (2004) clearly affirms the storm generated nature to these deposits. This type of typical storm deposit and its distal expression (MARTINI & BANKS, 1989) are interpreted to be of inner and

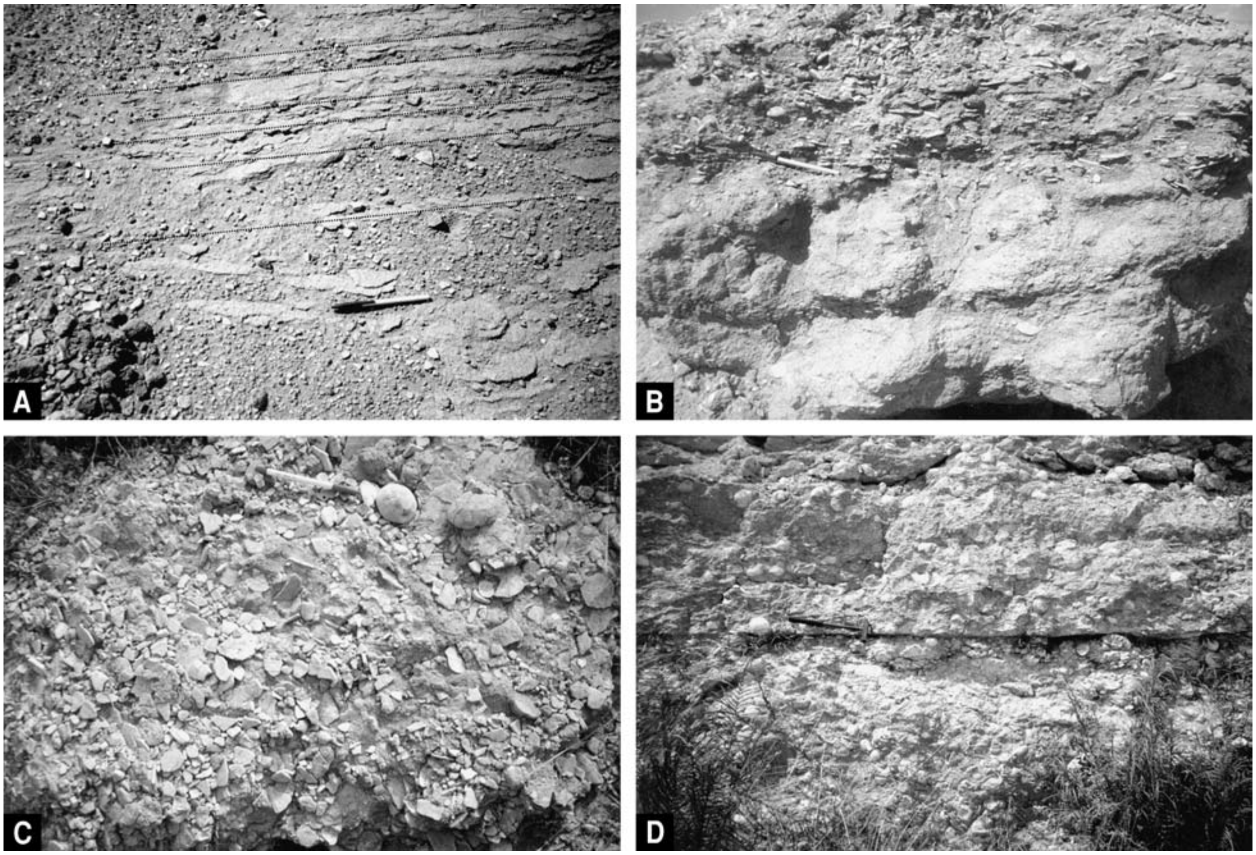

Fig. 2. **A**, Field photograph of planar cross bedded limestone exposed in a mine floor. Due to low dip and planar bedding, the exposure at the mine floor depicts only feeble bedding planes, indicated by dashed lines; **B**, Field photograph showing the nature of the HCS sequence in a mine section. The shoal facies is superposed by HCS beds. Note the sudden change from shoal facies limestone (lower) to edge polished fragmental limestone (HCS bed) as reflected by the sudden change in skeletal composition. Differential compaction of the shoal facies limestone and the HCS limestone has obliterated the sharp erosional bedding plane (indicated by pen in the photograph) between these two units; **C**, Close-up view of the HCS bed showing fragmented and rounded shell material. Also note the presence of Stigmatophygus in life position (indicated by pen in the photograph); **D**, Typical gryphean limestone deposit of the Kallankurichchi Formation. Occurrence of these gryphean colonies over the HCS unit denotes the return of normal depositional conditions after a major storm event.

middle shelf in origin respectively (DROSER & BOTTJER, 1988; BURCHELL *et al.*, 1990).

Since the storm bed with HCS is found to occur in between normal bedded and cross bedded deposits, the energy of the shoaling waves is presumed to have been short lived. The gradual change of the storm beds to cross bedded, well sorted carbonate sands is indicative of the waning period of the storm. The escape structure in a 'V'-shaped burrow at the base of the storm deposit (HECKEL, 1972) suggests the sudden appearance of storms. Oyster beds above the bedded and cross bedded carbonate deposits suggest that the colonization of oysters (Fig. 2D) started after the major storm event.

Conclusion

From the nature and sequence of the sedimentary structures, particularly the hummocky cross beds, it can be concluded that during the deposition of the Kallankurichchi Formation, there were storm events, which contributed to the continuous and homogenous deposition of bank deposits and middle shelf deposits. The intensity of the storm event was very high in the deposition of 1.8 meters thick fragmental shell beds. From the change in the nature of sediments within the storm bed, an easterly storm condition has been inferred. The storm deposits of the Kallankurichchi Formation show similarities in broader terms with that of the Cretaceous Mzamba Formation of South Africa, as reported by LIU & GREYLING (1996).

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Резиме

Олујна појава за време мастрихта у басену Каувери, јужна Индија

Кречњачке наслаге формације Каланкуричи, Аријалур групе у јужној Индији, садрже карактеристичну асоцијацију седиментних структура ограничених на одређену област у близини села Каланкуричи. Како су седиментне структуре битне за тумачење палеосредине, учињен је покушај да се упознају главни услови таложења, а тиме се дошло и до доказа појава снажне олује током мастрихта у басену Каувери у јужној Индији.

Формација Каланкуручи се састоји претежно од скелетних кречњака и фрагментарних кречњака што одговара обалским и пореклом обалским материјалима. Запажене су мање до знатне количине пелоида, кварца, литокласта и интракласта. Утврђено је шест стандардних типова микрофација ове формације и њихово таложење у средини доњег краја стрме карбонатне рампе.

Табуларна коса слојевитост је честа код слојева поломљених кречњака формације Каланкуручи. Максималне дебљина косо услојених кречњака је реда 1,8 метара. Због присуства одломака шкољака, коси слојеви не показују јасно дефинисане слојеве у вертикалном профилу. Међутим, на површини слојеви изгледају уједначено. Ова косо услојена јединица се може узети да представља косу услојеност већих размера. Како је ова јединица ограничена обалским наслагама, косо услојене наслаге се могу описати као подводне велике пешчане дине највероватније формиране таласима у области оплићалог шелфа.

Структуре спирања (накнадно запуњене вододерине) су честе у проучаваној области и карактеришу се плитком конкавном основом и заравњеним врхом. Те структуре се јављају изнад укрштених слојева и формирају основу брежуљкасте слојевитости. Материјал и испуне вододерина не показују никакву косу слојевитост, већ су вододерине испуњене крупнозрним карбонатним песком који се навише уситњава. Те структуре спирања постепено прелазе у брежуљкасту косу стратификацију (БКС).

На брежуљкасту косу слојевитост се наилази у близини места где преовлађују структуре спирања. Брежуљкаста коса стратификација се обично доводи у везу са олујним наносима. БКС се објашњава да потиче од комбинованог дејства олујне и геострофне струје. Сада су у тој области нађене појаве преталожене аутохтоне фауне у БКС са малом бочном разликом у структури и текстури. Та структура указује да за време олује није стигао материјал са веће удаљености нарочито у ову јединицу формације Каланкуричи. Одсуство читавих, изражено слојевитих, фрагмената фосила шкољки углачаних ивица поред појаве олујних наслага у виду једне дебеле јединице и друго указује да је доминантна, већа олуја можда покренула седименте већ наталожене на дну. На основу тога што је појава олујног слоја са БКС нађена између нормално услојених и косо услојених наслага, претпоставља се да је енергија таласа у оплићалој средини кратко трајала. Постепени прелаз олујних слојева у косо услојене наслаге, добро сортирани карбонатни пескови, указују на период слабљења олује. Структура испирања у бразди у облику слова “V” у бази олујне наслаге указује на наглу појаву олуја. Слојеви острига изнад слојевитих и косо услојених карбонатних наслага указују да је колонизација острига почела пре главне олује.

На основу природе и секвенце седиментних структура, нарочито брежуљкасто-косих слојева, може се закључити да су се за време таложења Каланкуричи формације јављале олује које су допринеле сталном и уједначеном таложењу обаских наслага и наслага средњег шелфа. Олује су биле врло великог интензитета кад су се наталожили слојеви одломака шкољки дебљине 1,8 метара. Из промене природе седимената унутар олујног слоја закључује се да је олују стварао источни ветар. Олујне наслаге формације Каланкуричи показују сличност у ширем смислу са кредним олујним наслагама формације Мзамба у Јужној Африци.

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The Cretaceous/Paleogene (K/Pg) boundary in the Mezdra and Lyutidol syncline, Vratza District (West-Fore Balkan, Bulgaria)

Nikola A. Jolkičev

Abstract. This paper discusses the unjustified assignment (based on calcareous nannofossils) of a large portion of the Maastrichtian strata in the Mezdra and Lyutidol synclines (West Fore Balkan, Bulgaria) to the Paleogene. The co-occurrence of Paleocene nannofossils, reported by some authors, and Maastrichtian macrofossil taxa in these sections indicates diachronism in the appearance of macro- and nannofossils across the K/Pg boundary. Thus, this boundary cannot be precisely localised except if the Maastrichtian fossils are assumed to have been redeposited, but there is no evidence of resedimentation. Maastrichtian macrofossils are found not only within the range of the Paleogene nannofossil zones, but also in sections overlying them in the Kajlâka Formation where new Maastrichtian macrofossil taxa, such as the echinoid *Hemipneustes striatoradiatus* (Leske), appear and some inoceramid and cephalopod taxa range into this unit. These facts shed doubt over the applicability of nannofossils in determining the K/Pg boundary where this has already been firmly documented by macrofauna.

Key words: Cretaceous/Paleogene boundary, Maastrichtian strata, nannofossils, foraminifers, inoceramids, ammonites, echinoids, West Fore Balkan, Bulgaria.

Апстракт. У раду се расправља о неоправданом приписивању (на основу кречњачких нанофосила) великог дела мастрихтског профила у синклиналама Мездре и Љутидола (западни Предбалкан, Бугарска) палеогену. Истовремено појављивање палеоценских нанофосила, о којима пишу неки аутори, са мастрихтским макрофосилним таксонима у овим профилима указује на диахронизам у појави макрофосила и нанофосила на граници K/Pg. Према томе, ова граница се не може прецизно утврдити осим ако се не претпостави да су махстритски фосили били преталожени, али не постоје докази преталоживања. Мастрихтски нанофосили су нађени не само у оквиру вертикалног простирања палеогених нанофосилних зона, већ и у формацији Кајлака где се јављају нови мастрихтски макрофосилни таксони као што је *Hemipneustes striatoradiatus* (Leske) и неки иноцерамски и цефалоподски таксони. Ове чињенице бацају сенку сумње на примењивост нанофосила у одређивању границе K/Pg где је она већ поуздано доказана на основу макрофауне.

Кључне речи: граница креда–палеоген, мастрихтски слојеви, нанофосили, фораминифери, иноцерамуси, амонити, ехиниди, западни Предбалкан, Бугарска.

Inroduction

Upper Cretaceous sediments in the Mezdra and Lyutidol synclines in the Vratza District, West Fore Balkan, Bulgaria are widely distributed and of essential tectonic importance. For a long time, based on erroneously identified fossils, these were assumed to be of Cenomanian age (Zlatarski, 1904, 1905, 1910). This author (Zlatarski, 1905) assigned only a portion of the limestones exposed at the village of Varbeshnitza, northwest of Mezdra and those around the village of Lyuta (now Vladimirovo) to the Senonian. Later, Zlatarski (1910) pointed out that the limestones at Lyuta were certainly of Senonian age but those at Varbeshnitza were of doubtful Senonian age, although he cited some Senonian fossils found earlier by him. He assumed these sediments to be of Cenomanian age but later again referred them to the Senonian (Zlatarski, 1927). The same author (Zlatarski, 1904) assigned a Cenomanian age also to Eocene sandstones resting upon the "Cenomanian" limestones which, as he pointed out, were easily distinguished from the Lower Cretaceous sandstones in the Vratza area. For the first time, Bončev (1932) proved that the Upper Cretaceous sediments in the Fore Balkan to the south of the Iskar River were of Maastrichtian, not Cenomanian, age. Simultaneously, Bončev & Kamenov

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(1932) extended the studies of this stage to the north of the Iskar River – between Mezdra and Roman, and later they (BONČEV & KAMENOV, 1934) continued these to the west – between the rivers of Iskar and Ogosta. Based on inoceramids, cephalopods, echinoids and other macrofossil taxa, they documented in detail the biostratigraphy of the Maastrichtian Stage in the western Fore Balkan. The Maastrichtian age of the Upper Cretaceous sediments in this area was confirmed by all subsequent investigators, based on macrofossil fauna (COHEN, 1946; TZANKOV, 1968; JOLKIČEV, 1982, 1986, 1989, and others).

During recent years, calcareous nannofossils have been assumed to be of extreme importance for the subdivision of Upper Cretaceous and Cenozoic sediments – an importance that, seemingly, cannot be put in question. However, NAIDIN (2002, p. 46) has recently pointed out that "nevertheless we should have some doubts" of the applicability of nannofossils.

Under the influence of nannoplankton euphoria, a number of publications have recently appeared in which the Cretaceous/Paleogene boundary in the study area was traced without taking into account the presence of characteristic macrofauna in the same sections that were subdivided by means of nannoplankton. The Cretaceous/Paleogene boundary as determined by macrofauna was disregarded in these papers.

The macrofaunal data presented below raise questions about the applicability of nannofossils in defining the Cretaceous/Paleogene boundary in the study area.

Facts and discussion

This paper discusses the Maastrichtian strata in the southern limb of the Mezdra syncline and the same deposits in the northern and southern limb of the Lyutidol syncline in the southern parts of the West Fore Balkan (Fig. 1).

The stratigraphic section in these two structures comprises the following lithostratigraphic units in ascending order (JOLKIČEV, 1986): Dârmanci Formation – Lower Maastrichtian; Kunino Formation – Lower Maastrichtian; Mezdra Formation – Lower Maastrichtian and Kajlâka Formation – Upper Maastrichtian (Fig. 2).

The studies of SINNYOVSKY (1991, 1993, 1998, 2001), SINNYOVSKY & CHRISTOVA-SINNYOVSKA (1993) and STOYKOVA *et al*. (2000) all focused on the Dârmanci, Kunino and Mezdra Formations. It is unexplainable why they did not discuss the age of the overlying Kajlâka Formation.

The Mezdra Formation in the two structures comprises three lithological units of variable thickness: the lower unit – microgranular limestones with flint concretions; the middle unit – argillaceous limestones without flint concretions with interbeds or in alternation with marls and the upper unit – microgranular limestones with flint concretions (Figs. 2–4). SINNYOVSKY & CHRISTOVA-SINNYOVSKA (1993, p. 32) referred to the middle unit in the Lyutidol syncline as the "Limestone Formation". In this unit EK. DIMITROVA (Geological Institute, Bulgarian Academy of Sciences (BAS), unpublished data) identified a foraminiferal assemblage (see Fig. 3). From the same strata at the southerly limb of the Mezdra syncline (at the village of Chelopeck), Y. MALIAKOV (Geological Institute, BAS) collected eighteen echinoid tests (now housed at the museum of the Geological Institute, BAS No F.002525 to 002542). Among these, the following taxa have recently been identified (Fig. 2): *Echinocorys conoidea* GOLDFUSS as well as several *Echinocorys* sp. which belong to a group of species morphologically close to *E*. gr. *marginata/subglobosa* (of early to late Campanian age; compare ERNST, 1972, 1975; JAGT *et al*., 2004); this may represent a continuation into, or recurrence(?) during the Maastrichtian of such test morphologies (compare JAGT, 2000). In the Maastrichtian type area, these forms occur as well, and are nearly always associated with typical

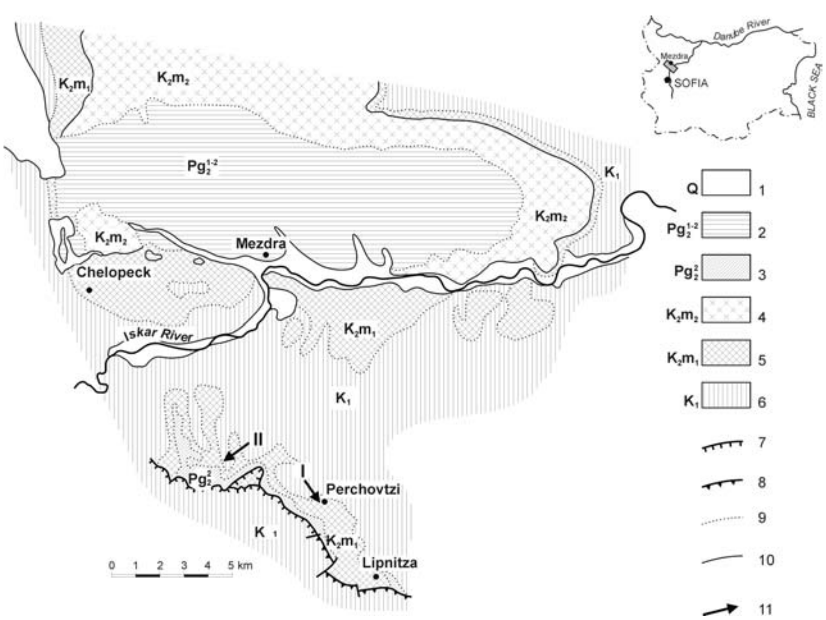

Fig. 1. Sketch map (inset) of Bulgaria with location and geological map of the study area (after TZANKOV *et al*., 1991, modified). **1**, Quaternary; **2**, Lower–Middle Eocene; **3**, Middle Eocene; **4**, Kajlâka Formation – Upper Maastrichtian; **5**, Dârmanci, Kunino, Mezdra formations – Lower Maastrichtian; **6**, Lower Cretaceous; **7**, thrust; **8**, reverse fault; **9**, transgressive boundary; **10**, boundary of Quaternary sediments; **11**, stratigraphic sections (sections I and II, shown in Figs, 3, 4, respectively).

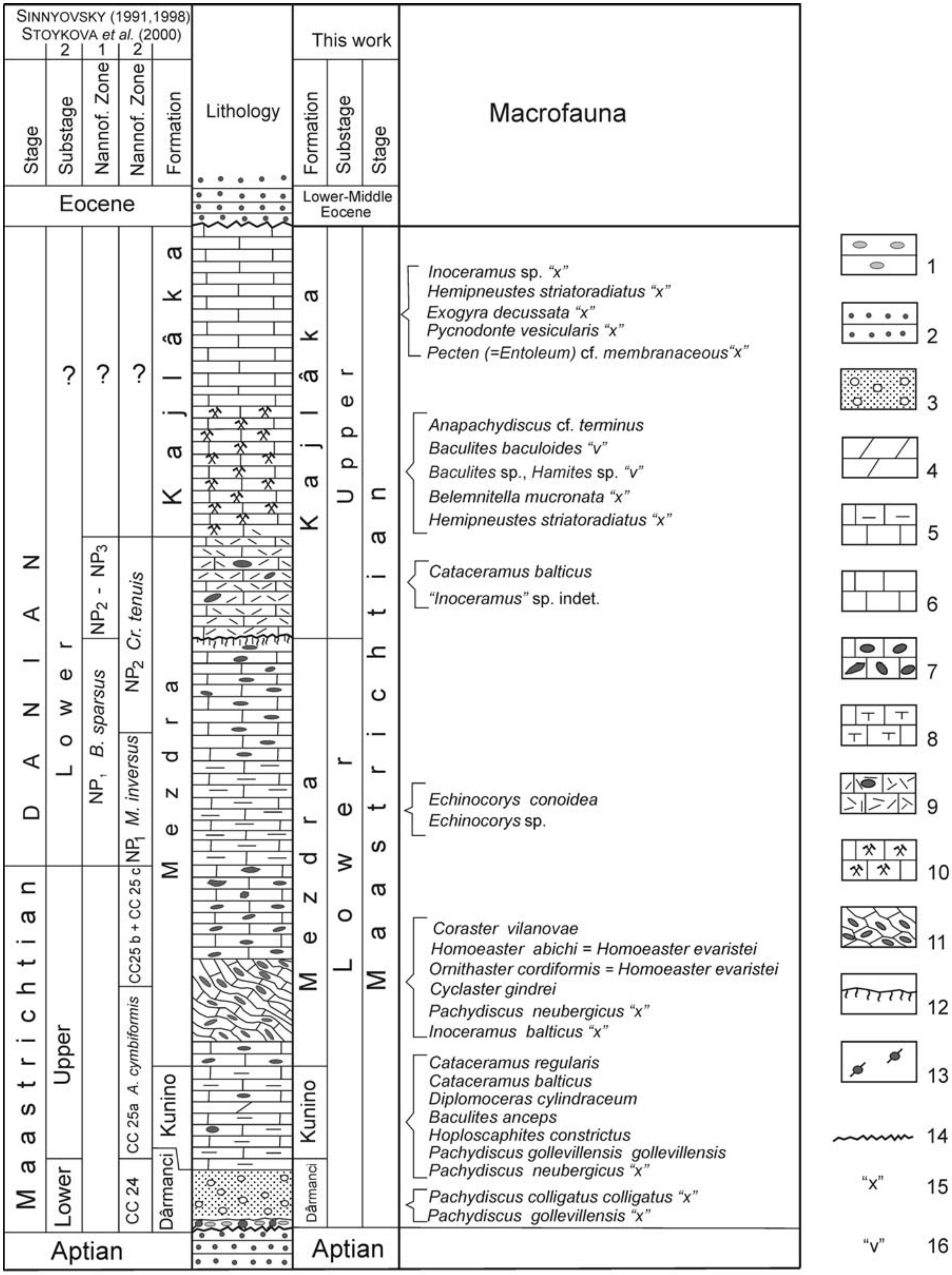

Fig. 2. Generalized stratigraphic section of the Mezdra syncline. **1**, conglomerates; **2**, sandstones; **3**, glauconitic sandstones; **4**, marls; **5**, clayey limestones; **6**, medium- to coarse-grained limestones; **7**, limestones with flints; **8**, chalky limestones; **9**, biomorphic limestones; **10**, "quarry type" limestones; **11**, megaslump; **12**, hardground; **13**, phosphorites; **14**, transgressive boundary; **15**, "x", fossils discovered by Bončev & Kamenov (1934) and probably some of them misidentified; **16**, "v", fossils discovered by Zlatarski (1910) and probably some of them misidentified. The meaning of the question marks "?" in Figs. 2, 3 and 4 is as follows: Fig. 2 – part of the section unstudied by Sinnyovsky (1998) and Stoykova *et al*. (2000); Fig. 3 – the upper part of Mezdra Fm is not shown in the paper of Sinnyovsky & Christova-Sinnyovska (1993, fig. 8); Fig. 4 – the middle part of Mezdra Fm is not shown in the section of Sinnyovsky (2001, fig. 3).

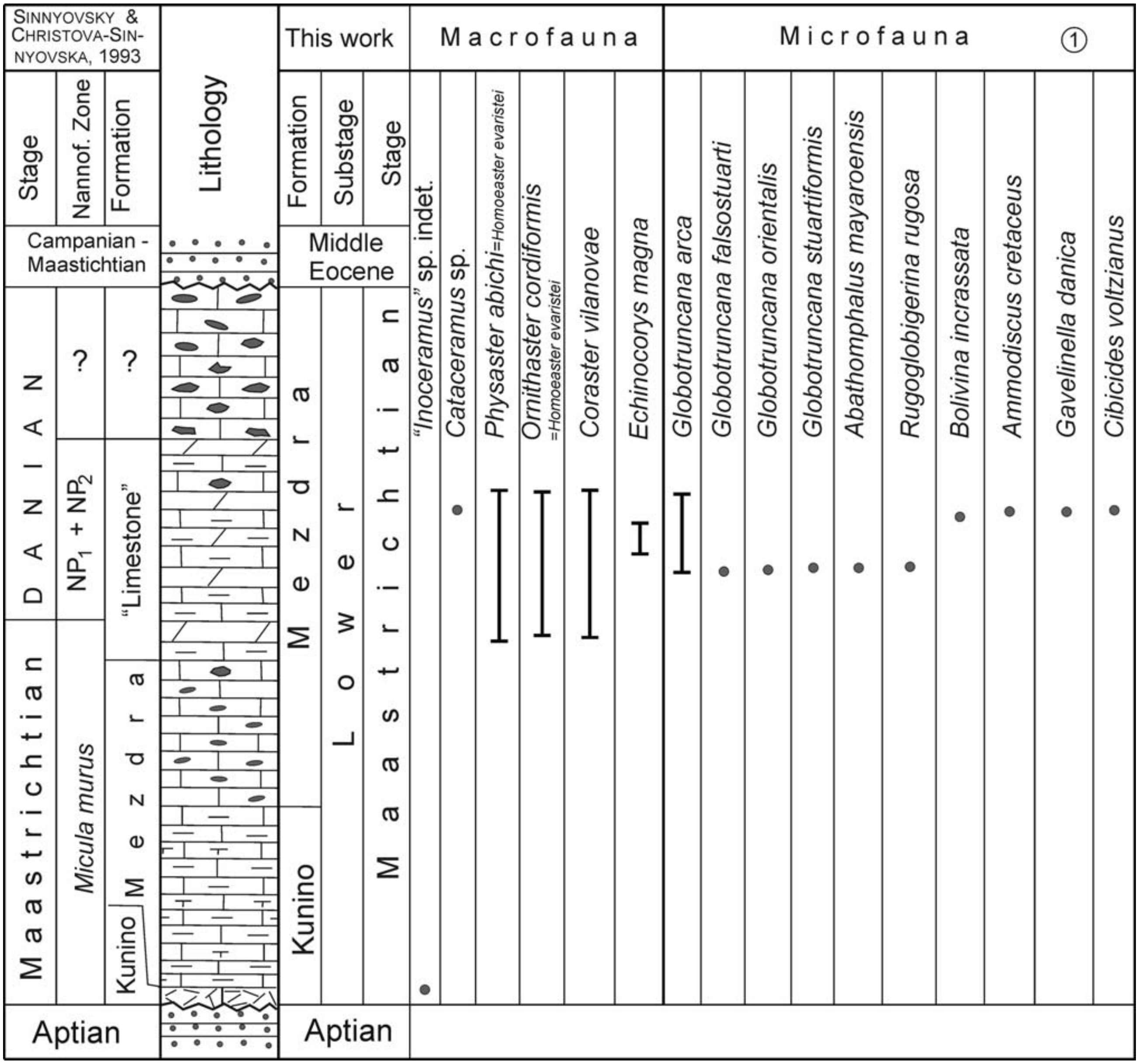

Fig. 3. Schematic stratigraphic section of the Maastrichtian Stage south of the village of Perchovtzi (Section I in Fig. 1). (**1**) - EK. DIMITROVA, unpublished data. For legend see Fig. 2.

Echinocorys gr. *conoidea,* hence a Maastrichtian age is not in doubt (J.W.M. JAGT, pers. comm., April 2006).

In outcrops south of the village of Perchovtzi (Section I in Fig. 1; Fig. 3) and at the Malata reka River (Section II in Fig. 1; Fig. 4), SINNYOVSKY & CHRISTOVA-SINNYOVSKA (1993, p. 38, fig. 8) and SINNYOVSKY (2001, p. 15, fig. 3) did not include the normal and complete magnitude of the Mezdra Formation. Furthermore, in the "Paleocene nannofossil zone" in these sections, single specimens of *Cataceramus* sp. and *Cataceramus* cf. *regularis* (Figs. 5A, B), and a juvenile ammonite undeterminable to the species level cf. Pachydiscidae (Figs. 5C, D) have been found. Ammonites are common in the "limestone formation" along the southern limb of the Lyutidol syncline, SW of the village of Lipnitza (Fig. 1).

In my opinion, the upper portion of the Mezdra Formation in the southern limb of the Mezdra syncline (Fig. 2) above the hardground (SINNYOVSKY, 1991, p. 264, fig. 2; 1998, p. 12, fig. 4; p.14, fig. 6), which comprises bioclastic, medium- to coarse-grained limestones, in fact belong to the base of the Kajlâka Formation. These limestones are analogous to the limestones of Unit 9 in the northern limb of the Mezdra syncline (JOLKIČEV, 1982, pp. 18–19, fig. 7). From these, in the eastern centricline of the Mezdra syncline, a single specimen of *Cataceramus balticus* BÖHM and one of *"Inoceramus"* sp. indet. have been found.

The transitional limestones are followed upwards by whitish (with beige), indistinctly bedded micro- to medium-grained quarry limestones – the so-called "Vratza

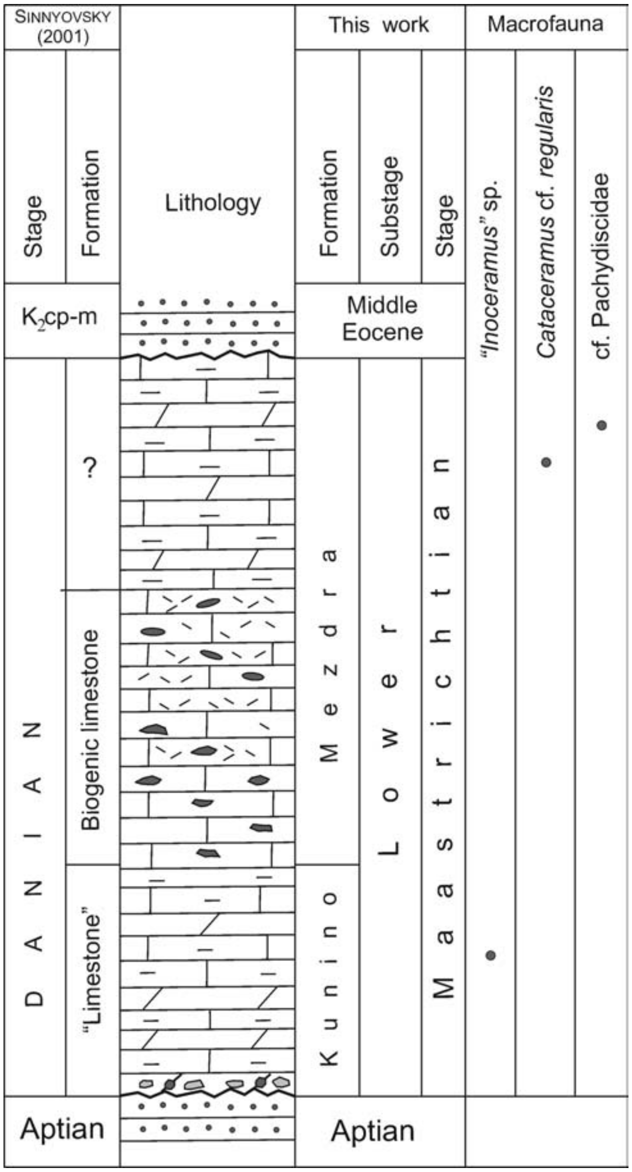

Fig. 4. Schematic stratigraphic section of the Maastrichtian Stage near to the village of Lyutidol – on the left bank of the Malata River (Section II in Fig.1). For dating the “Danian” strata SINNYOVSKY refers to the nannofosil taxa mentioned in the same paper (SINNYOVSKY, 2001, p. 12). For legend see Fig. 2

Stone”. From these limestones, ZLATARSKI (1910) mentioned *Baculites baculoides* ROEMER (probably misidentified ammonite), *Baculites* sp., *Hamites* sp.; while BONČEV & KAMENOV (1934, p. 81) reported *Hemipneustes striatoradiatus* (LESKE) and *Belemnitella mucronata* (SCHLOTHEIM) (probably misidentified *Belemnitella*), and JOLKIČEV (1982, p. 18 – packet 9; p. 19, fig. 7) noted a *Pachydiscus gollevillensis gollevillensis* (D’ORBIGNY), = *Anapachydiscus* cf. *terminus* WARD & KENNEDY, 1993 which is figured here (Fig. 5E).

These sediments are overlain by light grey to whitish fine-, medium- to coarse-grained limestones from which BONČEV & KAMENOV (1934, p. 82) collected *Hemipneustes striatoradiatus*, “*Inoceramus*” sp., *Pycnodonte vesicularis* (LAMARCK), *Exogyra decussata* COQUAND and *Pecten* (=*Entolium*) cf. *membranaceus* (NILSSON) (Fig. 2).

In the area of the Lyutidol syncline, the Kajlâka Formation is preserved only in the southern limb of the structure – along the left bank of the Malata River, at the southern end of the village of Lyutidol. There, different horizons of Maastrichtian strata are transgressively overlain by terrigenous Middle Eocene deposits (TZANKOV *et al*., 1991), which SINNYOVSKY & CHRISTOVA-SINNYOVSKA (1993) and SINNYOVSKY (1993, 2001) assumed to be in allochthonous position and of Campanian–Maastrichtian age, as defined by nannofossils (Figs. 3, 4). I subscribe to the transgressive, but not allochthonous, position of the terrigenous sediments upon the Maastrichtian ones. The nannofossil samples have presumably been collected from Upper Cretaceous blocks, included as a common component within Middle Eocene terrigenous sediments.

Disregarding the presence of inoceramids, cephalopods and characteristic Maastrichtian echinoid fauna in the whole section of the Upper Cretaceous series in these structures, SINNYOVSKY & CHRISTOVA-SINNYOVSKA (1993), SINNYOVSKY (1991, 1993, 1998, 2001) and STOYKOVA *et al*. (2000), on the basis of nannofossils, defined the Paleocene age for most of this section (Figs. 2–4). They assumed (pers. comm., 2004) the Maastrichtian inoceramid, cephalopod and echinoid fauna, which occurs in the range of their “nannofossil zones”, as well as the macrofauna from the Kajlâka Formation, to have been redeposited. I assert that this does not correspond to the fossil sequences in the section and there is no physical evidence of resedimentation of Maastrichtian macrofossils.

The outcrops of the Mezdra Formation continue into the Fore Balkan and to the west of the Mezdra syncline as far west as the valley of the Ogosta River. There, in a quarry at the village of Lyuta (now Vladimirovo), Vratza District, BONČEV & KAMENOV (1934, p. 80) found *Pachydiscus neubergicus* (VON HAUER) together with numerous echinoids, analogous in specific content to those from the Mezdra Formation in the area of Mezdra (determined also by the present author). SINNYOVSKY (2003, p. 152) analysed the limestones in this quarry for nannoplankton and “proved” that they are of Paleocene and not of Maastrichtian age. SINNYOVSKY is well aware of the presence of Maastrichtian macrofossil taxa at this locality, cited by him in this paper (p. 149), but fails to comment on this fact.

Conclusion

The normal superposition of lithostratigraphic units, which form the limbs of the Mezdra and Lyutidol synclines, as well as their macro- and microfossil content unambiguously confirm their Maastrichtian age.

The co-occurrence of Paleocene nannofossils and Maastrichtian macrofossil taxa in the sections of these

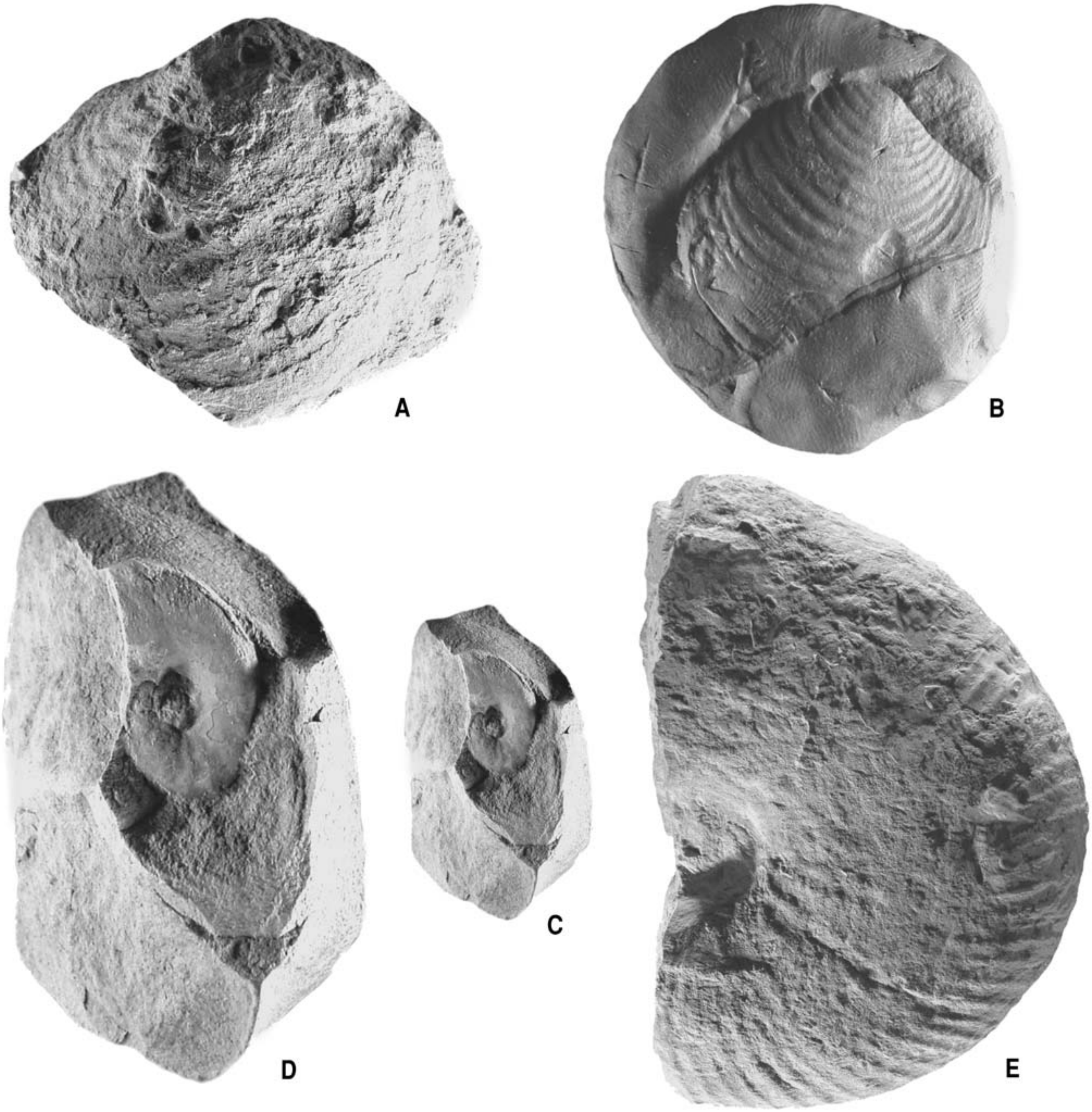

Fig. 5. **A**. *Cataceramus* sp., specimen No SU6030, Mezdra Formation, south of the village of Perchovtzi (section I from Fig. 1; Fig. 3); x 1. **B**. *Cataceramus* cf. *regularis* D'ORBIGNY, specimen No SU6029 (plaster cast), Mezdra Formation, on the left bank of Malata River, near the village of Lyutidol (section II from Fig. 1, Fig. 4); x 1. **C**, **D**. A juvenile ammonite undeterminable to the species level cf. Pachydiscidae, specimen No SU6028, Mezdra Formation, on the left bank of Malata River, near the village of Lyutidol (section II from Fig. 1, Fig. 4); C, × 1; D, × 2. **E**. *Anapachydiscus* cf. *terminus* WARD & KENNEDY, specimen No SU267, found in Kajlâka Formation, the quarry at the village of Varbeshnitza, NW from Mezdra (mentioned in JOLKIČEV, 1982, p. 18, packet 9, p. 19, fig. 7 as *Pachydiscus gollevillensis gollevilensis* (D'ORBIGNY), x 0.5. SU – collection numbers from the Museum of Paleontology at Sofia University "St. Kliment Ohridski".

structures indicates the diachronic appearance of macro- and nannofossils at the Cretaceous/Paleogene boundary. From this viewpoint, the respective boundary cannot be fixed by nannofossils except if it is assume the Maastrichtian macrofossils to have been re-deposited, but this is not the case. Furthermore, the Maastrichtian macrofauna is found not only within the ranges of the "nannofossil zones" but also in the sections overlying them – in the Kajlâka Formation, where a number of new Maastrichtian taxa, such as *Hemipneustes stria-*

toradiatus, appear. Accompaning to this taxon, inoceramids and cephalopods continue to occur (Fig. 2). These facts call into question the applicability of nannofossils for defining the Cretaceous/Paleogene boundary.

This recalls the situation in the type area of the Maastrichtian Stage, where all nannofossil taxa except one (*Biantholithus sparsus*), including the ones held to be indicative of the lower Paleocene, already occur in the underlying Maastricht Formation [(MAI *et al*, 1994; MAI *et al*, 1997a; MAI *et al*, 1997b; MAI, 1999; MAI *et al*, 2003), yet in a different size category], which is well dated by macrofossil taxa as late Maastrichtian (J.W.M. JAGT, pers. comm., 2005).

Diachronism in the occurrences of macro- and nannofossils is observed not only at the boundary Cretaceous/Paleogene, but also at other boundaries, e. g. the Campanian/Maastrichtian boundary in some European outcrops (JAGT & FELDER, 2003; KÜCHLER & WAGREICH, 1999; WAGREICH *et al.,* 2003). ROBASZYNSKI *et al.* (1985) also expressed some doubts on the applicability of nannofossils in determining the Campanian–Maastrichtian boundary and pointed out that "the Campanian–Maastrichtian boundary is somewhat difficult to recognize with nannoplankton because of problems in determining the index species and possible diachronism of their appearances and extinctions from the Tethyan to the Boreal realms". WAGREICH (1987, p. 85) stated that "no exact correlation of nannoplankton and macrofossil zonation at the Campanian/Maastrichtian boundary for low and high latitudes exists". According to BURNETT (1998, p. 137) "stages have been historically defined onshore using macrofossils. In the absence of macrofossil data from oceanic cores, stages boundaries started to be "defined" using microfossil events". Finally, BURNETT (1998, p. 137) concluded: "Nannofossils do not define the bases of any Upper Cretaceous stages." This evidence, as well as the data presented above, shows that nannofossils should be used in biostratigraphy with more care in the case of chronostratigraphic boundaries already fixed by macrofauna.

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Резиме

Граница креде и палеогена у синклиналама Мездре и Љутидола у области Враца (западни Предбалкан, Бугарска)

У раду се говори о неоправданом приписивању (на основу кречњачких нанофосила) великог дела мастрихтског профила у синклиналама Мездре и Љутидола (западни Предбалкан, Бугарска) палеогену. Горњокредни седменти у синклиналама Мездре и Љутидола врацке области западног дела Предбалкана у Бугарској широко су распрострањени и великог су тектонског значаја. BONČEV

(1932) је први доказао да су горњокредни седименти Предбалкана јужно од реке Искар мастрихтске старости. Мастрихтску старост су потврдили сви каснији истраживачи на основу макрофосилне фауне (COHEN, 1946; TZANKOV, 1968; JOLKIČEV, 1986, 1989; и други).

За кречњачке нанофосиле се последњих година претпоставља да су изузетно важни за расчлањавање горњокредних и кенозојских седимената – важност коју изгледа не можемо да доведемо у питање. Под утицајем нанопланктонске еуфорије недавно се појавило неколико публикованих радова у којима се граница креде и палеогена у проучаваном подручју прати не узимајући у обзир присуство карактеристичне макрофауне у истим слојевима који су расчлањени на основу нанопланктона. Граница креде и палеогена одређена помоћу макрофауне занемарује се у тим радовима.

Макрофаунистички подаци приказани у овом раду покрећу питање применљивости нанофосила за дефинисање границе креда–палеоген у датој области. Занемарујући присуство иноцерамуса, цефалопода и карактеристичне мастрихтске ехинидске фауне у целом профилу горњокредне серије у овим структурама, SYNNOVSKY & CHRISTOVA-SYNNOVSKA (1993), SYNNOVSKY (1991, 1993, 1998, 2001) и STOYKOVA *et al*. (2000) одредили су на основу нанофосила палеоценску старост највећег дела профила (сл. 2–4). Они претпостављају (усмено саопштење, 2004) да су мастрихтска иноцерамска, цефалоподска и ехинидска фауна, која се јавља у границама њихових "нанофосилних зона", као и макрофауна формације Кајлака, преталожене. Ја тврдим да то одговара фосилној секвенци у профилу и да не постоји материјални доказ преталоживања мастрихтских макрофосила.

Нормална суперпозиција литостратиграфских јединица које формирају крила синклинала Мездра и Љутидол, као и њихов макро и микрофосилни садржај недвосмислено потврђују њихову мастрихтску старост. То је приказано у овом раду бројним чињеницама.

Истовремена појава палеоценских нанофосила и мастрихтских макрофосилних таксона у профилима ових структура указује на дијахроничну појаву макро и нанофосила на граници креде и палеогена. Са овог становишта одговарајућа граница се не може утврдити помоћу нанофосила осим ако не претпоставимо да су мастрихтски макрофосили били преталожени, али то овде није био случај. Осим тога, мастрихтска макрофауна је нађена не само у границама "нанофосилних зона" већ и у слојевима изнад њих – у формацији Кајлака, где се јавља више нових мастрихтских таксона као што је *Hemipneustes striatoradiatus*. Поред овог таксона и даље се јављају иноцерамуси и цефалоподи (сл. 2). Ове чињенице доводе у питање применљивост нанофосила за дефинисање границе креда–палеоген.

То потсећа на ситуацију у типској области мастрихтског ката, где се сви нанофосилни таксони осим једног (*Biantholithus sparsus*) укључујући и оне за које се сматра да указују на доњи палеоцен, јављају у подини Мастрихтске формације [(MAI, 1999; MAI *et al*., 1994, 1997a, 1997b, 2002), мада другачијих димензија], која је поуздано одређена на основу макрофосилних таксона као горњомастрихтска (JAGT, усмено саопштење, 2005).

Дијахронизам у појавама макро и нанофосила запажен је не само на граници креде и палеогена, већ и на другим границама, напр. граници кампана и мастрихта у неким инданцима у Европи (JAGT & FELDER, 2003; KÜCHLER & WAGREICH, 1999; WAGREICH *et al*., 2003). ROBASZYNSKI *et al*. (1985) такође су изразили сумњу у применљивост нанофосила за одређивање границе кампан–мастрихт и указали да је "границу кампан–мастрихта донекле тешко препознати на основу нанопланктона због проблема утврђивања водеће врсте и могућег дијахронизма њиховог појављивања и изумирања од Тетиса до бореалних области". WAGREICH (1987, стр. 85) констатује да "не постоји тачна корелација нанопланктонског и макрофосилног зонирања на граници кампан–мастрихт за мање и веће географске ширине". Према BURNETT-у (1998, стр. 137), "катови су историјски дефинисани на копну помоћу макрофосила. У недостатку макрофосилних података из океанских језгара, границе катова су почеле да се "одређују" помоћу микрофосила". На крају, BURNETT (1998, стр. 137) закључује: "Нанофосили не одређују базе било којих катова горње креде". Овај доказ као и подаци приказани у овом раду показују да у биостратиграфији нанофосиле треба користити са више пажње у случају хроностратиграфских граница које су већ утврђене помоћу макрофауне.

ГЕОЛОШКИ АНАЛИ БАЛКАНСКОГА ПОЛУОСТРВА ANNALES GÉOLOGIQUES DE LA PÉNINSULE BALKANIQUE	67	51–63	БЕОГРАД, децембар 2006 BELGRADE, December 2006

Latest Cretaceous mosasaurs and lamniform sharks from Labirinta cave, Vratsa district (northwest Bulgaria): a preliminary note

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Abstract. Preliminary descriptions are given of selected specimens from an assemblage of >65 isolated vertebrate remains, collected in 1985 at the Labirinta cave, situated between the villages of Drashan and Breste, east of Cherven Briag (Vratsa district, northwest Bulgaria), from strata of late Maastrichtian age (Kajlâka Formation). Recorded are a fragmentary lower jaw of a mosasaurine squamate, *Mosasaurus* cf. *hoffmanni* (MANTELL, 1829), with two teeth preserved *in situ*, as well as two isolated teeth of lamniform sharks, assigned to *Squalicorax pristodontus* (AGASSIZ, 1843) and *Anomotodon* sp. Other vertebrate remains in this assemblage include rather poorly preserved fragments of ?skull and appendicular skeleton of mosasaurs, but it cannot be ruled out that other vertebrate groups (?elasmosaurid plesiosaurs) are represented as well. To establish this, the additional material needs to be studied in detail and compared with existing collections; it will be described in full at a later date. A partial phragmocone of a scaphitid ammonite, found associated, is here assigned to *Hoploscaphites constrictus* (J. SOWERBY, 1817) and briefly described as well. This record dates the Labirinta cave sequence as Maastrichtian, as does the echinoid *Hemipneustes striatoradiatus* (LESKE, 1778); tooth morphology of *Squalicorax pristodontus* and a find of the pachydiscid ammonite *Anapachydiscus* (*Menuites*) cf. *terminus* WARD & KENNEDY, 1993 from correlative strata nearby narrow this down to late, or even latest, Maastrichtian. Finally, some remarks on mosasaur and plesiosaur distribution during the Campanian–Maastrichtian across Europe are added.

Key words: Mosasaurs, lamniform sharks, Maastrichtian, Bulgaria, scaphitid ammonites, echinoids, stratigraphy.

Апстракт. Дају се претходни описи примерака одабраних из асоцијације од преко 65 издвојених остатака кичмењака, сакупљених 1985. године у пећини Лабиринта између села Драшан и Бресте источно од Червеног Бриага (Врачански крај, северозападна Бугарска) из слојева горњомастрихтске старости (формација Кајлака). Регистрован је део доње вилице краљуштастог мозазаура, *Mosasaurus* cf. *hoffmanni* (MANTELL, 1829), са два очувана зуба ин ситу, као и два посебна зуба ламниформних ајкула, који се приписују *Squalicorax pristodontus* (AGASSIZ, 1843) и *Anomotodon* sp. Међу осталим остацима кичмењака у овој асоцијацији налазе се доста слабо очувани фрагменти ?лобање и припадајућег скелета мозазаура, али се не искључује присуство и других група кичмењака (?еласмозауридски плезиозаури). Да би се то утврдило, потребно је детаљно проучити допунски материјал и упоредити га са постојећим колекцијама. Потпунији опис ће бити накнадно урађен. Делимични фрагмакон скафитидног амонита, нађен у асоцијацији, приписује се *Hoploscaphites constrictus* (J. SOWERBY, 1817) и укратко се описује. Према овом налазу, као и на основу јежа *Hemipneustes striatoradiatus* (LESKE, 1778); секвенца пећине Лабиринта одређује се као мастрихтска; морфологија зуба *Squalicorax pristodontus* и налазак пахидисцидног амонита *Anapachydiscus*

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(*Menuites*) cf. *terminus* Ward & Kennedy, 1993 из оближњег изданка формације Кајлака омогућава прецизнију одредбу старости као касни мастрихт, или чак најкаснији мастрихт. Ближа одредба на горњи мастрихт заснива се на морфологији зуба. На крају, дају се и нека запажања у вези распрострањености мозазаура и плезиозаура за време кампан–мастрихта широм Европе.

Кључне речи: Мозозаур, ламниформне ајкуле, мастрихт, Бугарска, скафитидни амонити, јежеви, стратиграфија.

Introduction

In the summer of 1981, a team of speleologists discovered a new, unexplored cave in Upper Cretaceous limestones between the villages of Drashan and Breste, Vratsa district (northwest Bulgaria; Fig. 1). This expedition was organised by the speleoclub 'Stalacton', based in the nearby town of Cherven Briag. After a vertical descent of eight metres, the speleologists encountered a labyrinth of several galleries with a total length of about 1 km. The new cave was named Labirinta, Bulgarian for 'The labyrinth'. On the way back to the entrance, 28 m below the surface, the group came across several fossil bones protruding from the cave wall at two sites (A, B in Fig. 2). During a subsequent expedition to the same area, the speleologist Zdravko Iliev invited two palaeontologists, Drs Stoycho Breskovski and Vassil Popov, who noted that this fossil occurrence was significant and rather unique. Together with Dr Nikolay Spassov they were responsible for a preliminary identification of the bones excavated. They attributed them to the extinct squamate family Mosasauridae and, more specifically, to the genus *Mosasaurus*. In the summer of 1985, a palaeontological excavation was carried out, during which all fossil material accessible was collected, albeit rather chaotically without documenting the exact position of specimens taken from the rock. The material from the two sites was subsequently mixed and transferred to the collections of the National Museum of Natural History Sofia (NMNHS). This excavation has so far been described in a popular paper (Genov, 1985) only. Part of the material was later sent to the Paleontological Institute of the Russian Academy of Sciences (Moscow) for detailed examination, while the remainder stayed at Sofia. After that, studies came to a halt. A single tooth from this lot was put on exhibit in the Paleontology Hall of the National Museum of Natural History, but the material was never formally published. The current whereabouts of the specimens sent to Moscow is unknown.

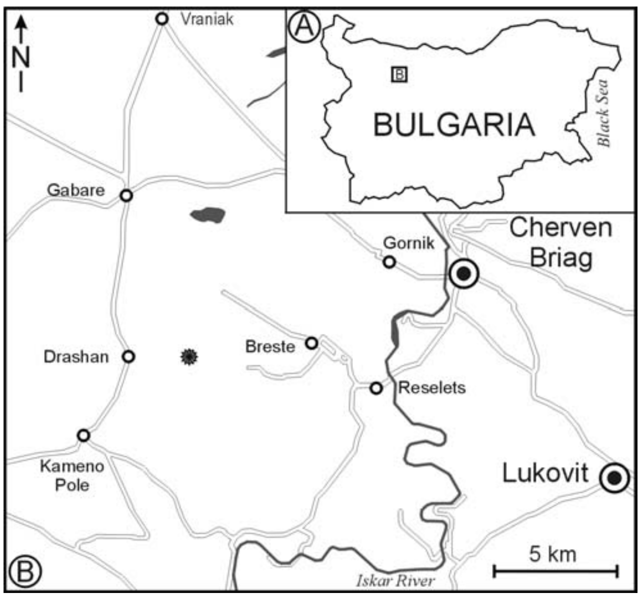

Fig. 1. Locality map of the study area in Vratsa district, northwest Bulgaria; the asterisk denotes the location of the Labirinta cave between the villages of Drashan and Breste.

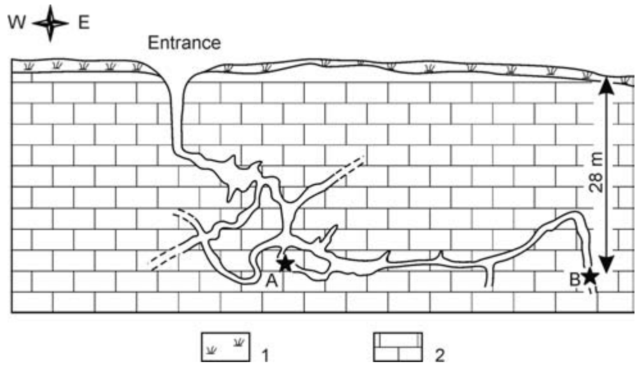

Fig. 2. Schematic vertical section of the Labirinta cave, showing the provenance (A and B) of macrofossil collections described herein; 1, soil; 2, limestones of the Kajlâka Formation.

In total, this lot comprises sixty registered, mostly fragmentary, specimens. Amongst them are two teeth (one of which is described below) associated with part of a jaw bone [NMNHS 11897/1 (*ex* Mos 60) and 11897/2 (*ex* Mos 20)], a radius, single phalanges, ribs, and vertebrae. For the present note, we have selected the following elements for brief discussion: a fragment of a lower jaw (NMNHS 11897/1) of a mosasaurine mosasaur with a tooth preserved *in situ*, and two isolated teeth of lamniform sharks [NMNHS 31362 (*ex* Mos 55) and NMNHS 31363 (*ex* Mos 7)]. Some of the other material is rather poorly preserved, being embedded in an indurated matrix not conducive to mechanical preparation. It may be that the present lot also includes isolated bones of other vertebrate groups, e.g. elasmosaurid plesiosaurs. Our aim is to provide, at a later date, detailed descriptions of this material (held at NMNHS), within the framework of a revision of all mosasaur material from the Upper Cretaceous of Bulgaria known to date, inclusive of the originals of TZANKOV (1939) and NIKOLOV & WESTPHAL (1976).

Of interest is a single scaphitid phragmocone (NMNHS 29929), collected when recovering the vertebrate remains from the Labirinta cave; its stratigraphic value is briefly commented on. Added also are more general notes on mosasaur and plesiosaur distribution in the Campanian–Maastrichtian across Europe, with references to a few recent papers.

Geological and stratigraphical setting

The Labirinta cave is situated within limestones assigned to the Kajlâka Formation (JOLKIČEV, 1986), a unit widely distributed in the Fore-Balkan and Moesian Platform of northern Bulgaria and usually the highest Cretaceous unit in outcrops in this area. Geomorphologically, the entrance to the Labirinta cave is situated in a sinkhole; such karst phenomena are very common in this area and are developed along vertical fractures in the Kajlâka Formation. This formation comprises whitish or beige, medium- to thick-bedded (albeit indistinctly), recrystallised limestones, and varies in total thickness between 10–25 and 200–280 m. In places, the limestones contain organogenic layers composed of shells and detritus mostly of bryozoans, bivalves and echinoids and rarely of gastropods, brachiopods and cephalopods. In the study area, within this limestone unit, there is an interval of 50–60 metres of whitish (with a beige hue), indistinctly bedded, fine- to medium-grained 'quarry type' limestones, the so-called Vratsa Stone, famous in Bulgaria and some other European countries for wall tiling (see JOLKIČEV, 2006, fig. 2). We assume that the mosasaurid material described by NIKOLOV & WESTPHAL (1976), and briefly commented upon below, originated from this interval.

The rock which yielded the mosasaur and shark material from the Labirinta cave described herein is a light grey, strongly recrystallised, slightly sandy limestone, containing Mn-oxihydroxide dendrites. This interval of the Kajlâka Formation probably correlates with the highest limestone unit in a section near the village of Varbeshnitsa, northwest of Mezdra. This highest unit overlies the 'quarry type' limestones (see description of section in JOLKIČEV, 1982, p. 18, fig. 7; topmost limestone unit 10).

The age assignment of the Kajlâka Formation in the study area has been based mostly on the superposition of this unit on strata of early Maastrichtian age, and on ammonite and echinoid evidence. A single echinoid species, commonly recorded from this formation, *Hemipneustes striatoradiatus* (LESKE, 1778), corroborates a Maastrichtian date [it occurring most commonly in the upper Maastrichtian]. The isolated scaphitid phragmocone (Fig. 3) found associated with the vertebrate remains from Labirinta cave is here assigned to *Hoploscaphites constrictus* (J. SOWERBY, 1817), also confirms a Maastrichtian date. The tooth morphology of the lamniform shark described here as *Squalicorax pristodontus* (AGASSIZ, 1843) allows this to be specified as late Maastrichtian, and the pachydiscid ammonite, *Anapachydiscus (Menuites)* cf. *terminus* WARD & KENNEDY, 1993, recorded from the 'quarry type' limestones of the Kajlâka Formation at the nearby village of Varbeshnitsa (see JOLKIČEV, 2006, fig. 5E) narrows the dating more precisely to the latest part of the late Maastrichtian. *Anapachydiscus (Menuites) terminus* is also known from the uppermost Maastrichtian of the Bay of Biscay sections (France, Spain), the southeast Netherlands, northern and eastern Denmark, central Poland, Azerbaijan, Crimea and South Africa (see WARD & KENNEDY, 1993) and the Bjala area of eastern Bulgaria (IVANOV, 1995).

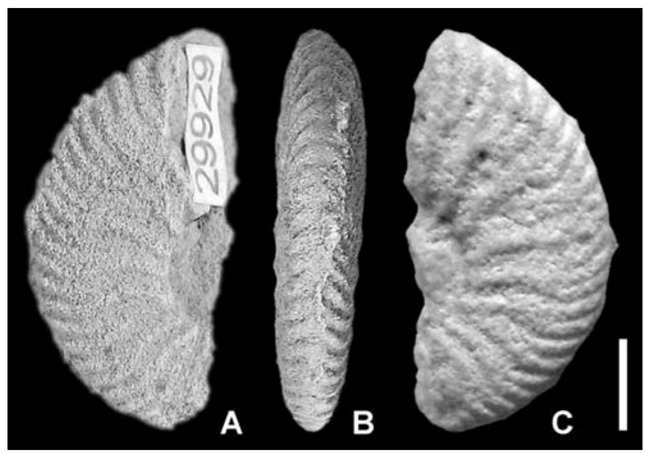

Fig. 3 A–C. *Hoploscaphites constrictus* (J. SOWERBY, 1817), NMNHS 29929, partial phragmocone, in lateral (left and right) and ventral views. Scale bar equals 5 mm.

Preliminary descriptions

To denote the repositories of material described, illustrated and/or referred to, the following abbreviations are used in the text: IRScNB, Institut Royal des Sciences Naturelles de Belgique, Brussels; MNHN, Muséum National d'Histoire Naturelle, Paris; NHMM, Natuurhistorisch Museum Maastricht, Maastricht; NMNHS, National Museum of Natural History, Sofia.

Mosasaurs

From what can be seen, the fragmentary lower jaw with two teeth preserved can be assigned to the mosasaurinae genus *Mosasaurus* CONYBEARE, 1822 (type species: *Mosasaurus hoffmanni* MANTELL, 1829).

Mosasaurus cf. ***hoffmanni*** Mantell, 1829
Fig. 4 A–D

Material. A partial lower jaw with two teeth associated (NMNHS 11897); here, we only describe the larger tooth (NMNHS 11897/1). The smaller one, situated more posteriorly, is longitudinally broken and not prepared yet.

Description. Being partially embedded in hard matrix and, in general, of rather poor preservation, the jaw bone cannot be described in detail. From what can be seen (e.g., foramina, overall size and height as compared to tooth size, as well as dental and root structure; Fig. 4A), this fragment is best interpreted as the anterior/mesial portion of a lower jaw (dentary) of an adult individual, pending further preparation. It contains two teeth *in situ*; the larger of these is a sturdy, bicarinate crown (incomplete, tip broken off; Figs. 4 A–D) measuring 43 mm in overall height (as preserved; original height estimated to have been 46 mm), and 19 mm in basal width, in mesodistal direction. It has an elliptical, typically U-shaped cross section (Fig. 4 D), with unequal labial and lingual surfaces; labial face gently convex with no facetting visible, not even proximally; lingual face deeply U-shaped and no facetting seen either. Enamel beading is not well developed; it is seen only in patches proximally. The crown is moderately posteriorly and lingually recurved. Both anterior and posterior carinae are well developed, but partially damaged; carinae minutely serrated over their entire length. The uppermost portion of the root is exposed considerably (Fig. 4A), being reversed conical in shape but lacking a clearly developed 'rim'; its length cannot be determined and the resorption pit is not seen. The extent to which the root is exposed is exceptional in comparison to material of *M. hoffmanni* from the Maastrichtian type area; it could be a pathological feature of the present individual.

Remarks. Tooth morphology (U-shaped cross section, minutely serrated carinae, obliquely positioned carinae, recurvature and enamel beading) allow this material to be compared favourably with *Mosasaurus hoffmanni*, the largest species in the genus *Mosasaurus*. The type material of *M. hoffmanni* is from the upper part of the Maastricht Formation (upper Nekum Member; holotype is MNHN AC 9648) in the type area of the Maastrichtian Stage (St Pietersberg, Maastricht and environs, the Netherlands; see Lingham-Soliar, 1995; Bardet & Jagt, 1996; Kuypers *et al*., 1998) and is of late Maastrichtian age (*Belemnitella junior* Zone of authors). In southern Limburg (the Netherlands) and adjacent Belgian territory (provinces of Liège and Limburg), *M. hoffmanni* (or a closely related taxon) first appears, albeit extremely rarely, in the upper Vijlen Member (Gulpen Formation; interval 6), is comparatively rare in the remainder of this formation (Lixhe 1–3 and Lanaye members) and the lower portion of the overlying Maastricht Formation (Valkenburg, Gronsveld and Schiepersberg members), but common in the Emael

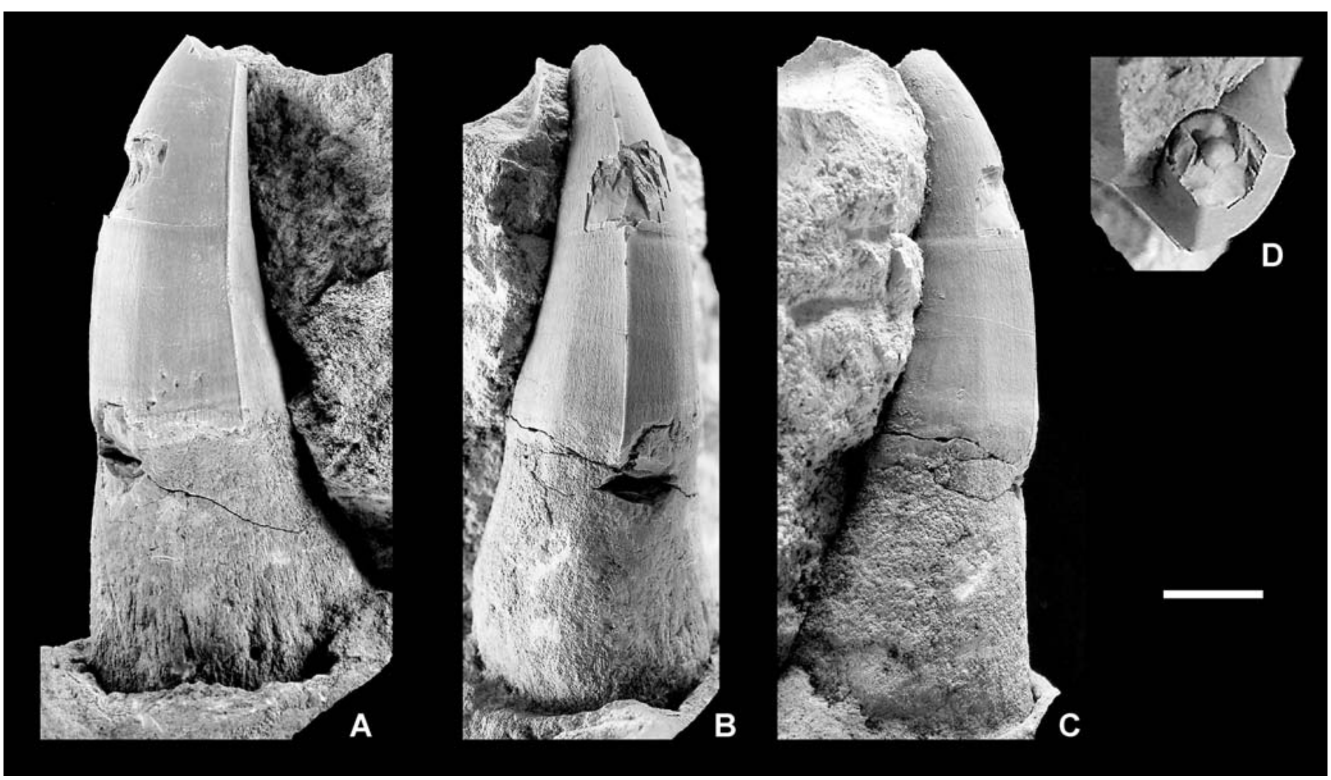

Fig. 4 **A–D**. *Mosasaurus* cf. *hoffmanni* Mantell, 1829, anterior-mesial fragment of lower jaw (NMNHS 11897/1), with a single tooth preserved *in situ*; tooth shown in labio-mesial (**A**), mesial (**B**), lingual (**C**) and apical (**D**) views, respectively. Scale bar equals 10 mm.

and Nekum members of that formation, in particular. The species ranges to within a metre below the Cretaceous–Paleogene (K/Pg) boundary in the area, and shows a wide range of variation in tooth morphology (facetting, size, enamel structure) which may be ontogenetically controlled (compare MERTENS, 1942); there is currently no evidence of sexual dimorphism in mosasaur taxa. From the Eben Emael area (northwest Belgium) in particular, fairly numerous finds have been made of articulated material in the past decade, inclusive of at least five skulls (JAGT *et al.*, 2002). This material is currently being studied, in an attempt to describe the species in detail and better determine its range of morphological and ontogenetic variation. Tooth morphology along the dental and (pre)maxillar rami in particular is assessed to allow isolated tooth crowns and teeth to be assigned with more confidence.

MULDER (1999) relegated the North American (New Jersey) species, *M. maximus* COPE, 1869 into the synonymy of *M. hoffmanni*, and subsequently MULDER *et al.* (2004) expressed doubts over the specific status of *M. lemonnieri* DOLLO, 1889 (holotype is IRScNB R 28 [*ex* 1470]) from the lower Maastrichtian ('Craie phosphatée de Ciply'; *Belemnella obtusa* Zone) at Mesvin, Mons Basin (southern Belgium), noting that it might well be nothing more than a juvenile *M. hoffmanni*. Interestingly, CALDWELL *et al.* (2004) noted that the type lot of *M. lemonnieri* from that unit included a specimen (IRScNB R3211) that would be better assigned to *Moanasaurus*, a genus otherwise known only from the Campanian (Haumurian) of New Zealand (WIFFEN, 1980).

The current stratigraphic and geographic range of *M. hoffmanni*, or of closely related taxa generally referred to in the literature as *M.* cf. *hoffmanni*, corresponds to the late Campanian to latest Maastrichtian in a belt across the Northern Hemisphere (LINDGREN & JAGT, 2005). From west to east this includes Missouri, Alabama, New Jersey (all USA), southern and northeast Belgium, southeast Netherlands, Denmark, northern Germany, central Poland, northwest Bulgaria and Turkey (BARDET & TUNOĞLU, 2002; KIERNAN, 2002; REICH & FRENZEL, 2002; MACHALSKI *et al.*, 2003; GALLAGHER *et al.*, 2005; TUNOĞLU & BARDET, 2006).

Sharks

The present lot from the Labirinta cave comprises two isolated neoselachian teeth, both assignable to lamniforms, with the larger one representing the anacoracid genus *Squalicorax* WHITLEY, 1949, and the other the ?alopiid genus *Anomotodon* ARAMBOURG, 1952.

Squalicorax pristodontus (AGASSIZ, 1843)
Fig. 5 A, B

Material. A single, incomplete lateral tooth (NMNHS 31362 [*ex* Mos 55]).

Description. This is an element of the lateral file, the crown being well preserved, broad and triangular, with a regularly convex cutting edge, bearing strong serrations. The distal cutting edge is oblique on the whole, with a slight concavity in its upper two-thirds; the labial face is very flat while the lingual one, much more reduced, is slightly convex. The root, not perfectly preserved, is also labio-lingually flattened and shows many small, irregularly spaced foramina on the labial face.

Remarks. Morphologically, this tooth can be identified as *S. pristodontus* beyond any doubt. Considering its general design, a late Maastrichtian age can be assigned to this specimen, by comparison with Maastrichtian material collected from the phosphate series of Benguerir (Morocco), currently under study (H. CAPPETTA, pers. obs.). Thus, this allows the general age assignment of the vertebrate association of Labirinta cave to be narrowed down to the late Maastrichtian.

Occurrence. This species is widely distributed and occurs in the Campanian of Belgium, France and Germany (LERICHE, 1929; ALBERS & WEILER, 1964; VULLO, 2005), but is particularly common in the Maastrichtian of the Netherlands and Belgium (LERICHE, 1929; HERMAN, 1977), Spain (CAPPETTA & CARMELO CORRAL, 1999), northern Bulgaria (TZANKOV & DATCHEV, 1966), Morocco (ARAMBOURG, 1952; NOUBHANI & CAPPETTA, 1997), Angola (ANTUNES & CAPPETTA, 2002), Syria (BARDET *et al.*, 2000), New Jersey and Texas (CAPPETTA & CASE, 1975; WELTON & FARISH, 1993) and Brazil (REBOUÇAS & DA SILVA SANTOS, 1956).

Anomotodon sp.
Fig. 5 C–E

Material. A single, incomplete latero-anterior tooth (NMNHS 31363 [*ex* Mos 7]).

Description. This is an element of a latero-anterior file, the crown being fairly high, narrow, and with a sharp apex. The labial face is slightly convex transversely but shows a basal median excavation of triangular outline; the lingual face is transversely convex and completely smooth. On one side, a short oblique heel, slightly and irregularly serrated, can be seen. The root is damaged and only one side is preserved; its lingual face is rather high, and it seems that there was not a long lobe.

Remarks. In lateral teeth of *Anomotodon*, the lingual face of the crown often is devoid of folds. The same is seen in teeth of the genus *Paranomotodon* HERMAN *in* CAPPETTA & CASE, 1975, the crown of which completely lacks folds (SIVERSON, 1992; VULLO, 2005). So, on the basis of the material available, it is quite difficult to give a definite generic assignment. NMNHS 31363 can be compared to *A. toddi* CASE & CAPPETTA, 1997 (p. 142, pl. 5, figs. 1, 2) from the upper Maastrichtian Kemp Clay Formation of Texas, but also to *A. hermani* SIVERSON, 1992 (p. 544, pl. 5, figs. 1, 2) from the lower-upper Campanian of southern Belgium and south-

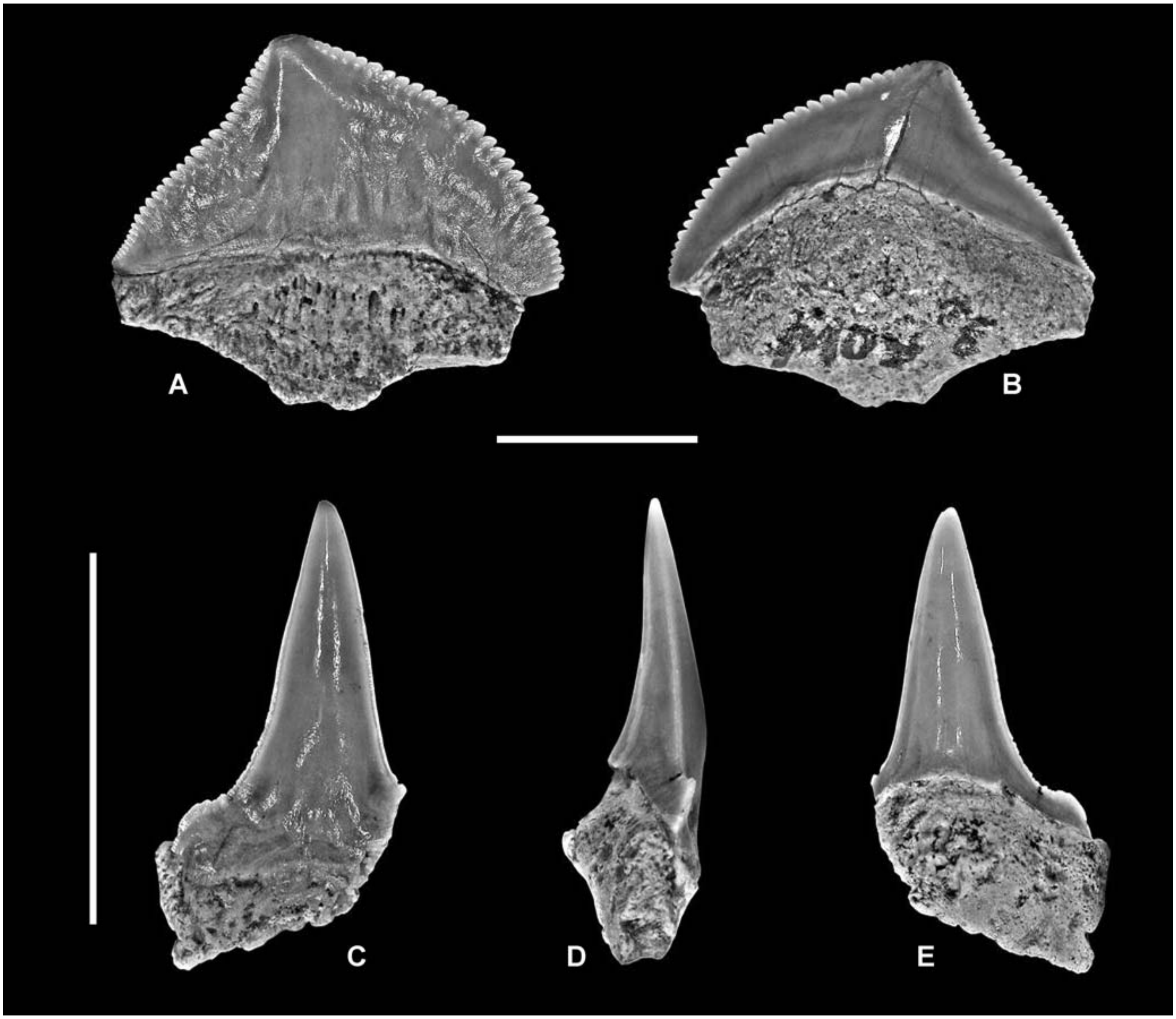

Fig. 5. Lamniform shark teeth. **A, B**. *Squalicorax pristodontus* (L. AGASSIZ, 1843), lateral tooth (NMNHS 31362), in labial and lingual view, respectively. **C–E.** *Anomotodon* sp., lateral anterior tooth (NMNHS 31363), in labial (**C**), lateral (profile) (**D**) and lingual (**E**) view. Scale bars equal 10 mm.

ern Sweden. Yet, as a definite specific identification is difficult on the basis of a single, imperfect tooth, it appears better to leave it in open nomenclature.

Discussion

Earlier records of mosasaurs from the Upper Cretaceous of northern Bulgaria include dissociated teeth and tooth crowns from near the village of Somovit at the River Danube, listed and illustrated by TZANKOV (1939). That author referred these strata to the uppermost Maastrichtian, but his listing [in original nomenclature] of characteristic macrofossil taxa from there shows that a modern revision is called for, as there appears to be a curious mixture of typically Campanian and Maastrichtian elements (e.g., *Echinocorys gibbus*, *Bostrychoceras polyplocum*, *Belemnitella mucronata* and *Parapachydiscus colligatus* being Campanian, and *Hemipneustes striato-radiatus* and *Discoscaphites constrictus* being Maastrichtian). Mosasaur taxa recorded by TZANKOV are *Leiodon anceps*, *Mosasaurus giganteus* (= *M. hoffmanni*) and *Globidens fraasi* (= *Carinodens belgicus*). Judging from his description of the matrix and based on the occurrence of the echinoid *Hemipneustes striatoradiatus* (which cannot be misidentified), we assume the material described by TZANKOV (1939) to have come from strata assignable to the Kajlâka Formation as well, and thus to be of (late) Maastrichtian age.

NIKOLOV & WESTPHAL (1976) recorded from an active quarry c. 2 km east of Varbeshnitsa, northwest of

Mezdra, part of the vertebral column (580 mm in length, 14 vertebrae) of a mosasaur, as well as three teeth, possibly of a single individual. The level from which these remains came was described as a unit of white to yellowish, fine-grained limestone quarried for wall tiles, c. 40 m thick, with occasional, scattered flint nodules, yielding the coleoid cephalopod *Belemnitella mucronata* and the holasteroid echinoid *Hemipneustes striatoradiatus*. The quarry exposing the Kajlâka Formation near Varbeshnitsa is in unit 9 of 'quarry-type' limestones (see JOLKIČEV, 1982, p. 18, fig. 7, limestone unit 9), having yielded *Pachydiscus gollevillensis gollevillensis* (*sensu* JOLKIČEV, 1982 = *Anapachydiscus* cf. *terminus*; see JOLKIČEV, 2006). *Anapachydiscus (Menuites) terminus* is characteristic only of the latest part of the late Maastrichtian (see remarks about the species distribution above).

With regard to the macrofossil taxa mentioned in NIKOLOV & WESTPHAL (1976), we wish to observe the following. Amongst belemnite workers, there currently is consensus that *B. mucronata* is a predominantly late Campanian species (CHRISTENSEN, 1997a, b; compare STOYANOVA-VERGILOVA & JOLKIČEV, 1993), which is why the record by NIKOLOV & WESTPHAL (1976) may be taken to refer to another species of *Belemnitella*, probably of the *B. junior* group which in northwest Europe characterises the late Maastrichtian. The presence of *B. junior* in the lower Maastrichtian of southern Limburg (the Netherlands), as noted by KEUTGEN (1996) and CHRISTENSEN *et al.* (2004), could not be substantiated in recent belemnite studies in the area (KEUTGEN *et al.*, in prep.). The holasteroid echinoid *Hemipneustes striatoradiatus* is widely distributed in the Kajlâka Formation (JOLKIČEV, 1989, 2006). This species is a typically Tethyan element, known to range through the whole of the Maastrichtian, but particularly characteristic of the latter part of the stage in the Netherlands, northeast Belgium, French Pyrenees, Navarra and Alicante (Spain), Bulgaria, Georgia, Kazakhstan, northern Caucasus and Tadzhikistan (SMITH & JEFFERY, 2000). In the Maastrichtian type area, *H. striatoradiatus* first appears in the lower Lanaye Member (Gulpen Formation), of late Maastrichtian age (*Belemnitella junior* Zone of authors; equivalents of *tegulatus*/*junior* Zone *sensu* SCHULZ & SCHMID, 1983) and ranges to the top of the Meerssen Member (Maastricht Formation, IVf-7; *Belemnella (Neobelemnella) kazimiroviensis* Zone) (JAGT, 2000).

Elsewhere in Bulgaria, the age of Kajlâka Formation is late Maastrichtian as based on records of the ammonite *Sphenodiscus binckhorsti* J. BÖHM, 1898 (see TZANKOV, 1982; KENNEDY, 1987; JAGT, 2002, 2005; MACHALSKI, 2005a), as well as on the basis of regular superposition in several outcrops with underlying lower Maastrichtian sediments.

For dating the present material from the Labirinta cave, an associated scaphitid phragmocone (NMNHS 29929) collected during recovery of the vertebrate material, is of importance. This consists of half a whorl (Fig. 3), of c. 22 mm in length (as preserved) and represents a highly compressed, flat-sided phragmocone, with fairly broadly rounded ventrolateral shoulders and a narrow, flattened venter (Fig. 3B). The diameter of the umbilicus is c. 6.5 mm. Ornament consists of up to nine flexuous primary ribs, arising at the umbilical seam (Fig. 3A, C); these are feebly concave and prorsiradiate on the inner flank, convex at mid-flank and concave on the outer flank and ventrolateral shoulder and convex over the venter. Primary ribs divide at mid-flank, and single (or double) intercalatories are inserted on the outer flank, giving a total of c. 22 ribs at this growth stage. No ventrolateral tubercles are seen at the largest diameter, but this may in part be preservation induced. No sutures can be seen.

Comparison with similar-sized material from the Maastrichtian type area (Maastricht Formation, Meerssen Member, subunits IVf-5 and -6; NHMM JJ 8297 and JJ 13341a–c), the upper Maastrichtian of Petites-Pyrénées, France (KENNEDY *et al.*, 1986, pl. 4) and the uppermost Maastrichtian of Turkmenia (JAGT *et al.*, in prep.) shows NMNHS 29929 to be comparatively coarsely ribbed and with a large umbilicus, but this is well within the range of variation documented for corresponding growth stages of *Hoploscaphites constrictus* (J. SOWERBY, 1817). This species is typically Maastrichtian, with records from southern Sweden, Denmark, northern Germany, the Netherlands, southern and northeast Belgium, Cotentin (Manche), Landes and Petites-Pyrénées (all France), Lleida (Spain), Switzerland, Austria, the Czech Republic, Poland, Bulgaria, the Ukraine, Carpathians, Donbass, Transcaspia, Kazakhstan and Kopet Dag, Turkmenia (KENNEDY, 1987; JAGT, 2002; NIEBUHR, 2003; MACHALSKI, 2005a, b). At least at two localities, Stevns Klint (Denmark) and the Maastrichtian type area (the Netherlands), it extends into the lower Paleocene (MACHALSKI & HEINBERG, 2005). On the basis of a detailed study of shell ornament, both of micro- and macroconchs, MACHALSKI (2005a, b) was able to demonstrate the occurrence of several temporal subspecies during the late Maastrichtian. Unfortunately, with but a single, incomplete phragmocone available, it cannot be determined to which of these taxa NMNHS 29929 might be assigned. A more detailed age assignment than Maastrichtian is thus impossible on the basis of this scaphitid record.

Isolated teeth of neoselachian sharks are common in epicontinental Upper Cretaceous strata in Bulgaria. TZANKOV & DATCHEV (1966, pl. 7, figs. 6–16) recorded, for the first time in Bulgaria, the species *Anacorax* (= *Squalicorax*) *pristodontus* (AGASSIZ, 1843) (erroneously spelled *priostodontus*) from Maastrichtian strata near the towns of Pleven and Shumen, and near the village of Somovit on the River Danube, but they did not provide a description of the occurrence of the strata, hence, it is difficult to judge from which exact level of the Maastrichtian their material came. It is presumed that their material also originates from the Kajlâka Formation. The good preservation of the specimen described here allows a comparison with Maastrichtian material from Morocco and, thus, enables a more precise age to be assigned to this specimen.

In summary, the Labirinta cave material is definitely of late (?latest) Maastrichtian date as based on dental morphology of *Squalicorax pristodontus* and on correlation with nearby outcrops, which have been dated on echinoid and ammonoid evidence.

Remarks on mosasaur and plesiosaur distribution across Europe

Mosasaurid occurrences are known from numerous outcrops of Campanian and Maastrichtian strata across Europe. Distinct stratigraphic levels, representing mostly shallow-water, (sub)littoral settings, in three areas in particular have yielded diverse assemblages, and at two of these, more or less completely preserved cranial and post-cranial material has been shown to be relatively common. These are:

1. The lower Maastrichtian 'Craie phosphatée de Mons' (*Belemnella obtusa* Zone) in the Mons Basin, southern Belgium (Lingham-Soliar & Nolf, 1990; Lingham-Soliar, 1992, 1993, 1994, 1999, 2000; Caldwell *et al*., 2004; Mulder *et al*., 2004; Jagt, 2005), which has produced '*Mosasaurus lemonnieri*' (= *M. hoffmanni* juv.?; *Moanasaurus* sp.), *Plioplatecarpus houzeaui*, *Halisaurus ortliebi*, *Prognathodon solvayi* and *Hainosaurus bernardi*. Two additional species, *Prognathodon giganteus* and *Globidens dakotensis*, are of Campanian age (Jagt, 2005);

2. The extended type area of the Maastrichtian Stage (Lingham-Soliar, 1993, 1994, 1995, 1996, 1999; Dortangs *et al*., 2002; Jagt *et al*., 2002; Mulder, 2003a, b; Schulp *et al*., 2004; Jagt, 2005; Schulp, 2006; see also Mulder & Mai, 1999). Here, Maastrichtian strata (Vijlen Member, Gulpen Formation to Meerssen Member, Maastricht Formation) have yielded *Mosasaurus hoffmanni*, '*M. lemonnieri*' (= *M. hoffmanni* juv.?), *Plioplatecarpus marshi*, *Liodon 'sectorius'*, *Carinodens belgicus* and *Prognathodon saturator*. Campanian species include *Prognathodon 'solvayi'* and *Hainosaurus* sp. (Jagt, 2005);

3. Skåne (southern Sweden, Kristianstad Basin), from where almost no articulated material is known, but which shows a remarkably high diversity in the lower and upper Campanian in particular, having yielded material assigned to *Platecarpus* sp., *Clidastes propython*, *Platecarpus* cf. *somenensis*, *Halisaurus sternbergi*, *Dollosaurus* sp., *Hainosaurus* sp., *Tylosaurus ivoensis*, *Prognathodon* sp. and *Plioplatecarpus* sp. From the lower Maastrichtian, two species are known, namely *Plioplatecarpus primaevus* and *Mosasaurus* aff. *lemonnieri* (Lindgren, 2005a, b; Lindgren & Siverson, 2002, 2004, 2005).

Taken together, these three areas can be assumed to represent all mosasaur taxa distributed across Europe during the Campanian–Maastrichtian, with the possible exception of one or two rare taxa. From other localities in Europe, far less common, and usually highly fragmentary material (with few exceptions), is known. These probably all represent deeper-water settings, far from coastal areas, and include:

4. The Münsterland (northwest Germany; Caldwell & Diedrich, 2005), from where a late Campanian species of *Clidastes* has been recorded;

5. England (Milner, 2002), from where material assigned to *Clidastes* sp. (Santonian–Campanian; Surrey, Sussex), indeterminate mosasaurines (Campanian–Maastrichtian; Norfolk), *Prognathodon* (upper Campanian; Norfolk), indeterminate plioplatecarpines (Santonian–Campanian; Sussex, Hampshire), ?*Tylosaurus* (upper Santonian–lower Campanian; Hampshire, Kent and Yorkshire) and *Leiodon anceps* (= ?*Hainosaurus*, Coniacian–upper Campanian; Sussex, Essex and Norfolk) has been recorded;

6. Southwest Russia and Crimea (Ukraine) (Yarkov, 1993; Storrs *et al*., 2000; Schulp *et al*., in press), with a cranial and post-cranial skeleton of *Dollosaurus lutugini* from the upper Campanian of central Russia and isolated tooth crowns of *Carinodens belgicus* from the upper Maastrichtian of Trudołyubovka, Crimea and Volgogradskaya oblast', Russia;

7. Northern Spain (Bardet *et al*., 1993, 1997b, 1999; Bardet & Pereda Suberbiola, 1996), with isolated teeth and tooth crowns of *Prognathodon solvayi*, *Platecarpus* cf. *ictericus*, *Leiodon anceps*, *Leiodon* sp., *Mosasaurus* sp. and indeterminate mosasaurines;

8. Central Poland (Machalski *et al*., 2003; Jagt *et al*., 2005), with records of *Mosasaurus* cf. *hoffmanni* from the upper Campanian and uppermost Maastrichtian, *M*. cf. *lemonnieri* from the upper Maastrichtian, '*M. (Leiodon)* cfr. *anceps*' [*sensu* Arambourg, 1952] from the same level, *Hainosaurus* sp. 1 and *Prognathodon* sp. from the upper Campanian, and *Hainosaurus* sp. 2 from the upper Maastrichtian, all from sections in the Wisla River valley;

9. France (Bardet, 1990; Bardet *et al*., 1991, 1997a), with records of *Hainosaurus bernardi* and ?*Hainosaurus* sp. from the Santonian–Campanian (Somme, Aude), *Prognathodon giganteus* from the lower Campanian (Champagne) and *Platecarpus* sp. from the lower Campanian of Corbières;

10. Denmark where lower and upper Maastrichtian strata in Jylland and Sjælland have yielded very rare remains, mostly tooth crowns, of *Mosasaurus* cf. *hoffmanni* and *Plioplatecarpus* sp. (Lindgren & Jagt, 2005).

Interesting is also Rügen (northeast Germany) from where historical material of early Maastrichtian age, the current whereabouts of which is unknown, was illustrated by Reich & Frenzel (2002, pl. 2, fig. 4). This isolated tooth from the von Hagenow Collection appears conspecific to material recorded from the upper Maastrichtian of central Poland by JAGT *et al*. (2005), as *Hainosaurus* sp. 2. Representatives of the tylosaurine genus *Hainosaurus* may thus have been more widely distributed in the European Campanian–Maastrichtian than previously assumed. In general, mosasaur remains from deeper-water settings represented by the 'white chalk facies' of northeast Germany and Denmark are comparatively rare; a few isolated tooth crowns of *Mosasaurus* cf. *hoffmanni* are known from Rügen (REICH *et al*., 2005). With the exception of some vertebrae in matrix, none of the vertebrate fossils recorded by LADWIG (1997) from Lägerdorf (northern Germany) can be assigned to mosasaurs; the majority of teeth illustrated are of enchodont teleosts and allies.

In comparison to mosasaurs, plesiosaurs in the Campanian–Maastrichtian are much rarer, and mostly refer to isolated cranial and post-cranial elements, rarely to associated skeletal elements of a single animal. Plesiosaurs appear to have frequented upwelling areas, rich in food; occurrences in shallow-water environments such as the upper Campanian of the Mons Basin (BARDET & GODEFROIT, 1995) and the upper Maastrichtian of the Maastricht area (MULDER *et al*., 2000) are best explained as stemming from floating carcasses, or from animals that only on certain occasions visited the area to feed. Anomalous in this respect is the comparative richness of plesiosaur remains from the Campanian of southern Sweden (PERSSON, 1959, 1962, 1963, 1967); this may be related to preferred feeding and/or breeding grounds in the shallow-water settings of the Kristianstad Basin and other areas there. The find of a partial elasmosaurid skeleton in the uppermost Campanian (*grimmensis*/*granulosus* Zone) of Lägerdorf, northern Germany (MAISCH & SPAETH, 2004) is of special interest, in being one of the very few examples of associated plesiosaur remains known to us.

Conclusions

During the latest Cretaceous (Campanian–Maastrichtian), marine lizard (mosasaurid) species inhabited the epicontinental seas along the northerly margins of the Tethyan ocean. Mosasaurid records from Bulgaria are very rare and refer mostly to fragmentary material, all collected from strata assigned to the Kajlâka Formation. The new material described herein adds to our understanding of mosasaur distribution across Europe during the Campanian–Maastrichtian. For a proper documentation of all of the Bulgarian material, detailed comparisons with identified material contained in museum collections, both in Bulgaria and elsewhere in Europe, are needed. Future fieldwork in northern Bulgaria is also called for, in an attempt to recover more, and stratigraphically well-documented, skeletal remains there.

Rare and randomly distributed cephalopods and other characteristic macrofossils in the epicontinental Upper Cretaceous cause problems in Bulgaria, because there are no zonal subdivisions for the whole of the Upper Cretaceous based on ammonites or belemnites, or any other macrofossil group for that matter. For the Maastrichtian, in particular, only schemes based on microfossils are available. This study shows that shark teeth may be used for dating some strata where other characteristic fossils in the Upper Cretaceous of Bulgaria are missing.

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Резиме

Најмлађи кредни мозазаури и ламниформне ајкуле из пећине Лабиринта, Врачанска област (северозападна Бугарска) – претходна белешка

Из слојева који припадају формацији Кајлака, откривених у пећини Лабиринта у Врачанском крају, северозападна Бугарска, прикупљена је 1985. године збирка остатака кичмењака (укупно 65 регистрованих примерака у колекцијама Народног природњачког музеја у Софији). Од свих ових налаза даје се опис и слике једног дела доње вилице морског гуштера (мозозаура) са два зуба *in situ* и два изолована зуба ајкула (*Squalicorax pristodontus* и *Anomotodon* sp.). На основу величине, јако удубљеног попречног пресека у облику латиничног слова “U”, карине и глеђног низа, овај мозозаурски материјал је условно одређен као *Mosasaurus* cf. *hoffmanni*, врсте познате из доњег и горњег мастрихта Мисурија, Алабаме, Њу Џерсија, Данске, северне Немачке, средње Пољске, Холандије, Белгије и Турске. Асоцијација макрофосилних таксона садржи и део фрагмакона скафитида, који припада *Hoploscaphites constrictus* по којем је одређена мастрихтска старост збирке. Морфологија зуба *S. pristodontus* указује на касно мастрихтску старост. Присуство ехинида *Hemipneustes striatoradiatus* такође указује на мастрихтску старост. Налаз пахидисцидног амонита *Anapachydiscus* (*Menuites*) cf. *terminus* из оближњег изданка формације Кајлака омогућава ужу одредбу старости – касни мастрихт. Ускоро ће бити извршена ревизија целокупног регистрованог материјала мозозаура из Бугарске, заједно са наласцима из пећине Лабиринта (који можда садрже и друге групе кичменјака као што су еластосауридски плесиосаури). Осим тога, потребна су нова теренска испитивања у северозападној Бугарској ради прикупљања више, стратиграфски поузданијег материјала. Изгледа да постоји добра корелација Бугарске са другим плитководним, епиконтиненталним срединама у Европи које су се крајем креде налазиле на ободу Тетиског океана. Ретки и случајни наласци цефалопода и других карактеристичних макро фосила у горњој креди стварају проблеме у Бугарској, јер не постоји зонална подела целе горње креде на основу амонита или белемнита, или неке друге макро фосилне групе. За мастрихт, углавном, постоје поделе засноване на микрофосилима. Наша проучавања су показала да се зуби ајкуле могу употребити за одредбу старости тамо где други карактеристични фосили у горњој креди Бугарске изостају.

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Trinocladus divnae and *Montiella filipovici* – a new species (Dasycladales, green algae) from the Upper Cretaceous of the Mountain Paštrik (Mirdita Zone)

Rajka Radoičić

Abstract. Two new dasycladalean species from the Upper Cretaceous of the Mountain Paštrik, Kukes Cretaceous Unit of the Mirdita Zone are described:

Trinocladus divnae sp. nov. is characterized by variable size of the thallus, relatively narrow main axis, typical *Trinocladus* organization of the laterals and thin calcification limited to the distal part of the thallus which includes a swollen part of secondaries and short tertiaries. Often, the internal portion of the whorls (except sometimes the main stem membrane), tends to dissolve and form dissolution cavities filled with cement.

Montiella filipovici sp. nov. is characterized by a primary skeleton made of a thin individual sheath around a fertile ampullae, often obliterated by recrystallization. Four to six laterals, each giving one secondary and one fertile ampulla located on the upper side of the relatively thick short primary lateral.

Upper Cenomanian limestone with *Cisalveolina fraasi* and *Trinocladus divnae* sp. nov. was deposited immediately before the events that resulted in sea level rising. The middle and upper Cenomanian eustatic-tectonic processes had different effects in the Paštrik shallow water areas, depending on the distance from the basinal part of the Unit. Bathymetric changes in a part of the Paštrik sedimentary area were not significant, even negligible. *Montiella filipovici* is found in the post-*fraasi* shallow water sequence, assigned to the ?uppermost Cenomanian–lowermost Turonian (= *Whiteinella archaeocretacea* Zone *p. p.*; a short stratigraphic gap, in a part of the area, is noted). Shallow water limestone with Turonian taxa, corresponding to the *helvetca* Zone, occurs a few meters upward.

Supplementary note: the species *Cylindroporella parva* Radoičić is transferred in the genus *Montiella*, the species *Permocalculus elliotti* Johnson is transferred in the genus *Trinocladus*, while the species *Trinocladus bellus* Yu Jing is transferred in the genus *Belzungia*.

Key words: Dasycladales, new species, new combination, Cenomanian, Turonian, Mountain Paštrik, Kukes Cretaceous Unit, Mirdita Zone

Абстракт. Описане су двије нове врсте дазикладалеских алги: *Trinocladus divnae* sp. nov. из ценомана и *Montiella filipovici* sp. nov. из ?највишег ценомана–најнижег турона Паштрика (Кукеска кредна јединица, Мирдита Зона):

Врсту *Trinocladus divnae* sp. nov. карактерише талус веома варијабилних димензија, узана главна оса, организација огранака *Trinocladus* типа и слаба калцификација најчешће ограничена само на дистални дио талуса: око дисталног проширења секундарних и око терцијарних огранака. Унутарња структура, изузев каткада калцифициране мембране главне осе, била је веома подложна дисолуцији. Тако настала празнина обично је бивала испуњена цементом. Векстон-пекстоне са *Trinocladus divnae* sp. nov. Потиче из највишег дијела *Cisalveolina fraasi* зоне

Врсту *Montiella filipovici* sp. nov. карактерише танак примарни карбонатни омотач само око фертилних ампула који је најчешће уништен услед прекристализације. 4–6 релативно кратких масивних примарних огранака носе по један секундарни огранак и једну фертилну ампулу смјештену навише.

Горњоценомански кречњак са *Cisalveolina fraasi* и *Trinocladus divnae* sp. nov. депонован је непосредно прије догађаја који су узроковали пораст морског нивоа.

Средњо–горњоценомански тектонско-еустатички процеси различито су се одражавали на плитководни ареал зависно од удаљености односно близине басенског дијела Кукеске кредне јединице. Батиметријске промјене у дијелу овог плитководног седиментационог простора биле су незнатне. Пост-*fraasi* плитководну секвенцу карактерише исчезавање карактеристичних ценоманских фосила, осиромашење биоте,

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теригени принос (кварц), а мјестимично и разорени слојеви. *Montiella filipovici* нађена је у кречњачком слоју ове секвенце са учесталом *Halimeda elliotti* CONARD & RIOULT испод карбонатне секвенце која је латерални еквиваленат *helvetica* зоне. Овај дио пост-*fraasi* стуба приписан је ?највишем ценоману–најнижем турону (= *Whiteinella archaeocretacea* зона *p. p.*).

У додатној биљешци дати су подаци о новим комбинацијама: врста *Cylindroporella parva* пребачена је у род *Montiella*, *Permocalculus elliotti* у род *Trinocladus*, а *Trinocladus bellus* у род *Belzungia*.

Кључне ријечи: Dasycladales, нове врсте, нове комбинације, ценоман, турон, Паштрик, Кукеска кредна јединица, Мирдита зона.

Introduction

The Cretaceous succession of the Mountain Paštrik is an attached platform (superimposed paleogeography) overlaying the Diabase Chert Formation, serpentinite and Tithonian–Berriasian carbonate clastics (flysch auct.) in the north. From the middle Cenomanian into the Turonian, it was a ramp – a transitional stage from the platform to the basin.

Dasycladales, common in some of shallow water Albian, Cenomanian and Turonian levels of this area, have been mentioned or described by PEJOVIĆ & RADOIČIĆ, (1974), CHERCHI *et al.* (1976), CONRAD *et al.* (1977) and RADOIČIĆ (1978, 1983, 1984, 1994, 1998). The present note is a further contribution to the Dasycladales in Paštrik limestone: two new species – *Trinocladus divnae* and *Montiella filipovici* are described.

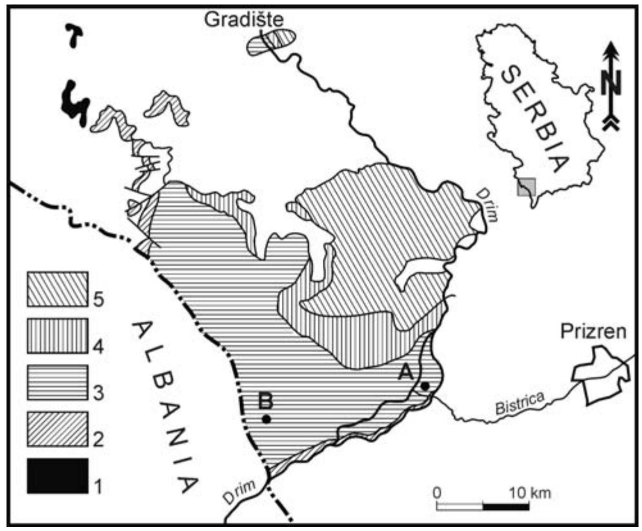

Fig. 1. Geological map of the Paštrik area, according to Geological map 1:000000, sheet Prizren (MENKOVIĆ *et al.*, 1982), simplified (new stratigraphic data are not included). **1**, ?Barremian–Aptian, carbonate breccia and bioclastic limestone; **2**, shallow water Albian sediments, **3**, shallow water lower into upper Cenomanian; **4**, shallow water Turonian carbonates with rudists and hemipelagic limestone; **5**, Senonian, breccia, microbreccia, calcarenites and marly limestone with planktonics. New stratigraphic data are not included. **A**, Bistrica section; **B**, – Vrbnica 1 section.

Systematics

Order Dasycladales PACHER, 1931
Family *Triploporellaceae* (PIA, 1920) emend. BERGER & KAEVER, 1992
Subtribe *Triploporellinae* (PIA, 1920) emend. ASSOULLET *et al.*, 1979

Genus *Trinocladus* RAINERI, 1922

According to ELLIOTT (1972, p. 619), the tubular thallus of *Trinocladus* is composed of "Successive verticils of radial branches, each branch showing outwardly widening primaries giving rise to several secondaries, and these in turn to bunches of tertiaries. Branches of the lower verticils may not show the full detail. Branches usually not alternate in position from verticil to verticil."

Based only on a transversal section, RAINERI (1922) maintained that a trichotomic partitition of the laterals is characteristic of the genus. In fact, the main generic feature is the form of laterals: club-shaped phloiophorous primaries with a more or less large subspheric distal part, similar shaped thinner secondaries, four or more per each primary, and bunches of similar short tertiaries.

It should be mentioned that, in some cases, recrystallized or poorly preserved *Trinocladus* tubes were also ascribed to *Permocalculus* or to *Griphoporella*. Specimens of such preservation are often really difficult to distinguish from some *Permocalculus*. Compare: fragments of *T. divnae* in Pl. 3, Figs. 10, 11, with "typical *Permocalculus* debris" illustrated by JOHNSON (1969, pl. 17) and by JOHNSON *in* JOHNSON & KASKA (1965, pl. 14). In the same paper, JOHNSON introduced a new species *Permocalculus elliotti,* which is, in fact, *Trinocladus* (see further text).

Among the species ascribed to the genus *Trinocladus,* there are those which do not have a branching pattern characteristic to *Trinocladus*. Only Paleogene species from China, *Trinocladus bellus* JU YING, 1976, which has a *Belzungia* type of arrangement of the laterals will be mentioned (see farther text).

Trinocladus divnae sp. nov.
Pl. 1, Figs. 1–14; Pl. 2, Figs. 1–8; Pl. 3, Figs. 1–6

Origin of name. The species is dedicated to my friend and colleague Dr. DIVNA JOVANOVIĆ (Belgrade) for her contribution to the study of depositional environments of the Late Paleozoic in northwestern Serbia.

Holotype. Slightly oblique transversal section of the calcareous tube shown in Fig. 2 (= Pl. 1, Fig. 1), thin slide RR2379, sample 013577, author's collection deposited in the Geological Institute, Belgrade.

This section shows the thinly calcified central stem membrane with well preserved insertion points of 4 laterals. The central stem, the irregular space around it and between the laterals were early post mortem filled with matrix. Open pores on the calcareous tube surface (dentate surface) is the evidence of the tertiaries. Primary and secondary laterals are not preserved predominantly due to dissolution in the post-filling phase with matrix. The two primaries are not completely obliterated by recrystalization (arrows). Dissolution cavities were subsequently filled with cement. This space, corresponding to the space of the laterals R1-R3 has an inverted triangular form (Fig. 2, arrows).

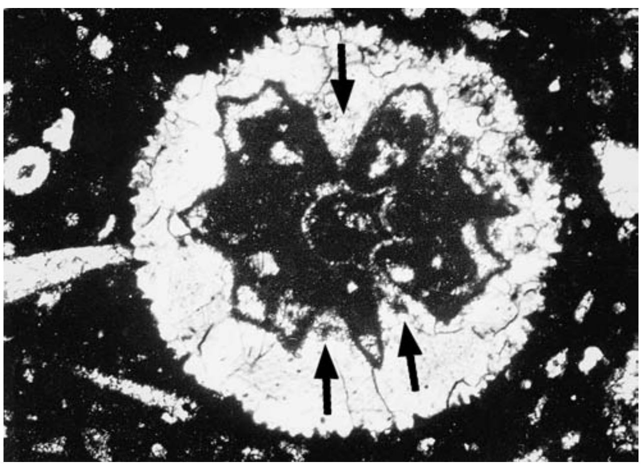

Fig. 2. *Trinocladus divnae* sp. nov. Holotype, slightly oblique section; thin slide RR2379, × 61,5. Notice the insertion points of 4 laterals. Arrows: recrystallized space of inverted triangular forms corresponding to units of laterals (R1-R3), and on the bellow the two pores of primaries which are not completely obliterated by recrystalization.

Isotypes. Specimens in thin slides RR2379 and 2380. Some of them illustrated in Pl 1, Figs. 2, 3, 9, 13; Pl. 2, Figs. 2, 9; Pl. 3, Figs. 2, 3, 4.

Other materials. Specimens in thin slides RR2448-2351 and RR2343-2346a, samples 015126 and 015130 collected in 1973 near Miljaj

Type locality and type level. Southeastern slope of Mountain Paštrik, Graždanik–Bistrica–Dobrušte belt, Geological map SFRJ 1:100 000, Sheet Prizren. The sample 013577 was collected in 1972 from the top part of the *Cisalveolina fraasi* Zone in the Bistrica section north of the Bistrica River, east of the Drim River (Fig. 1).

The Albian–Cenomanian succession of the Bistrica lies on Upper Triassic limestone (= large block sliding, during the Cimmerian event in the Diabase Chert Formation) and on the Diabase Chert Formation (RADOIČIĆ, 1994).

In the Bistrica column, about 220–230 meters thick, *Salpingoporella milovanovici* RADOIĆIĆ (last occurrence) and *Suppiluliumaella schroederi* BARATTOLO (Pl. 7, Figs. 2–4) occur in the level at about 180 meters. Upward from 200 meters, the foraminiferal assemblage is notably impoverished (*Cuneolina*, *Nezzazatinella*, miliolids, a few *Pseudolituonella reicheli* MARIE, *Chrysalidina gradata* D'ORBIGNY and *Pseudocyclammina)*; the new datum is the first occurrence of the "*Bry*2" – bryozoan species known only from the *Cisalveolina fraasi* Zone. *Cisalveolina fraasi* REICHEL was found in the 210th meter. Some beds of the *fraasi* Zone abound in hydrozoans (monospecific assemblage, RADOIČIĆ, 1994, pl. 2, fig. 4). Frequent sponge spicules, *Pieninia oblonga*, bryozoan zoeciums, rare *Heteroporella lepina* PRATURLON, *Montiella parva* (RADOIĆIĆ), microproblematica "*Pr10*", a few corals, gastropods, moluscan fragments, *Neithea* and *Eoradiolites* are also present. Sediments younger than the Cenomanian are outcropping in the western Drim riverside (Western Našec section, RADOIČIĆ, 1994).

Diagnosis. Thallus cylindrical, central stem narrow with whorls consisting of three orders of similarly shaped phloiophorous laterals; 7–8 primary laterals bear probably six relatively long secondaries, giving rise to bunches of fine short tertiaries. Distal widening of the laterals relatively small, maximum of 0,076 mm in the primaries, about 0,050 mm in the secondaries and about 0.025 mm in the tertiaries. Length of the primary lateral is almost equal to both secondary and tertiary laterals. Primary calcification delicate, prevailing around the distal portion of the thallus.

Dimensions (in mm) (extreme in the brackets):

Outer diameter 0.710–1.640 (1.947).

Main stem diameter (given on a few sections only) 0.126–0.177.

Length of primary laterals (= pores) nearly half the wall thickness.

Distance between whorls about 0.100.

Description. *Trinocladus divnae* sp. nov. in the Paštrik material is quite differently preserved. The primary feature of some specimens are completely or prevailing obliterated by recrystallization (Pl. 1, Figs. 4, 7, 10, 11, 14; Pl. 3, Figs. 1–4). Open pores on many of the corpuscule surface (dentate surface) correspond to external moulds of parts of the tertiaries (Pl. 1); their distal unpreserved part form a cortex. In a few sections, some pores, swelling of secondaries or rarely of primaries, are visible (Pl. 1, Figs. 5, 8, 10; Pl. 3, Figs. 5, 6).

Sometimes, the contour of the main stem is also recognizable (Pl. 1, Figs. 5, 9; Pl. 3, Figs. 2, 4), or, even, the calcified stem membrane is preserved as a thin black line (Pl. 1, Fig. 7). The central stem and proximal whorl area, in a few individuals, occur as a cavity with the internal wall surface more or less zig-zag undulated (Pl. 1, Figs. 6, 9, 10).

The internal structure of the specimen shown in Pl. 1, Fig. 9 seems, at a first glance, relatively well preserved. The structure of the whorls, in this case, is obliterated: only contours of the recrystallized whorl areas and the intervening space can be distinguished.

Here, subcircular sections give a wrong impression that they are sections through thick laterals. Most likely, the membrane of the primary and secondary laterals are not at all or only slightly calcified. They were enveloped in a thick mucilage layer giving a cuplike form to every unit of laterals (triangular in the sections), which are, in this case, completely recrystallized.

Individuals with a calcified distal thallus area, around the swelling of secondaries and of dense short tertiaries, are presented as thin-walled cylindrical calcareous tubes, relatively resistant to dissolution and abrasion (Pl. 2, Figs. 1–5). The small sized fragments of this thin fineporous calcified wall is difficult to recognize as dasycladalean skeleton elements (Pl. 3, Figs. 10, 11).

Comparing these differently preserved specimens, I could not immediately decide: whether they were the same species. Specimens with a thin distal calcification are ascribed to *Trinocladus divnae* because of the somewhat larger size of the thallus and, especially, the difference in the preservation are not of specific maximal values. Smaller individuals generally had an early-altered internal structure (recrystallized) and were more resistant to break. The thin calcareous wall of larger specimens, although resistant to dissolution and abrasion, were more friable.

Relations. This species resembles *Trinocladus tripolitanus* RAINERI the most, which has the same number of primary laterals but is not so variable in the size of the thallus. The main difference lies in the distal part of the thallus: relatively delicate secondaries of *Trinocladus divnae* bear dense bunches of fine tertiaries, forming a resistant thin calcified wall.

Trinocladus sp. from the Maastrichtian of Iraq (RADOIČIĆ, 1979, pl. 2, fig. 4) now is tentatively referred to *Trinocladus divnae*.

It does not exclude that the alga presented as "*Griphoporella* sp." by SCHLAGINTWEIT, 1992, pl. 1, fig. 7 is a thin-walled specimen of *Trinocladus divnae*.

Family *Dasycladaceae* (KUTZING, 1843) emend. BERGER & KAEVER, 1992
Tribe *Dasycladeae* PIA, 1920

Genus *Montiella* MORELLET & MORELLET, 1922

The genus *Montiella* is characterized by a simple cylindrical thallus consisting of whorls with two orders of laterals. The primary laterals arranged in quincunxes bear one fertile ampulla and one secondary lateral enlarged distally.

Type species is *Montiella munieri*, from the Montian of Belgium. Other species of the genus, *Montiella macropora*, was contemporary described from the Thanetian of the Paris Basin. Isolated specimens and fragments of the both species were studied by GÉNOT (1978, 1987, *in*: DELOFFRE & GÉNOT, 1982). This author (1982, p. 108) compares the calcareous sleeve of both species with those in some *Neomeris* "chés lesquelles les ramifications primaries et l'extrémité proximale des ramifications secondaires ne sont jamais conservées."

The find of genus *Montiella* in the Cretaceous sediments is of a later datum: when *Cylindroporella elitzae* BAKALOVA and *Cylindroporella benizarensis* FOURCADE *et al*. were transferred to the genus *Montiella* (RADOIČIĆ, 1980, GRANIER, 1990). The difference in the extent of calcification of the Paleocene and Cretaceous *Montiellae* is readily evident. In contrast to the Paleocene species, the known Cretaceous species have a calcareous sheath around the proximal part of the whorl with, in the some specimens, a well preserved morphology of the central stem.

In the calcareous sheath of the known Cretaceous *Montiellae*, as a rule, the pore of the secondary is not differentiated from the pore of the primary lateral (secondary effect). They look like a single pore: a thick and short proximal part with a fertile ampulla followed by somewhat narrower tube, distally enlarged having the protective function of the ampulla.

Besides the fertile ampullae, other whorl elements are often not or only partially preserved. Therefore, it is often difficult to distinguish the calcareous sleeves of *Montiella* from those of *Cylindroporella*. Bearing in mind that the type species of the genus *Cylindroporella* is poorly preserved (some structural elements are obliterated), the question is: what is *Cylindroporella?* The *Cylindroporella* problem is discussed by BARATTOLO and PARENTE (2000).

Montiella filipovici sp. nov.
Pl. 4, Figs. 1–9; Pl. 5, Figs. 1–12; Pl. 6, Figs. 1–4

Origin of name. The species is dedicated to my friend and colleague Dr. Ivan Filipović (Belgrade), for his contribution to the study of on the Paleozoic in Western Serbia.

Holotype. Oblique section of the specimen in Pl. 4, Fig. 1, thin slide RR2328, sample 015117, author's collection deposited in the Geological Institute, Belgrade.

Isotypes. Different sections in thin slides RR2326 to 2336, partly illustrated in Pl. 1, Figs. 2–9; Pl. 3, Figs. 1–12; Pl. 3, Figs. 1–4.

Type level and locality. Sample 015117 was collected in 1973 from the upper part of the section Vrbnica 1, southern slope of the Mountain Paštrik. This section is exposed on the footpath between Vrbnica–Drim and Miljaj–Ninaj, east of the section Vrbnica 2 (CHERCHI *et al*., 1976); Geological map SFRJ 1:100000, Sheet Prizren (Fig. 1).

Lateral equivalents of the sediments with *Cisalveolina fraasi,* in the Vrbnica 1 section, are followed by some ten meters of limestone with a prevailing weak terrigenous influx, changed and impoverished biota. A few meters upward, limestone abounding in halimedacean algae was sampled (15117). This bed, grainstone-packstone dominated by *Halimeda elliotti* CONARD & RIOULT, *Halimeda* sp. and some other halimedacean algae is the type level of *Montiella filipovici* sp. nov. The association also contains *Montiella parva* (RADOIČIĆ), *Terquemella* sp., sparse fragments of *Neomeris* and *Heteroporella lepina* PRATURLON, a few foraminifera *Nezzazatinella*, *Cuneolina*, *Reticulinella*, miliolids, rare ostracodes and metazoan fragments (Pl. 6, Figs. 5, 6, 8–11).

Further upwards (the bedding is not well visible), the lower Turonian (equivalent to the *helvetica* Zone) is documented by *Moncharmontia apenninica* (DE CASTRO), *Pseudocyclammina sphaeroidea* GENDROT (sample 015119), and the rudists *Hippurites, Durania*, *Biradiolites* and *Distefanella*. The interval between the *Cisalveolina fraasi* Zone and the lower Turonian is equivalent or partly equivalent to the *Whiteinella archaeocretacea* Zone

In the Gradište succession (the same Cretaceous Unit, Fig. 1), *Halimeda elliotti* occurs abundandly in some beds of the Hemipelagic Sequence (= *Whitinella archaeocretacea* and *Helvetotruncana helvetica* zones). In the Metohija Cretaceous Unit, the abundance of *Halimeda elliotti* associated with *Helvetotruncana helvetica* is known from the Zabel Section (RADOIČIĆ, 1993, 1998).

Diagnosis. Thallus with a narrow central stem and whorls commonly consisting of 6 laterals, exceptionally 4 or 5. Primary laterals arranged in quincunxes, short and relatively thick, each bears a fertile ampulla and a secondary lateral. Egg shaped slightly inclined upward fertile ampulla located on the upper side of the primary lateral close to the central stem, a secondary lateral grows from its distal end. Ampulla pedunculus is short, usually not clearly differentiated.

Walls of the fertile ampullae have been individually calcified. This primary calcareous skeleton is altered or partly altered.

Dimensions (in mm) (extreme value in brackets):

External diameter 0.607–0.708 (0.759); the transverse section with 5 laterals in the whorl shown in Pl. 5, Fig. 5 is a specimen with a narrower thallus diameter – 0.430 mm.

Diameter of the main stem (0.075) 0.101 – 0.151 (0.177).

Length of the ampulla with pedunculus 0.180.

Length of the primary laterals up to 0.127.

Diameter of the fertile ampulla up to 0.170.

Diameter of the primary lateral about 0.051.

Description. The surface of the calcareous tubes was more or less eroded, often to half of the fertile ampullae (Pl. 4, Fig. 9). The fertile ampullae primary have been individually calcified as more or less thin carbonate envelopes (about 0.002 mm). A similar primary calcification is not observed in the laterals, they were poorly preserved, probably due to weak or no calcification at all. The form of their distal-cortical part is not known (it seems they were much enlarged). The best example of individual calcified fertile ampullae is the transverse section in Pl. 2, Fig. 5. Some other sections, with a preserved individual sheath around the ampullae, and primary contact between them are illustrated in the same plate. In the same calcareous tube, parts of the skeleton may be differently preserved. An example of the different grade of the obliterated structure in the same whorl is the transversal section in Pl. 2, Fig. 4: well preserved, slight contact between the ampullae observable as a black line, and both, the sheath and the space between the ampullae are almost obliterated by advanced recrystallization in the other part of the section. The mentioned transverse section with 5 laterals is also an example of gradual alteration. The original sheath around the ampullae is preserved in part of this section, and obliterated by recrystallization in the other part.

Relations. *Montiella elitzae* and the very similar *Montiella benizarensis* are species with a larger thallus bearing 6–8 laterals per whorl and more variable dimensions than *M. filipovici* characterized by slightly variable thallus dimensions.

Some specimens of *Cylindroporella elitzae* and *Cylindroporella benizarensis* (are these two species?) are a nice examples of a post-mortem process resulting in axis widening at the whorl level (RADOIČIĆ *et al*., 2005, pl 1, fig. 3). The primary calcification around the fertile ampullae in these species is not preserved, except the thin calcification around fertile ampulla of *Montiella elitzae* from Eastern Serbia (RADOIČIĆ, 1980, pl. 2, fig. 4), which indicates the same primary calcification as that of *Montiella filipovici*.

A list of algal flora in the Cretaceous of Paštrik

(in alphabetic order):

Acroporella radoicicae PRATURLON, Pl. 8, Fig. 3
Bacinella irregularis RADOIČIĆ
Charophyta
Coptocampylodon fontis (PATRULIUS)
Coptocampylodon sp.
Clypeina pastriki RADOIČIĆ
Cylindroporella sp. div.
Dissocladella?, Pl. 8, Fig. 5
Halimeda elliotti CONARD & RIOULT, Pl. 6, Figs. 8–10
Halimeda sp. (spec. nov.?), Pl. 6, Fig. 12
Halimedaceae sp. div.
Heteroporella lepina PRATURLON, Pl. 7, Fig. 10
Koskinobulina socialis CHERCHI & SCHROEDER
Lithocodium aggregatum ELLIOTT
Lithocodioidea, different species
Marinella lugeoni PFENDER, Pl. 7, Fig. 9
Montiella filipovici sp. nov., Pl. 1, Pl. 2, Pl. 3, Figs. 1–6
Montiella parva (RADOIČIĆ), Pl. 4, Pl. 5, Pl. 6, Figs. 1–4
Neomeris (Drimella) drimi RADOIČIĆ
Neomeris sp., Pl. 2, Fig. 9
Neomeridae, subgenus?
?*Pseudoclypeina*, Pl. 7, Fig. 6
Pseudolikanella cf. *danilovae* (RADOIĆIĆ)

Pseudolithotamnium album (PFENDER), Pl. 7, Fig. 7
Salpingoporella hasi CONRAD, RADOIČIĆ & PEYBERNES
Salpingoporella milovanovici RADOIČIĆ
Salpngoporella pygmaea (GÜMBEL)
Salpingoporella turgida (RADOIČIĆ)
Suppiluliumaella schroederi BARATTOLO, Pl. 7, Figs. 2–4
Solenoporaceae
Suppiluliumaella sp., Pl. 8, Fig. 1
Terquemella div. sp.
Trinocladus divnae sp. nov., Pl. 1, Pl. 2, Pl. 3, Figs. 1– 6
Trinocladus aff. *tripolitanus* RAINERI, Pl. 3, Figs. 8, 9
Trinocladus?, Pl. 3, Fig. 7
Triploporella sp.
Digfferent microbial epiliths

Supplementary note

Montiella parva (RADOIČIĆ, 1983) comb. nov.

Cylidroporella parva n. sp., RADOIČIĆ, 1983: pl. 1, figs. 1–5; pl. 2, figs. 1–2; thin slide RR3557, author's collection, Geological Institute of Serbia.

Turonian, Tripolitania, Libya,

The taxon is found in the type level of *Montiella filipovici* and also in association with *Trinocladus divnae* (Pl. 6, Figs. 5–7).The subaxial section, Fig. 7, is the only specimen of this species with preserved pores of primary laterals upward bearing the fertile ampulla (the structure of the genus *Montiella*). The secondary laterals most probably were not calcified.

From the Turonian of Sinai in Egypt, the species was presented by IMAM (1996, 1b, not 1a). A primary calcification of this specimen, the individual sheaths enclosing the fertile ampullae which is the feature of the genus *Montiella,* is well preserved in the part of this recrystallized body.

Trinocladus elliotti (JOHNSON, 1965) comb. nov.

Permocalculus elliotti n. sp., JOHNSON (*in* JOHNSON & KASKA) 1965: pl. 5, figs. 1–5; thin slide 18587, (USNM in Washington, Division of Paleobotany, no 42340), earliest Early Cretaceous, possibly Late Jurassic, Rosario area of Spanish Honduras.

Although the calcareous sheath of the illustrated specimens is diagenetically altered, sections in figures 1–3 give sufficient data on the dasycladalean nature of this species. Branching arrangement – primary, secondary (Figs. 2, 3, on left) and tertiary (Fig. 3) laterals is of the *Trinocladus* pattern. Accordingly, the species is transferred into the genus *Trinocladus* RAINERI, 1922. In order to obtain a diagnosis, a study of the type material is necessary.

Belzungia bella (YU JING, 1976) comb. nov.

Trinocladus bellus. spec. nov., YU JING, 1978: pl. 8, figs. 10 (thin slide 28434) and 11 (thin slide 28435), ?Fig. 9, non Fig. 12, Paleocene–Ypresian of Lungma Region, China

The holotype of *Trinocladus bellus* is a large fragment of the calcareous tube – longitudinal-oblique section through 6 or 7 whorls. The insertion points of the primary laterals in this section are not preserved because the main stem is secondary enlarged. Thick short primaries, thick irregular secondaries and somewhat thinner tertiaries, give rise to further laterals, thin and anarchically arranged. Whorls bearing such arrangement of laterals characterize the genus *Belzungia,* MORELLET, 1908. The new combination refers to two out of four sections illustrated by YU JING (1978, fig. 10), holotype and transversal section in Fig. 12. This species, introduced on insufficient material, is different from other *Belzungia* species by coarser proximal (3 orders) and seemingly somewhat more anarchically arranged distal laterals.

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Резиме

Trinocladus divnae и *Montiella filipovici* – нове врсте (Dasycladales, зелене алге) из горње креде Паштрика (Мирдита зона)

Из горњокредних седимената Паштрика (Кукеска кредна јединица, Мирдита зона) описане су двије нове врсте дазикладалеса:

Triploporella divnae sp. nov.

Холотип. Мало искошен попречан пресјек приказан на табли 1, сл. 1.

Дијагноза. Цилиндричан талус са узаном централном стабљиком која носи, на растојању, пршљенове са три реда огранака сличног облика. 7–8 примарних огранака дају највјероватније по сест секундарених, а ови по сноп кратких терцијарних огранака. Дужина оба, секундарног и терцијарног, приближно је једнака дужини примарног огранка. Калцифициран је често само танак дистални дио талуса (врх секундарних и терцијани огранци), ријетко и мембрана главне стабљике. Секундарне промјене знатне.

Стратиграфски положај и типски локалитет. Горњи (али не најгорњи ценоман), виши дио зоне са *Cisalveolina fraasi* у профилу Бистрице на југоисточним падинама Паштрика.

Montiella filipovici sp. nov.

Холотип. Кос лонгитудинални пресјек приказан на табли 4, сл. 1.

Дијагноза. Талус са узаном централном стабљиком и пршљеновима који обично имају 6, изузетно 4 или 5 огранака. Кратки релативно масивни примарни огранци носе фертилну ампулу и један секундарни дистално проширен огранак. Фертилна ампула је смјештена на гоњојој страни огранка близу централне стабљике, педункулус ампуле веома кратак, нејасно диференциран. Танак кречњачки омотач депонован је појединачно око фертилних ампула.

Примарни, а особито секундарни огранци били су слабо или нијесу уопште били калцифицирани.

Битне примарне црте рода *Montiella* прекристализацијом бивају изгубљене. Стога се такве кречњачке цјевчице могу погрешно приписати роду *Cylindroporella*, премда до данас, с обзиром на лошу очуваност типског материјала, није дефинисано што су битне одлике овог рода.

Montiella filipovici потиче из седимената највишег ценомана–најнижег турона који леже непосредно испод кречњака са туронским микрофосилима и рудистима, а откривени су у профилу Врбница 1 на јужним падинама Паштрика, између Миљаја и Нинаја.

У додатној биљешци дати су укратко подаци о новим комбинацијама за врсте *Cylindroporella parva* RADOICIC, 1983, која је преведена у род *Montiella* MORELLET & MORELLET, 1922, *Permocalculus elliotti* JOHNSON, 1965 која је пребачена у род *Trinocladus* RAINERI, 1922 и *Trinocladus bellus* YU JING, 1978, која је пребачена у pод *Belzungia* MORELLET, 1908.

PLATE 1

Figs. 1–14. *Trinocladus divnae* spec. nov.

1. Holotype, slightly oblique transversal section also shown in text-fig. 2; arrows: the inverted triangular form corresponds to the space of the laterals; thin slide RR2379; × 33.

2, 3, 6, 12. Oblique (2, 6, 12) and transversal (3) section. Specimens of the same preservation; thin slides RR2379, 2379, 2338, 2338; × 33.

5. Transversal section of the damaged specimen; notice poorly preserved primary latera (arrow); thin slide RR2344; × 53.

7. Oblique section (fragment). Pores of the primary and the secondary laterals have been completelly obliterated by recrystallization, thin central stem membrane with insertion points of worls is well preserved; thin slide RR2336; × 33.

8. Oblique section of recrystallized specimen with 3 deformed pores of primaries. Dense pores of tertiaries are visible at the top of the section; thin slide RR2338; × 33.

9. Oblique section of the strangely preserved specimen (see text); thin slide RR2379; × 33.

10. Slightly oblique transversal section with rare primary pores; thin slide RR2346/1; × 33.

11, 14. Recrystallized specimens, transversal sections: thin slide RR2344; × 33.

13. Oblique section of damaged specimen, the preservation similar to those in fig. 9, thin slide RR2378; × 33.

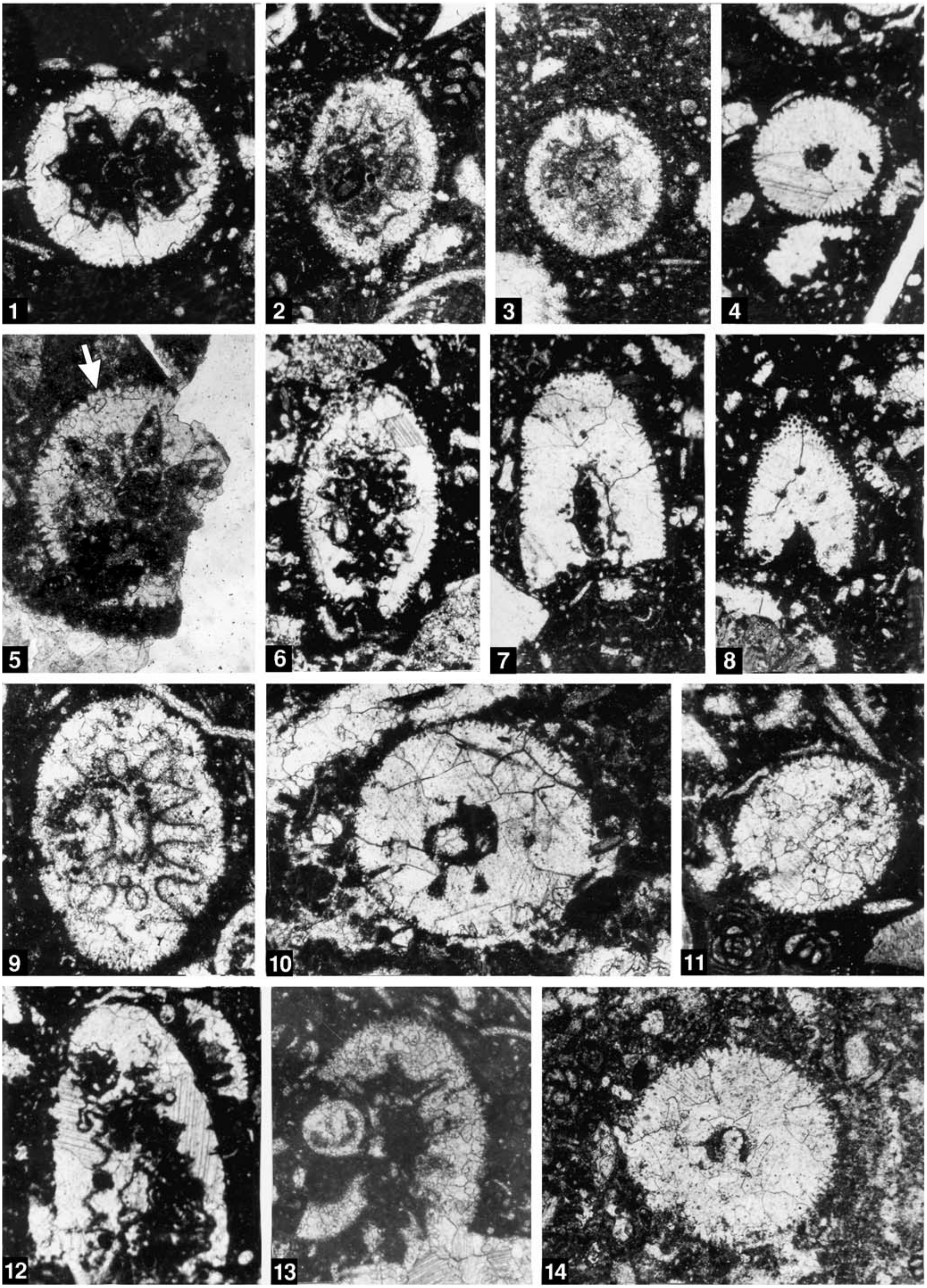
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PLATE 2

Figs. 1–8. *Trinocladus divnae* spec. nov.

1, 4, 5, 7. Oblique and transversal sections of the specimens with calcified more or less thin distral area Fig. 1 is the largest specimen of the collection; in its middle tangential section of the fragment with pores of swollen parts of secondaries; thin slides RR2344, 2346, 2344/1, 2379; × 33.

2, 3. Fragments of longitudinal section; swollen parts of the secondaries are well preserved; thin slides RR2380, 2343/1; × 33.

6. Damaged specimens of partially recrystallized interior, some pores of seconradies recognizable; thin slide RR2343/1; × 33.

8. Fragment of prevailing recrystallized specimen with two primary pores and open pores of tertiaries at the outer surface; thin slide RR2344/1; × 52.

Fig. 9. *Neomeris* sp.. Oblique section, thin slide RR2345; × 20.

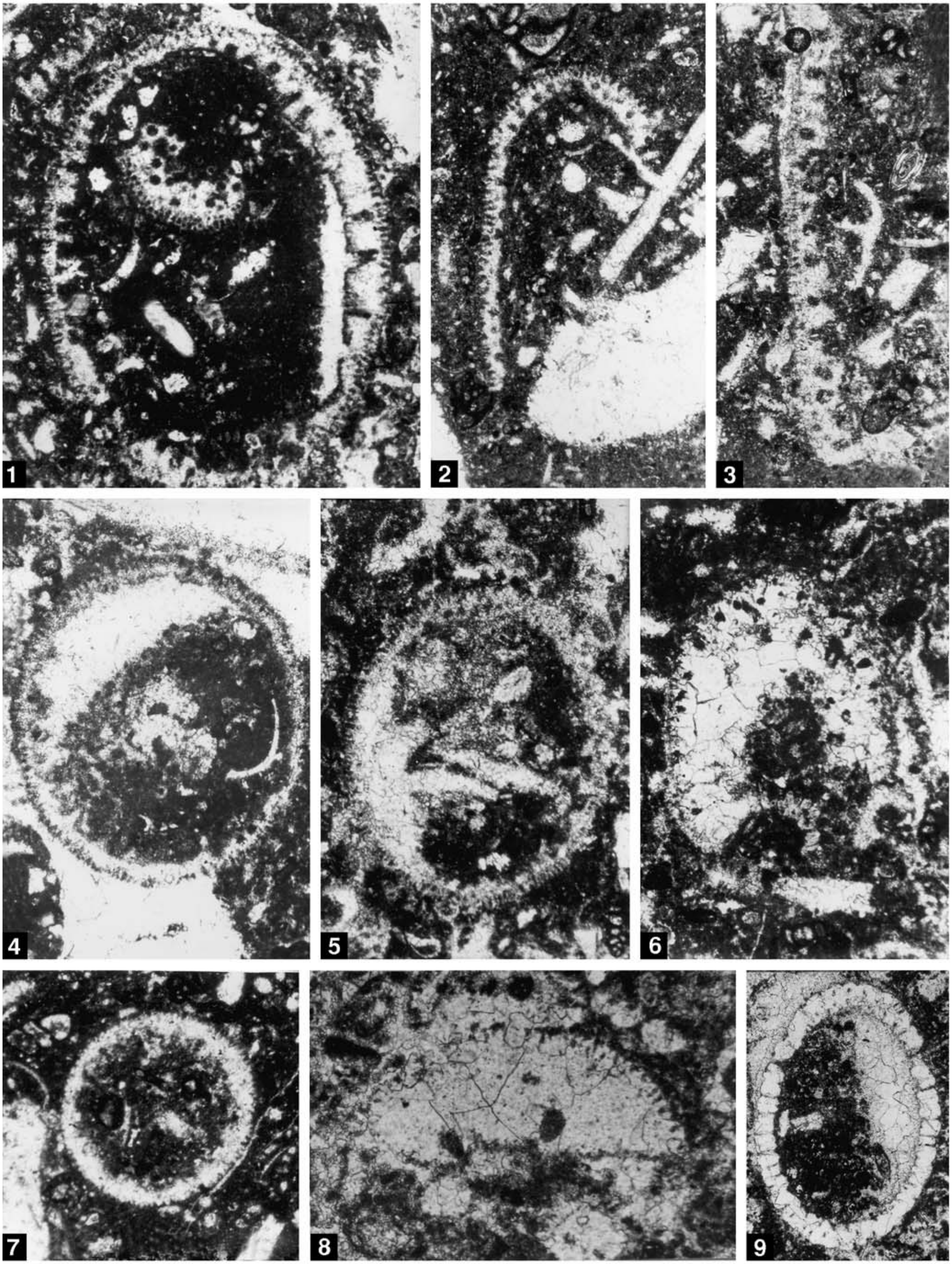

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PLATE 3

Figs. 1–6. *Trinocladus divnae* spec. nov.

1–4. Oblique (1, 2, 4) and transversal (3) section. Specimens obliterated by recrystallization; the contours of central stem, in the specimens 2 and 3, are recognizable, slightly deformed central stem of the specimen 1 is filled by micrite; thin slides RR2345, 2380, 2379, 2379; × 33.

5. Fragment of tangential section with pores of secondary laterals, thin slide RR2343/1; × 33.

6. Slightly oblique transversal section of recrystallized specimen with rare, pores of secondary laterals; thin slide RR2343/1; × 33.

Fig. 7. *Trinocladus* sp. Thin slide RR2380; × 52.

Figs. 8, 9. *Trinocladus* aff. *tripolitanu*s RAINERI. Fragmnts; thin slides RR2344 and RR 2346; × 52

Figs. 10, 11. *Trinocladus divnae* spec. nov. Fragments of calcified thin distal part, thin slides RR2348, 2346/1; × 30.

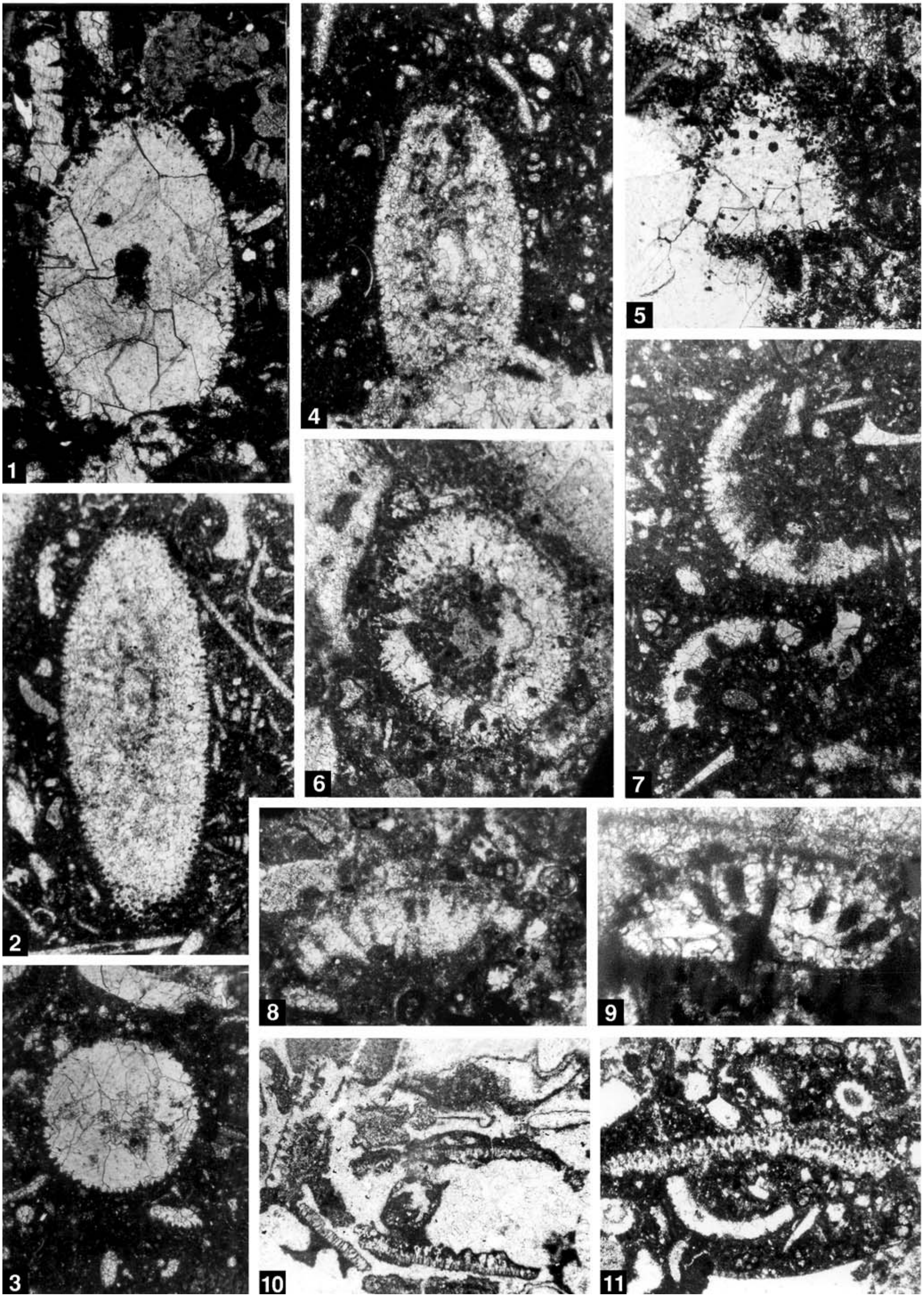
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PLATE 4

Figs. 1–9. *Montiella filipovici* spec. nov.

1. Holotype, sub-longitudinal oblique section; thin slide RR2328; × 60.

2–8. different more or less oblique sections; thin slides RR2334; 2335/2, 2330, 2335, 2327, 2326/1, 2326; 2 = × 40; 6, 7, 8 = × 60; 4, 5 = × 63.

9. slightly oblique longitudinal section; thin slide RR2328; × 40.

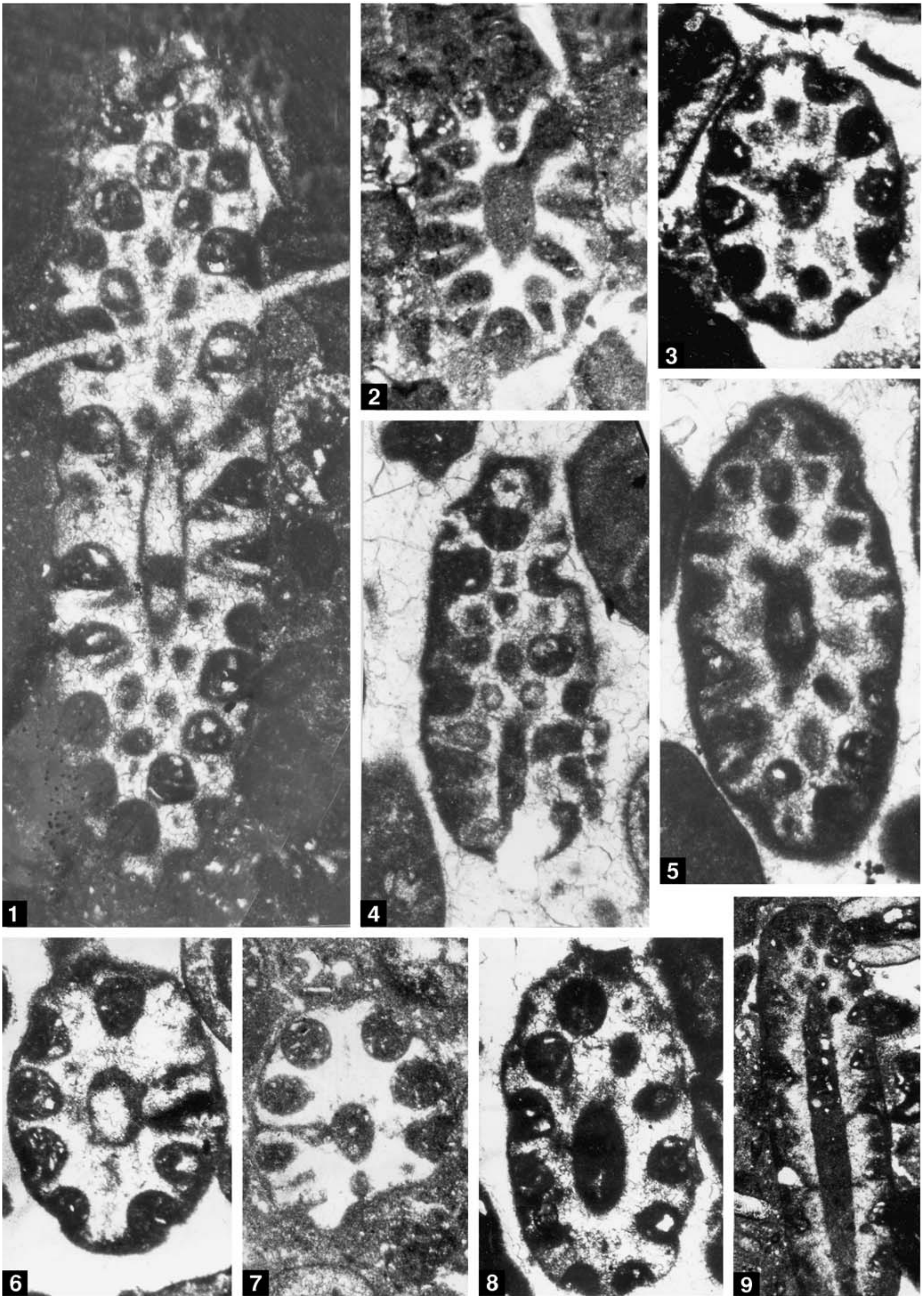
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PLATE 5

Figs. 1–12. *Montiella filipovici* spec. nov.

1. Tangential section. Notice characteristic section through primary laterals and ampulla (arrows); thin slide RR2327; × 63.

2, 3. Oblique sections; thin slides RR2335, 2326/1; × 63.

4–10. Transversal sections; thin slides RR2327/1, 2332, 2332, 2326/1, 2327, 2326, 2335/2; × 60; 9 = × 63.

11. Tangential-oblique section, fragment; thin slide RR2331; × 63.

12. Transversal-oblique section of damaged fragmen; thin slide RR2331; × 60.

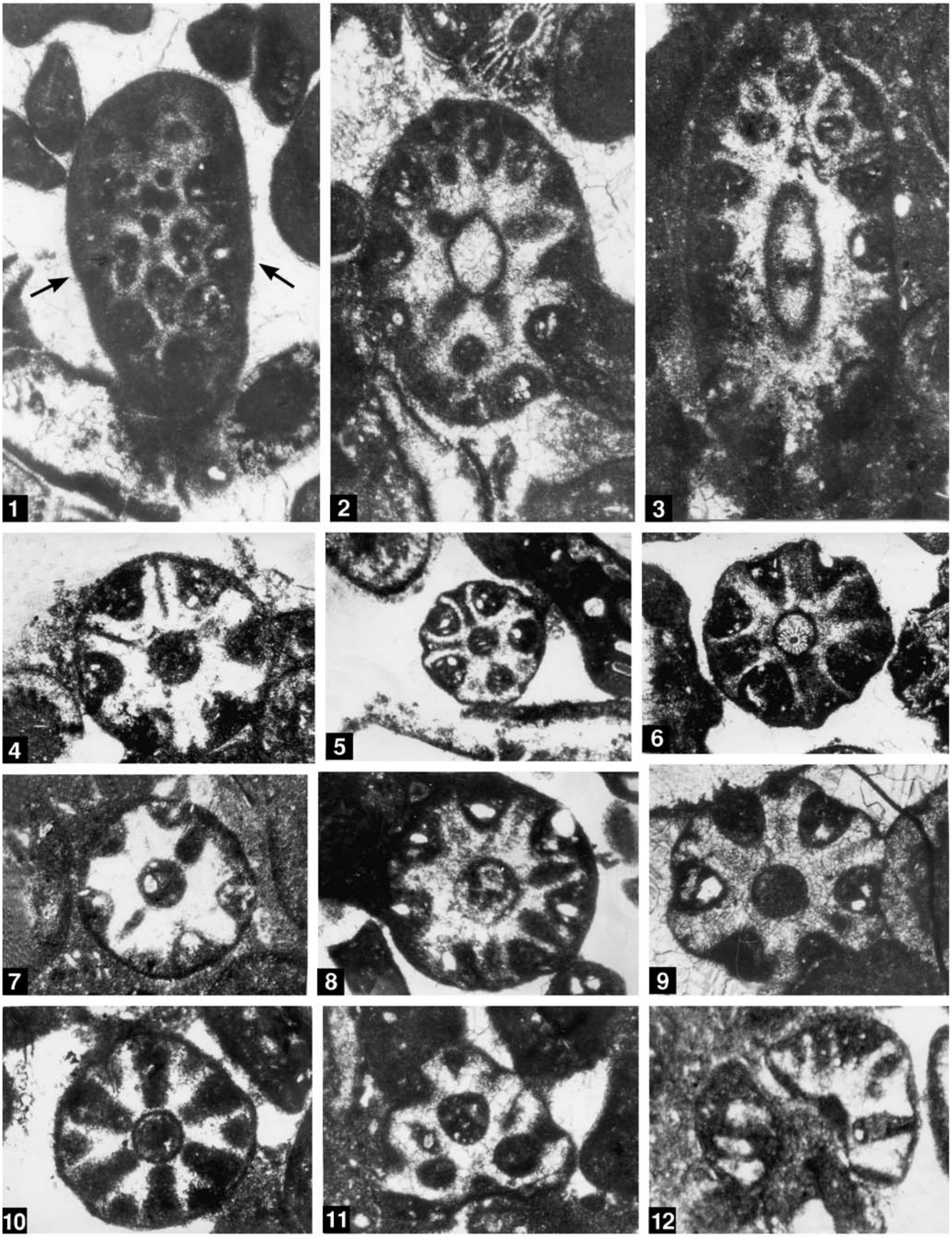
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PLATE 6

Figs. 1–4. *Montiella filipovici* spec. nov. Different oblique sections; thin slides RR2327, 2333, 2333, 2331; × 60; 4 = × 63.

Figs. 5–7. *Montiella parva* (RADOIČIĆ). Longitudinal (5, 6) and oblique section (7); thin slides RR2336, 2327 (type level of *M. filipovici*), 2379 (type level of *Trinocladus divnae*); × 63.

Figs. 8–10. *Halimeda elliotti* CONARD & RIOULT. Longitudinal, oblique and transversal section, thin slides RR2330, 2328, 2236/1; 8 = × 40; 9, 10 = × 45.

Fig. 11. *Neomeris* sp. Fragment; thin slide RR2331; × 60.

Fig. 12. *Halimeda* sp. (spec. nov.?). Thin slide RR2332; × 34.

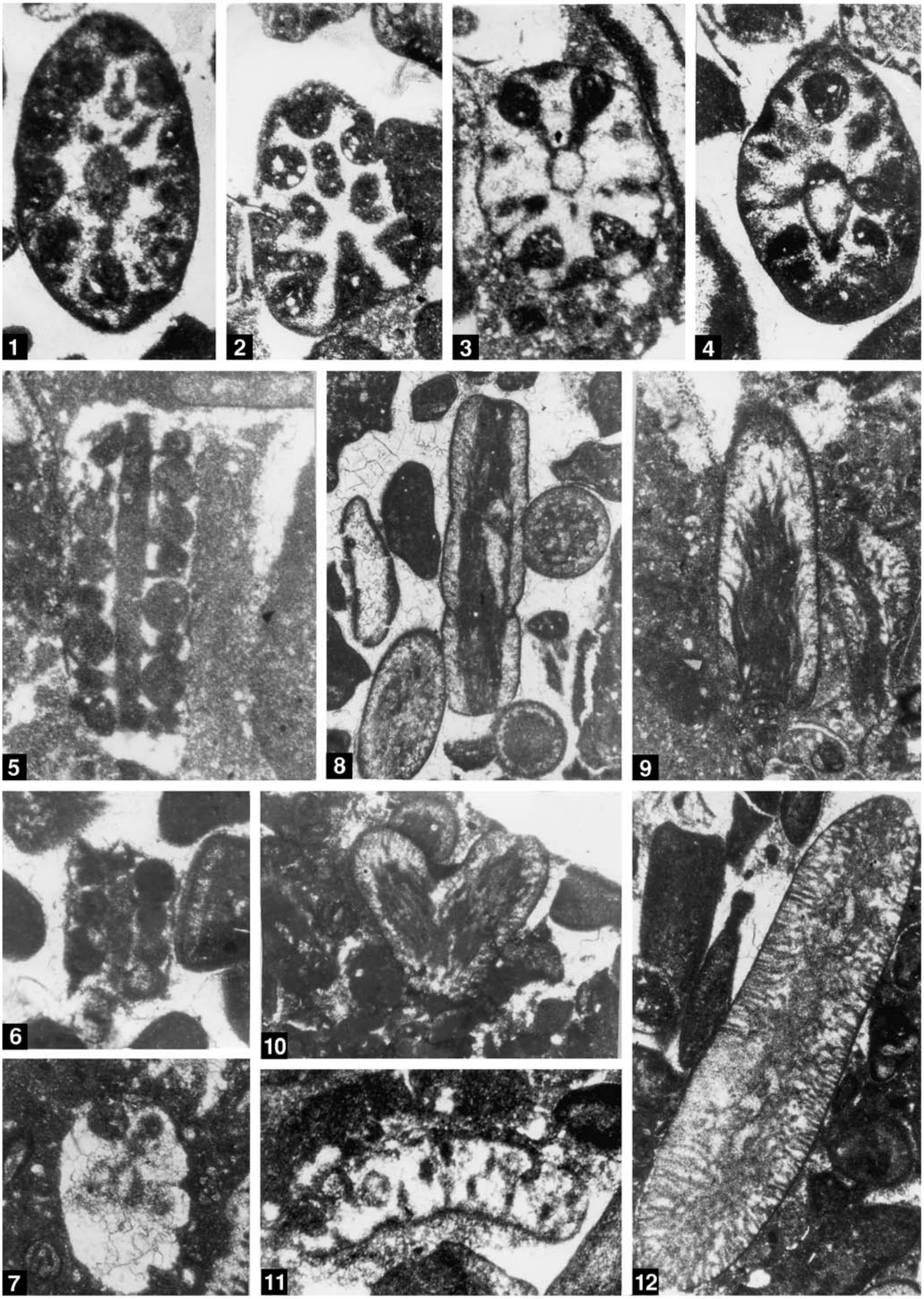
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PLATE 7

Figs. 1. *Salpingoporella hasi* CONRAD, RADOIČIĆ & REY. Microfacies; thin side RR2389; × 37.

Figs. 2–4. *Suppiliuimaella schroederi* BARATTOLO (until recently known only from Apennines – BARATTOLO, 1984); thin slides RR2381, 2381/1; × 33.

Fig. 5. Problematic microfossil *"Pr-10"* and fragment of *Neomeris*; thin slide RR2345; × 44.

Fig. 6. *Pseudoclypenia*?. Fragment; thin slide RR6015 (*Valdanchella dercourti* Zone); × 67.

Fig. 7. *Pseudolithothamnium album* (PFENDER) (monospecific assemblage); thin slide RR23471/1; × 10.

Fig. 8. Sponge spicules, type level of *Trinpocladus divnae*; thin slide RR2379; × 33.

Fig. 9. *Marinella lugeoni* PFENDER. Thin slide RR2340; × 36.

Fig. 10. *Heteroporella lepina* PRATURLON. Fragment; thin section RR3246; × 36.

Figs. 11–12. Ostracods from the type level of *Montiella filipovici*; thin slide; RR2332; × 60.

Fig. 13. *Jurella*? from the type of *Montella filipovici*; thin slide RR2331; × 60.

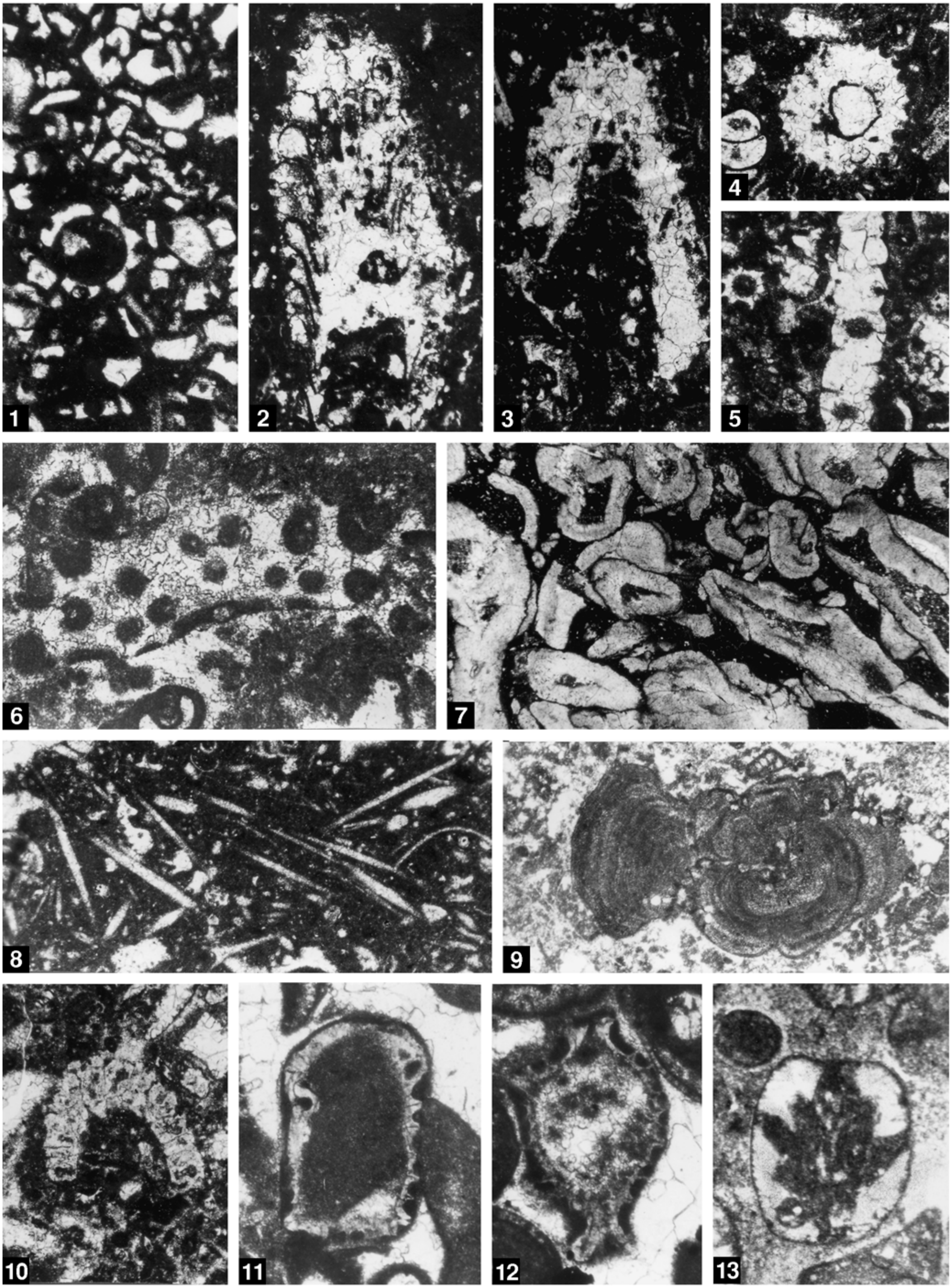
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PLATE 8

Figs. 1–6. Aptian bioclastic sediments of the northern Paštrik:

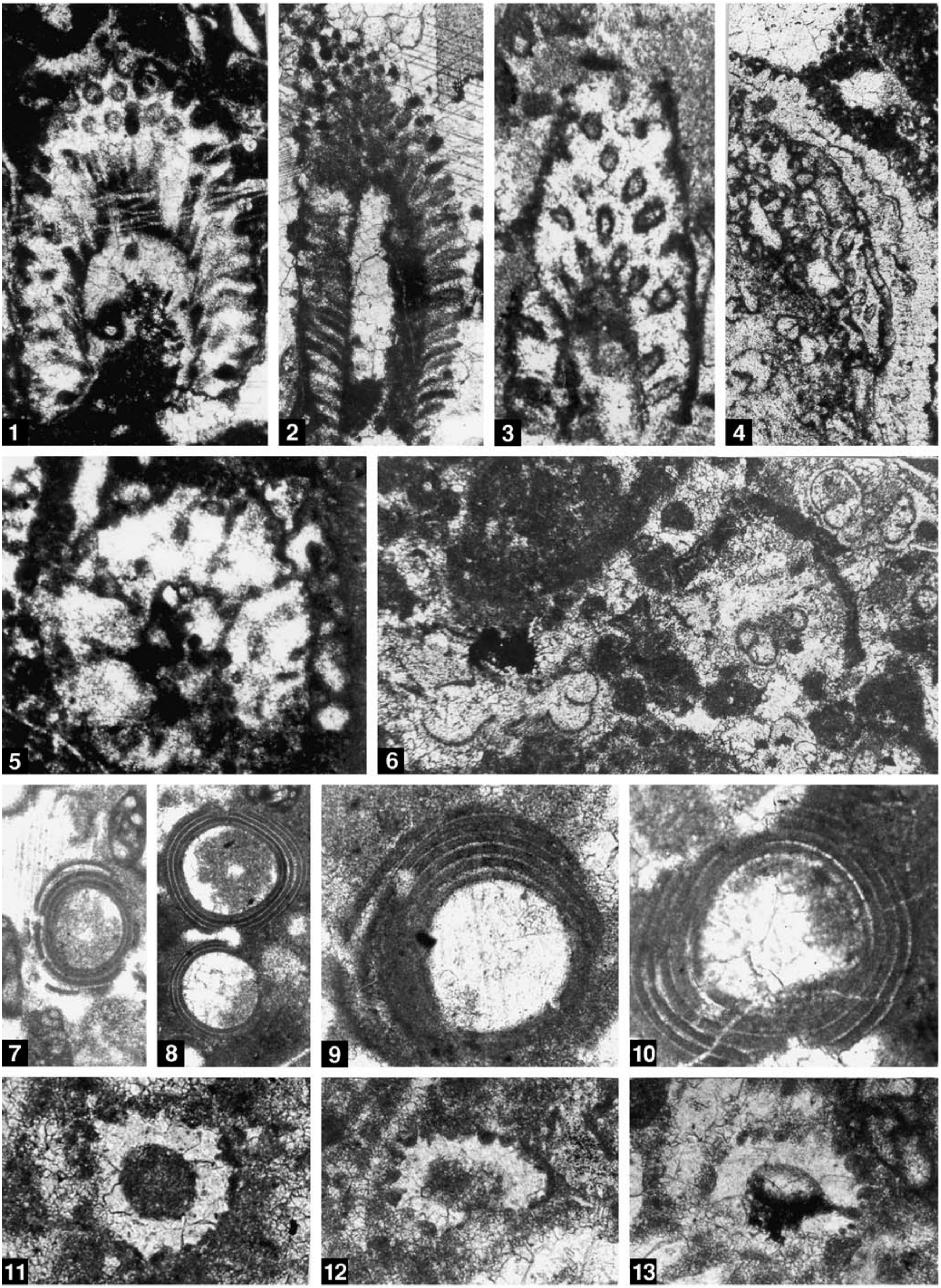
1. *Suppiluliumaella* sp. Thin slide RR2422; × 35,5.
2. *Salpingoporella pygmaea* (GÜMBEL). Thin slide RR2422; × 35,5.

3, 4, 6. *Acroporella radoicicae* PRATURLON (3) algal crusts (4) and *Planomalina* sp. (6); thin slide RR2045; 2045/1; 3 = × 43; 4, 6 = × 30.

5. *Dissocladella*?; thin slide RR2422, × 60.

Figs. 7–10. Problematic microfossil "*Pr 11*" from the Lower Cenomanian of the Vrbnica; Thin slide RR2318/4; 7, 8 = × 85; 9, 10 = × 175.

Figs. 11–13. Problematic microfossil "*Pr 10*" in association with *Trinocladus divnae*; thin slides RR2344, 2344, 2343; × 130.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Геолошки анали Балканскога полуострва Annales Géologiques de la Péninsule Balkanique	67	89–100	Београд, децембар 2006 Belgrade, December 2006

Late Miocene ostracodes of Serbia: morphologic and palaeoenvironmental considerations

Ljupko M. Rundić

Abstract. About 11.5 million years ago, a tectonic uplift of the Eastern and Western Carpathians separated the Pannonian Basin from the rest of the Paratethys. This orogenesis event caused an unconformity between the Sarmatian brackish sediments and the Pannonian lake-sea deposits. More than 6 Ma later, in these parts of the Paratethys, changes in the geographic framework, hydrological conditions and brackish – caspibrackish water chemistry led to the disappearance of restricted marine forms of life. A few euryhaline and marginal marine species survived this environmental change. Among the ostracodes, some originally freshwater taxa, such as *Candoninae,* entered the lake-sea. Many lineages show gradual morphological changes. The older, low diversity ostracode fauna from the Lower Pannonian dispersed to the endemic species and genera during the Upper Pannonian. This interval is assigned as the "bloom time" for many ostracodes, both qualitatively and quantitatively. This time sequence is the last appearances of genera such as *Aurila, Cytheridea*, *Propontoniella,* etc. and simultaneously, the first appearances for many new genera, such as *Zalanyiella, Serbiella, Camptocypria, Sinegubiella* etc. During the Pontian, migration processes were present. Therefore, it can be supposed that many eastern Paratethyan forms have Pannonian origin.

Key words: Late Miocene, ostracodes, morphology, paleoenvironment, Serbia.

Апстракт. На прелазу између средњег и горњег миоцена, пре око 11,5 милиона година, тектонска издизања у Карпатима су довела до одвајања Панонског простора од остатка Паратетиса. То је резултирало дискорданцијом између сарматских, бракичних и панонских, каспибракичних наслага. Скоро 6 милиона година касније, промене географских прилика, хидролошких услова и формирање ослађене водене средине, довеле су до потпуног изумирања морских организама. Само неколико еврихалинских форми као и оних који су настањивали приобалне делове успело је да се прилагоди и преживи. Код остракода, слатководни облици попут кандонина, све више настањују такво велико језеро-море док неки филогенетски низови показују постепене измене. Старије панонска, слабије разноврсна остракодска фауна еволуира у неке ендемичне облике током млађег панона када долази и до правог процвата остракода, како по броју врста тако и по броју јединки. То је период последњег појављивања родова *Aurila, Cytheridea*, *Propontoniella* односно време првог појављивања родова *Zalanyiella, Serbiella, Camptocypria, Sinegubiella*. За време понта, запажени су миграциони процеси на овом простору и сматра се да многи облици који живе у источном Паратетису имају панонско порекло.

Кључне речи: млађи миоцен, остракоде, морфологија, палеоекологија, Србија.

Introduction

As a product of Alpine tectonics in the Late Oligocene and the Early Miocene, a few molasse basins were created along the northern foreland of the uplifting mountain ranges in middle and southeastern Europe (Fig. 1). Although, each basin has its own individual history, their developments display some common features; repeated cycles of isolation from the world oceans, as inferred from the barrenness of the fauna or the presence of endemic organisms, and evolution from fully marine through brackish to caspibrackish and fluvial depo-environments (Kovač & Marton, 1998; Pipík, 2000; Fordinal *et al*., 2006;). Temporary isolation and filling of the western-central Paratethyan basins started from west to east. Firstly, the Alpine molasse

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basin was filled with sediments during the Middle Miocene, then the Pannonian Basin during the Late Miocene–Early Pliocene and, finally, the Dacian Basin during the Pliocene (HORVATH, 1990; MAGYAR *et al.*, 1999). Simultaneously, the eastern Paratethyan basins (Black Sea and Caspian) remained aquatic (SAFAK, 2002; TUNOGLU, 2001, 2002, 2003; WITT, 2003).

During the Late Miocene, most of Serbia belonged to the Pannonian Basin, while a small part of eastern Serbia corresponded to the Dacian area. During this time interval, there was a brief connection between them, but the most important period was during the existence of the so-called "Pannonian–Pontian lake-sea", a deposition area completely isolated and closed from the east by the Carpathian Mountains. Some authors when referring to the Pannonian and Pontian Stages used the name *Lake Pannon* (MAGYAR & GEARY, 1999; MAGYAR *et al.*, 1999; MÜLLER *et al.*, 1999; SZUROMI-KORECZ *et al.*, 2004). The above-mentioned connections between the basins established in the Pontian represented the last phase of the evolution of the western Paratethys. Subsequently, the Pannonian Basin disappeared as a lake-sea and transformed to a marshland environment. On the other side of the Carpathians Mt., the Dacian Basin still continued its existence during the early Pliocene.

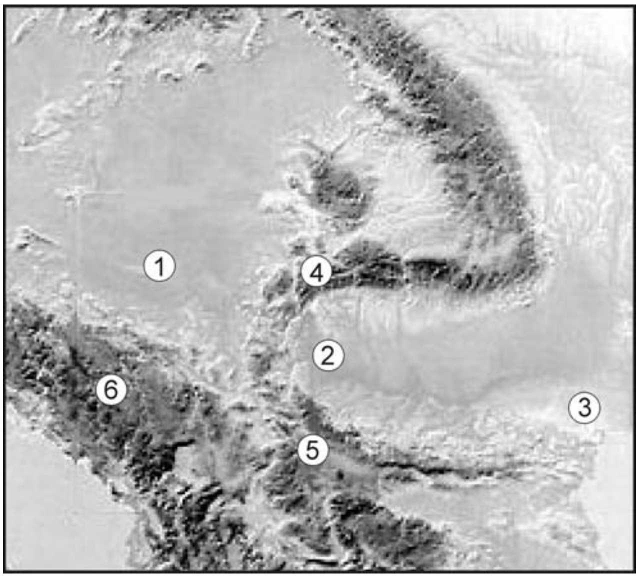


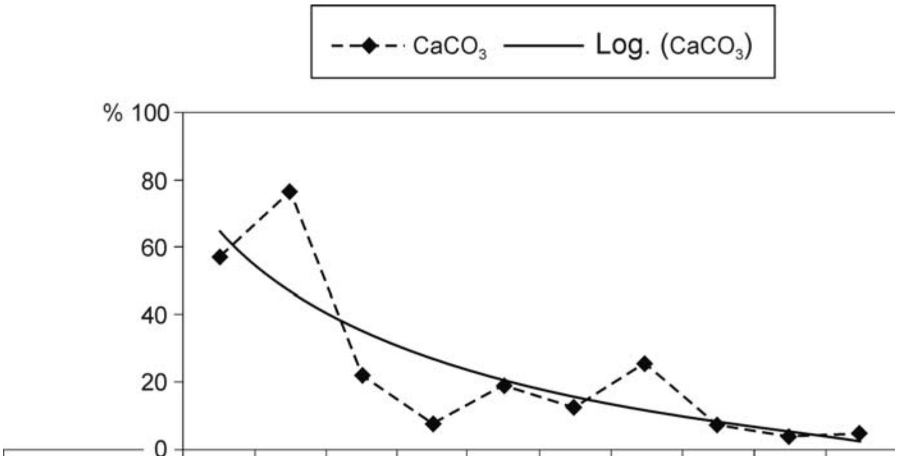
Fig. 1. The Late Miocene Paratethyan province: **1**, the Pannonian Basin; **2**, the Dacian Basin; and **3**, Euxinian Basin; **4**, the Carpathians Mt.; **5**, the Balkans Mt.; and **6**, the Dinarides.

Sedimentological studies have been limited to the investigation of main grain-size classes (rudites, arenites and lutites). Among forty samples, 42% of them are rudites (> 2mm), 38% are sand (0.63–2mm) and 20% are mud (< 0.63 mm). These deposits are slightly dominated by a coarse mean grain-size of gravel and sand (rudites, > 2mm). The distribution of the sedimentary material follows the expected general, fluvial lacustrine model: the coarsest deposits are distributed in the main channels, associated with a more dynamic water regime. On the contrary, the smaller particles occur in zones of low energy (OBRADOVIĆ & JOVANOVIĆ, 1987). Except in the opening of the main channel (the Kolubara Bay), where tidal currents and waves continuously generated high dynamic conditions throughout the year, the mean grain-size pattern does not correspond to a dynamic regime during the major part of the year.

Table 1. CO_2 and $CaCO_3$ content of the well Rgh-107.5, the Kolubara basin, western Serbia.

BOREHOLE Rgh-107.5	SAMPLES No.	SAMPLES Depth (m)	% CO_2	% $CaCO_3$
1	01	05.70–06.80	3.20	7.27
2	16	92.70–93.00	1.20	2.73
3	27	139.60–139.80	2.00	4.55
4	28	144.00–144.20	2.40	5.46
5	29	150.00–150.20	4.40	10.00
6	31	168.70–168.90	2.40	5.46
7	35	192.00–192.20	2.80	6.36
8	41	234.00–234.20	5.60	12.73
9	42	240.30–240.50	14.40	32.73
10	43	247.30–247.50	1.20	2.73
11	44	257.00–257.20	35.60	80.92
12	45	262.40–262.60	29.60	67.28
13	46	267.50–267.70	34.40	78.19

For example, in the well Rgh-107.5 (Kolubara Basin), there are rapid decreases of calcium carbonate from the bottom to the top of the investigated well (Table 1). More consolidated deposits, such as Sarmatian limestones and sandstones, contain up to 80% of $CaCO_3$. On the other hand, semi-consolidated Pannonian and Pontian marls and sands contain a low percent of carbonate, as well as of carbon dioxide. Sample No. 28 (144.00–144.20 m) corresponds to marly sands and marls (OBRADOVIĆ & JOVANOVIĆ, 1987). Sands have a symmetrical grain size distribution and good sorting. Sandy marls shown similar effects. It is concluded that there was multiple alteration in the profile of the fluvial and near shore lake-sea deposits. Fluvial flows dispersed silicoclastites to the near shore parts and temporary deposited them on the land or alluvial environment. Somewhat different cases were observed on the sandy-silts (maximum 21.46% sand) and silts (maximum 98.95% silt) from the Late Miocene sediments of eastern Serbia. These deposits were earlier investigated by KRSTIĆ *et al.* (1992, 1995, 1997) and MIHELČIĆ (1990, 1991). There is a clear trend of decreasing calcium carbonate toward the younger Miocene Stages (Fig. 2). Also, curves of sorting and grain-size values show that the sediments have middle to good sorting and dominantly an asymmetrical grain-size distribution. Some other characteristics, such as pH (7.7–7.9)



Sample	Rajac	Pant el. kr-	Pant el. kr-	E. VI-5	E. VI-4	E. VI-2a	E. VI-2	E. VI-3	E. VI-1	E. VI-6
$CaCO_3$	57.13	76.4	21.9	7.36	18.9	11.9	25	6.6	3.7	4.1

Fig. 2. Decreasing trend of $CaCO_3$ from the Bessarabian to the Pontian (sandy-silts and silts from some localities of the Dacian Basin of eastern Serbia, after DODIKOVIĆ, 2001).

and Eh (+26 to –20), indicate that these deposits are the products of a slightly alkaline and low reduction environment (DODIKOVIĆ, 2001).

Quantitative and qualitative diversity of ostracodes

In the western and central Serbia (an example of the Kolubara Basin), more than 36 genera with 206 ostracod species were identified in the Late Miocene (RUNDIĆ, 1997). The most abundant taxa are representatives of *Candoninae,* including genera such as *Camptocypria*, *Cryptocandona*, *Fabaeformiscandona*, *Hastacandona*, *Lineocypris*, *Pontoniella*, *Propontoniella*, *Serbiella*, *Sinegubiella*, *Thaminocypris* etc. with about 80 species. Among the more abundant genera are *Amplocypris* (25 species), *Cyprideis* (23), *Loxoconcha* (22), *Hemicytheria* (20) and *Amnicythere* (19), which represent together about 90% of the total number of specimens. The findings of *Cypria* (8 species), *Hungarocypris* (4), *Xestoleberis* (3), *Candona* (2), *Ilyocypris*, *Tyrrhenocythere*, *Mediocytherideis* and *Stenocypria* (all with one species) were scarce and they represent only 10% of the mentioned population. Most of them have been recognized as infra/sublittoral. A smaller number of taxa have been found in the intertidal zone. Individual abundance may exceed 400 individuals per sample. Species diversity increases appreciably from the Lower Pannonian and is maximal during the Upper Pannonian (Fig. 3). This basin is the most illustrative example of marginal deposition in the whole of western and central Serbia during the Late Miocene. Other areas have more-less similar characteristics, except the northern province of Serbia (Vojvodina), where there is carbonate development. The best example of this kind is on the Fruška Gora Mt., where the Upper Pannonian is represented by fine grained "cement marls", which correspond to the deeper part of the Pannonian Basin. The ostracod assemblages contain several genera, such as *Typhlocyprella,*

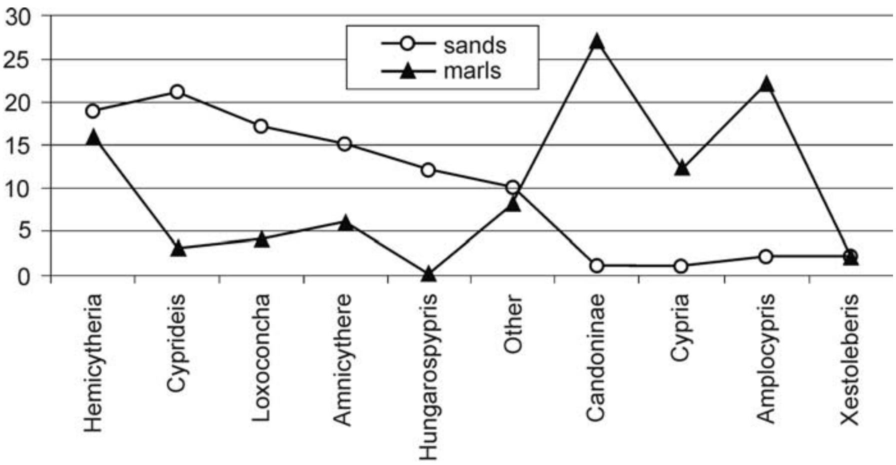


Fig. 3. Species number of main genera in relation to the sediments. The Lower Pannonian of the Kolubara Basin.

Zalanyiella, Camptocypria, *Serbiella*, *Amplocypris*, *Hemicytheria*, *and Cypria*. Apart from *Candoninae*, all other genera are represented by a few species only and their percentage contribution to the total population is small. The most abundant forms are different *Reticulocandona*, *Zalanyiella*, *Serbiella*, *Camptocypria*, etc. It seems that some representatives of *Candoninae* prefer more fine-grained deposits than the others.

In the eastern Serbia (Dacian Basin), there are certain similarities with the Pannonian basin but the ostracodes represent a different paleoenvironment, including a greater numbers and diversity of *Leptocytherinae* (Table 2). Conversely, the *Candoninae* are not as diversified as in the Pannonian Basin. During the Late Miocene (Late Bessarabian – Pontian), the ostracodes had the greatest diversity in the Maeotian and Pontian. The most abundant genera are representatives of *Leptocytherinae* (*Amnicythere*, *Euxinocythere*, *Maeotocythere*) on the one hand, and different forms of *Candoninae* on the other (> 80%). More than others, Dacian and Euxinian species, such as *Amnicythere sinegubi* KRSTIĆ, *A. alizadei* SHEIDAEVA, *A. palimpsesta* (LIVENTAL) *A. subcaspia* (LIVENTAL), *Maeotocythere prebaquana* (LIVENTAL), *Euxinocythere immutata* STANCHEVA, *E. suzini* (SCHNEIDER) etc., have been found.

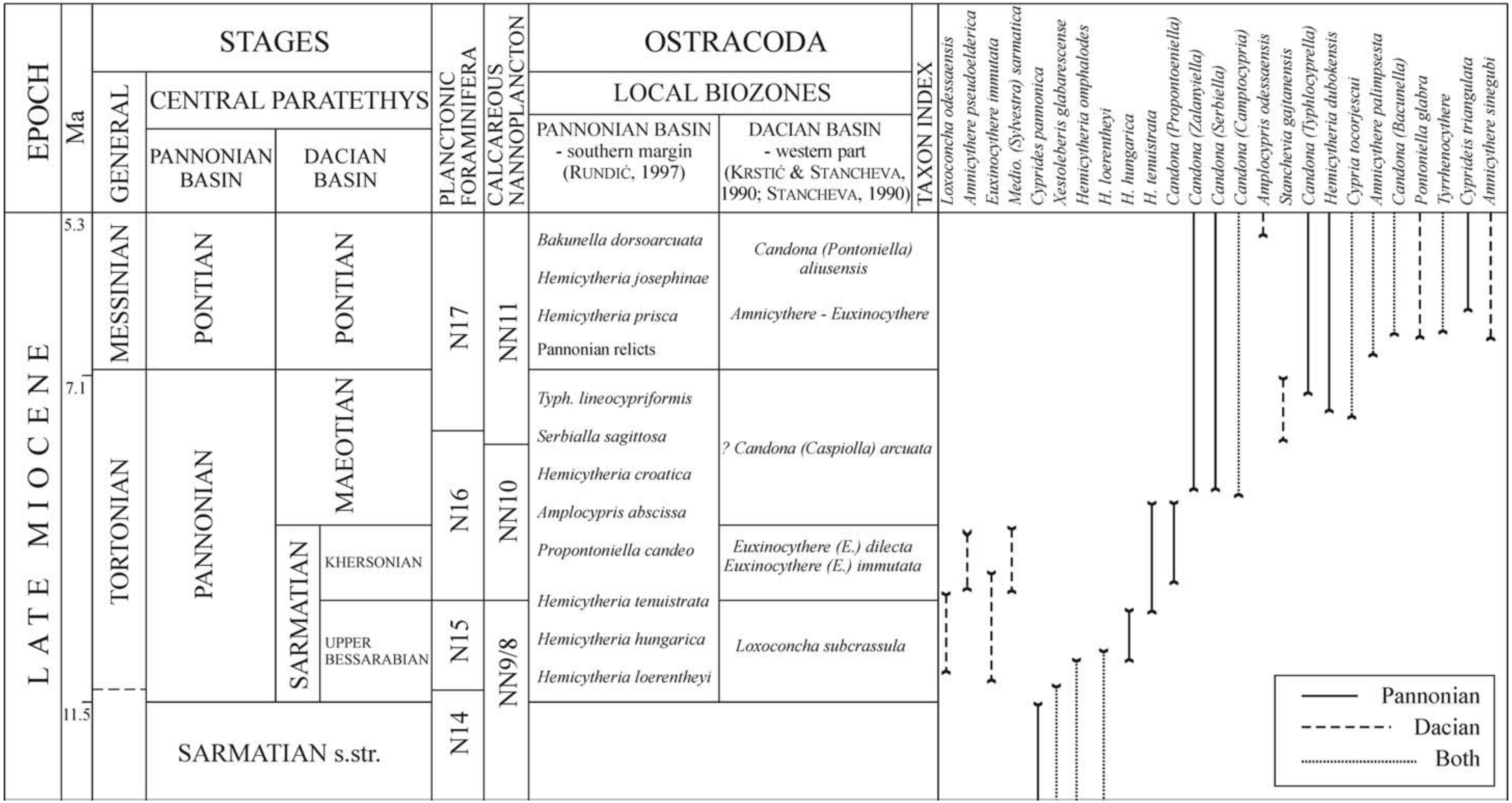
Among the *Candoninae*, *Candona* ex gr. *neglecta* Sars, *C. fagiolata* STANCHEVA, *Camptocypria ossoinensis* KRSTIĆ, *Camptocypria balcanica* ZALÁNYI, *Hastacandona pontica* AGALAROVA, *Bakunella guriana* (LIVENTAL), *Reticulocandona orientalis* KRSTIĆ, *Pontoniella paracuminata* KRSTIĆ, have been identified. Genera such as *Loxoconcha, Aurila, and Xestoleberis* are present in Sarmatian with a small number of species and relatively abundant specimens. In the higher stratigraphic levels, in addition to representatives of *Candoninae* and *Leptocytherinae*, the rare *Darwinula*, *Getocytheria, Stanchevia, Mediocytherideis, Tyrrhenocythere* etc. have been found. Most interestingly, representatives of the genus *Cyprideis* have a very small frequency and are limited to a few species, unlike the Pannonian basin. There are also similar results regarding the Pontian ostracodes from the eastern Black Sea region of Turkey (TUNOGLU, 2001, 2002, 2003).

Generally, there is a high diversity in the ostracod assemblages of the Upper Pannonian, Chersonian and also Maeotian. What are the possible reasons for this? First of all, there are some external factors, such as tectonic events and geographical isolation, the consequences of which were relatively stable aquatic conditions and an adequate range of time. If the Sarmatian *s. str.* – Upper Pannonian time period (over 2 Ma) is considered, then it can be said that the time interval was sufficient for taxonomic adaptation. During the older Pannonian, the first 'shock' affects the ostracodes and other fauna. The already freshened and relatively well-adapted Sarmatian brackish forms could not tolerate more freshening. Some of genera are completely absent, for example: *Cytheridea*, *Miocyprideis*, *Cyamocytheridea*, *Aurila,* etc. However, some other representatives, such as *Loxoconcha*, *Leptocythere*, *Hemicytheria,* etc., managed to survive the critical point and later developed special features as result of the adaptation. Mesohaline to freshwater and river-marsh genera, such as different *Candona*, *Cypria*, *Amplocypris*, and *Hungarocypris*, played the most important role. They are the markers for the future new ostracod assemblages, which consequently occur at the beginning of the Upper Pannonian. The second important event in the ostracod development during the Pannonian was the first appearance of many new taxons, such as *Zalanyiella*, *Camptocypria*, *Serbiella*, *Lineocypris*, *and Thaminocypris,* etc. There was also an increase in the ostracod abundance and diversity. An individual abundance may exceed a few hundred individuals per sample. At the same time, there was a high rate of speciation, which was probably the result of some optimal conditions and natural factors, such as geographic isolation, lake-sea adaptation, reproductive mode and dispersal, sexual selection, etc. (MARTENS, 1997). According to these authors, the tempo and manner of speciation were very different in various ancient lake assemblages. An example of a high diversity phenomenon, considered by MAYBURY & WHATLEY (1988), was the Upper Pliocene faunas of Cornwall, England and northwest France. They concluded that "*the high diversity symbolize general result of many factors as favourable preservation, high abundance, competent niche exploitation, the mixing of brackish, marine, cold and warm water species and some degree of allopatric speciation due to partial isolation of faunas because of the incomplete transgression of the Armorican and Cornubian massifs*".

It seems that there are many similarities between these and the Upper Pannonian assemblages. It was the time of the highest development of the faunas of the Pannonian basin. Biostratigraphically, it was the acme zone for many species (an example, the genus *Hemicytheria* represent 75% of all individuals).

After the Pannonian, tectonic subsidence of the Carpathian belt resulted in the reconnection of the Pannonian and Dacian Basins during the Pontian for the last time. At the beginning, thanatocoenoses were slightly different with many transitional types. Later, these differences became more visible. The faunal assemblages had new elements, such as *Bakunella*, *Tyrrhenocythere,* etc. During the Upper Pontian in this widespread environment, there was a trend of decreasing biodiversity among the ostracodes, unlike the previous period. The habitat was more saline and it resulted in species reduction. Analogous ideas were presented by BODERGAT (BONADUCE & SGARRELLA, 1999). The samples have numerous specimens but with relative few species. On the other hand, the faunas show an eastwards migration trend as some genera occupied eastern provinces and finally the Dacian Basin. In my opinion, many of the ostracod genera from the Dacian area have a Pannonian origin. In the Dacian Basin, for example,

Table 2. The correlation chart of the Late Miocene of Central Paratethys of Serbia and local ostracodes biozonation.



there are very abundant and diversified associations with *Amnicythere, Pontoniella*, *Candona*, *Bakunella* and *Tyrrhenocythere* in the younger levels of Pliocene (OLTEANU, 1998, 2000). There are also similar results regarding some representatives of molluscs (MÜLLER *et al*., 1999).

Morphological and phyllogenetical relationships (an example of the genus *Hemicytheria*, POKORNY)

An attempt has been made to correlate morphological features with some phylogenetical and paleoecological characteristics of the genus *Hemicytheria*. In earlier ostracod references, there are many different considerations concerning the genus *Hemicytheria*. In some, it was considered as an independent genus like in the first Pokorny description (POKORNY, 1955; STANCHEVA, 1971; SOKAČ, 1972; OLTEANU & VEKUA, 1989; OLTEANU, 2001; RUNDIĆ, 2002). Others considered it to be one of the subgenus: *Heterocythereis* (*Hemicytheria*) and *Heterocythereis* (*Tyrrhenocythere*) – MORKHOVEN (1962); *Graptocythere* (*Hemicytheria*) or *Aurila* (*Hemicytheria*) – KRSTIĆ, 1985, 1990. STANCHEVA (1971) divided the genus *Hemicytheria* on the three subgenus: *Getocytheria*, *Hemicytheria s. str*. and *Tyrrhenocythere*. The main parameters for these taxonomic relationships were: carapace morphology, hinge structure, muscle scars pattern and type of marginal pore canals. The anatomy of the soft body of recent representatives of the subfamily *Hemicytherinae* were also explored (MCKENZIE & BONADUCE, 1993).

Based on paleontological standards, some of the characteristics of the fossil representatives of the genus *Hemicytheria* could be shown. Above all, based on the carapace morphology, there are two main groups of *Hemicytheria*: one with a pitted and the other with a reticulated sculpture. It is not possible to clearly determine the phylogenetic evolution of *Hemicytheria*. It can be assumed because of biostratigraphical results in Early Pannonian deposits, that there was a branching off of the phylogenetic lineage in the Lower Pannonian. SOKAČ (1972) believed it probably occurred in the Upper Pannonian. The older Pannonian forms have pitted sculptures [*Hemicytheria ampullata* (MEHES), *H. hungarica* (MEHES)] which presented descendant species for smooth branch (*H. marginata* SOKAČ) and reticulate branch (*H. reticulata* SOKAČ, *H. dubokensis* KRSTIĆ). SOKAČ also considered the smooth forms to be phylogenetically younger because the marginal pore canals can be straight as well as bifurcated, whilst the pitted forms have only straight pore canals. The oldest Pannonian species, *H. omphaloedes* (REUSS) and *H. loerentheyi* (MEHES), also have a reticulated surface. Therefore, it could be said that the branching off occurred during the Lower Pannonian because there are representatives with both types of sculptures (only if the oldest forms of *Hemicytheria* are considered as the independent subgenus – *Graptocythere*). During the Upper Pannonian, there are forms with both types of ornamentation. In the Pontian, only three reticulated species remained whilst the pitted ones had disappeared. The ascendant/descendant problems are impossible to solve at this moment, because of the necessity for a very detailed instars analysis. If the marginal pore canals are considered, SOKAČ (1972) correctly claimed that the younger forms have both straight and bifurcated pore canals while the oldest pitted *Hemicytheria* have only straight ones. Meanwhile, investigations have shown that all the older species have straight pore canals, both the pitted and reticulated morphotypes.

The carapace size can reveal some of the rules of the development of *Hemicytheria*. Diagrams of the mean value of length and the L/H ratio are correlated and they show the trend of ostracod carapace development. In these diagrams (Figs. 4, 5), two trends in shell development can be seen. The first one is the continuous tendency of the value to increase from the Lower Pannonian to the Upper Pannonian, when some of the *Hemicytheria* have a maximal value. The second one, the opposite trend is visible during the Pontian when the *Hemicytheria* species decreased in value and lost some of their features, while some species disappeared completely. Most of large Upper Pannonian hemicytherids died off. During the Lower Pontian, there are transitional Pannonian/Pontian forms but they are not of great significance and disappear afterwards. From the relatively numerous Pannonian hemicytherids, only a few species survived [*H. josephinae* (ZALÁNYI), *H. portafericae* RUNDIĆ and *H. pejinovicensis* (ZALÁNYI)] in the Upper Pontian. Small forms represented only 5% of total number of species. There is gradual increase in value during the Pannonian. In the Late Pannonian, the ostracodes "bloom" and all of *Hemicytheria* species have maximal dimensions. Forms of 1 mm in length represented about 40% of the total species and they dominated throughout the Upper Pannonian. Some transitional Pannonian/Pontian types have large shells but later the carapace trends to decrease in size. The best examples are Late Pontian species, which have smaller dimensions. The five greatest forms, according to the size of their shells, represented about 25% of the total species and all of them occurred during the Upper Pannonian and Pontian, especially (*H. dubokensis* KRSTIĆ, *H. portafericae* RUNDIĆ – Figs. 3, 4).

It can be concluded that there was a gradual disappearance of hemicytherids during the Late Miocene in the Pannonian Basin, as well as during the Maeotian in the Dacian Basin. This was the result of an increasingly freshening environment, which led to a completely freshwater biotope at the beginning of the Pliocene. The low percentages of dissolved carbonates and low salinity tolerance were not sufficient for the existence of hemicytherids. Meanwhile, later in the Dacian Basin there were similar forms represented by the genus

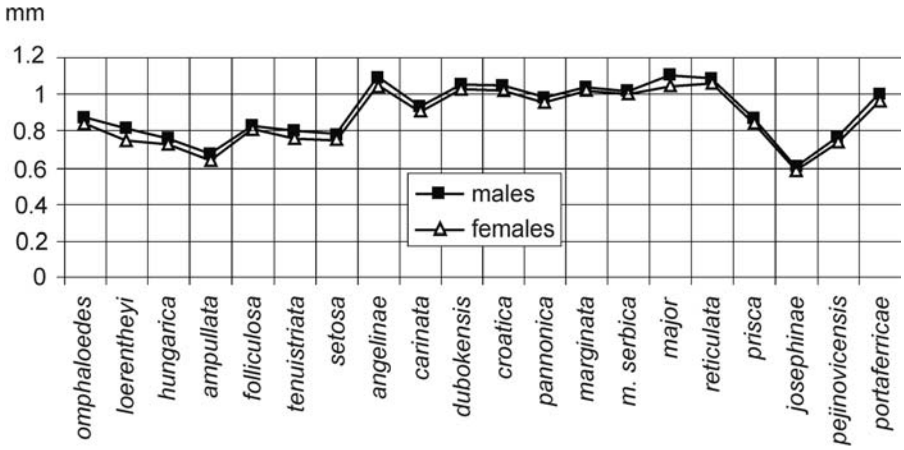
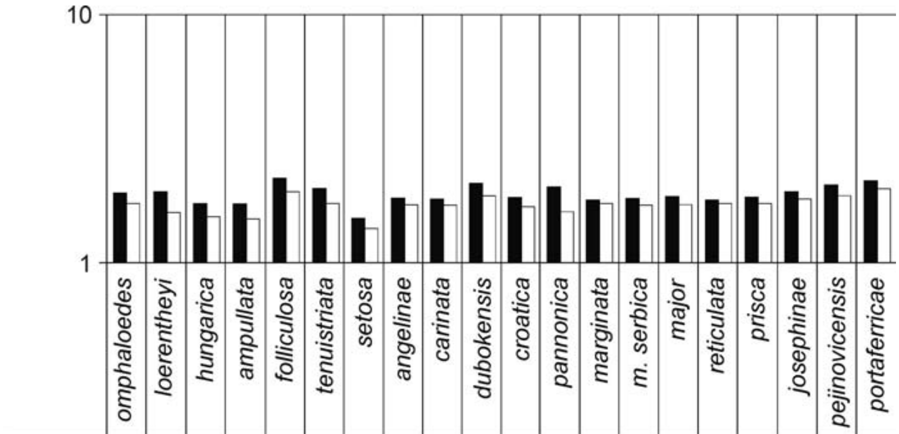


Fig. 4. The mean value of the length (mm) for the all of *Hemicytheria* species during the Pannonian and Pontian.



	omphaloedes	loerentheyi	hungarica	ampullata	folliculosa	tenuistriata	setosa	angelinae	carinata	dubokensis	croatica	pannonica	marginata	m. serbica	major	reticulata	prisca	josephinae	pejinovicensis	portaferricae
■ males	1.9	1.9	1.7	1.7	2.1	2	1.5	1.8	1.8	2.1	1.8	2	1.7	1.8	1.8	1.7	1.8	1.9	2	2.1
□ females	1.7	1.6	1.5	1.5	1.9	1.7	1.4	1.7	1.7	1.8	1.7	1.6	1.7	1.7	1.7	1.7	1.7	1.8	1.8	2

Fig. 5. Length/height ratio for some *Hemicytheria* species.

Tyrrhenocythere (KRSTIĆ, 1975; KRSTIĆ & STANCHEVA, 1990; OLTEANU, 2000; OLTEANU & VEKUA, 1989; STANCHEVA, 1990). The genus *Tyrrhenocythere* has only been found in two wells in the Kolubara Basin during the Pontian (RUNDIĆ, 1997), despite the fact that more than 40 wells have been investigated in a diameter of about 30 km. The findings of the Pannonian realm from other locations are very limited. This could be explained by the fact that during the Pontian both basins communicated and migration processes between their inhabitants occurred for the last time. In addition, some other genera found in the Dacian Basin, such as *Bakunella, Pontoniella* and *Mediocytherideis* and probably many molluscs, have a western origin. After the Pontian, the Pannonian Basin finally disappeared.

Paleoenvironmental considerations

The main paleoenvironmental interpretations are based on the quantitative and qualitative analyses of ostracod assemblages and their morphological reflection to the main physico-chemical parameters of the habitat, including temperature, oxygen content, ionic concentration, salinity, etc.

According to PEYPOUQUET (1979) and RUNDIĆ (1998), there is a connection between the sculpture and the Mg/Ca ratio of the carbonate of carapaces. Calcite crystals, constituting the hard layer of the carapace, are built perpendicular to the cuticle and their thickness is proportional to the Mg content of the crystal network. Frequently, the most gradated types are found in seawater conditions, the Mg content of which is higher than in freshwater conditions. As stated by SMITH & HORNE (2002), in nonmarine aquatic systems, the calcite mineral branch point represents an important step in determining the major ion composition of natural waters. In dilute water, below approximately 0.3 g/l, the most common major ions are bicarbonate, calcium and magnesium. With increasing salinity, these ionic concentrations rise, until calcite saturation is attained and calcite precipitates, at a total ionic concentration of approximately 0.3 g/l. This is the calcite branch point, the first mineral branch point in natural waters. Beyond this point, at about 1.4 g/l, the water becomes depleted in calcium and enriched in bicarbonates, or vice versa, resulting in a solute path towards bicarbonate enriched, calcium depleted saline water, or bicarbonate depleted, calcium enriched saline water. Ultimately, other mineral branch points are attained (gypsum, for example) and further changes in the major ion composition occurs [EUGSTER & JONES (1979), *in*: SMITH & HORNES, 2002]. However, some authors consider that this hypothesis is not sufficient. Namely, studies of the New Caledonia area have shown that, despite a high Mg/Ca ratio, the morphotypes are not more gradated than in others sites, and certainly less than the specimens living in seawaters where this ratio has only standard values. Other parameters, such as calcium content of the available food, pH and Redox potential (HOIBIAN *et al.*, 2000), may have a contributing effect on carapace calcification. Ornamentation of many ostracod shells is affected by the Mg/Ca ratio of lake water: with Mg/Ca >1, the carapaces are heavily reticulate and the opposite ratio favors smooth ostracod valves. For example, CHIVAS *et al.* (1983) noted the connection between the thickness and ornamentation of an ostracod carapace and the water depth for fossil material obtained from Lake Buchanan in Queensland. They found that ostracodes belonging to the genus *Paracypris* associated with charophytes had a thick shell with a rarely visible reticulation and commonly no spines. Assemblage with charophytes indicates shallow water (up to 2 m), since this is the preferred habitat of these algae. In the same core, specimens of *Reticypris* with reticulated and often spinose shells are thought to indicate deeper water (> 2 m), since remains of shallow-water charophytes are absent (CARBONEL *et al.*, 1988).

Essential in paleoenvironmental studies of the Serbian Late Miocene ostracod assemblages are 1) geographical position and 2) time range. It must be realised that there are extensive erosion and unconformity between Sarmatian restricted marine sediments and younger, caspibrackish deposits (RUNDIĆ, 1995, RUNDIĆ & MITROVIĆ,1998). This, by mountains enclosed system, was affected by continental water, which resulted in a brackish lake-sea and the nearly total extermination of marine biota. Only a few ostracod genera were able to survive these environmental changes (*Aurila*, *Loxoconcha*, *and Xestoleberis*). The newly formed habitats and gradually expanding lake-sea created a kind of "ecological gap", and stimulated the rapid evolution of survivors and the immigration of freshwater dwellers from the marshes, ponds and rivers (most of *Candona*, *Darwinula, Ilyocypris,* etc.). As with other fossils and in a still existing *long living lake* (MÜLLER *et al.*, 1999), the originally low diversity fauna radiated into a large number of related endemic species and genera in the expanding and ecologically unoccupied lake-sea. The best examples for this are the many genera of Candonids, which had a radiated development during the Pannonian Stage. From the small number of species and genera during the Lower Pannonian (such as *Propontoniella* and *Cryptocandona*), in the Upper Pannonian there was an expansive evolution of these lineages (*Serbiella, Zalanyiella, Camptocypria, Sirmiella, Lineocypris, Typhlocyprella,* etc.) in both species and specimens. They are immigration forms from the marginal rivers and swamps, but most of them are the result of time resolution. Most of them are endemic species and lived only in this realm, such as *Hungarocypris*, which is a typical near shore dweller, preferring a sandier type of stratum. It is scarce in associations from fine-grained sediments. Its large and massive carapace must be the result of a rich ionic concentration, as well as living in warm, oxygenated and clear water (RUNDIĆ, 1991). However, the fossil record includes only three species of *Hungarocypris* with numerous individuals during the Pannonian–Pontian. The genus *Amplocypris* shows similar characteristics. The appearance of corpulent forms, strong carapaces and clear ornamentation give evidence for a shallow-water basin type with mobile flow and an important donation of land material. In normal oxygenated habitats, increasing ionic concentrations led to an increase in the number of sculptured morphotypes. The best examples are representatives of the family Cytherideidae (*Hemicytheria*, *Loxoconcha*, *Leptocythere*, and *Cyprideis*) with mostly ornamented forms. Analyses of the genus *Hemicytheria* in both Pannonian and Pontian deposits show that more than 90% of the species have ornamented shells. Taphonomic analysis of fossil associations, particularly the numerous specimens of *Hemicytheria setosa* RUNDIĆ, shows that during the Late Miocene, salinity was not the principal influence on the occurrence of valves and the type of ornamentation. This ornamented form lived on coastal and mobile parts of the Pannonian lake-sea and its ornamentation is a reaction to the adaptation. On the other hand, the Upper Pontian nodose forms lived in environments with decreased salinity and increased organic matter and silica (*Leptocythere*, *Ilyocypris*). In the Kolubara coal basin, these forms were discovered in sediments with a rich organic content. Based on sedimentological studies, data concerning transport and depositional mechanisms, which appear with intermittent alteration between fluvial and coastal deposition, are obtained. Fluvial flows brought and deposited more silicoclastics in the coastal regions, but in the alluvial part of the land, this occurrence was only periodic (well Rgh-107.5). MÜLLER *et al.* (1999), suggesting that the Pannonian–Pontian lake-sea continuously shrank in the north, due to the prograding deltas. They stated that the more southerly shores were much less affected by progradation. The shoreline remained in more or less the same position for a longer period of time. Along these shores, successions of paralic lignite beds were formed (STEVANOVIĆ *et al.*, 1990). In phases of highstand, the lake-sea enlarged in some areas in the south and the shoreline became simpler as large islands became flooded. Coarse-grained clastic rims formed around the islands. From the very beginning of the lake-sea, these coarse clastics were often capped by white calcareous marl or limestone in the southern part of the basin, in locations far from the river mouths.

Modern analogues of Pannonian–Pontian ostracodes from the modern Ponto-Caspian regions have been used to estimate the paleosalinity of the lake-sea. These comparisons suggest that the average salinity of the Pannonian–Pontian lake-sea may have been approximately 10–12 ‰, but that significant local differences existed in shallow parts, such as the southern "shelf" dominated by river deltas. Natural water examination gives data similar to the results of the paleoecological approach. Down from the lacustrine prodelta silt, which is a regional stamp in the basin, inborn waters have salt in an amount approximately, or sometimes even higher, than that of normal marine salinity. Innate waters from above the silt, however, are diluted because of mixing with meteoric water, as shown by the diagenetic carbonates. The salinity of these diluted waters is about 5 ‰, which sets the lower limit for the original lake-sea salinity (MÜLLER *et al*., 1999).

Conclusions

According to qualitative and quantitative analysis of the ostracodes, the results of a factor analysis applied to the most frequent species to the population structures, it is possible to distinguish several different assemblages based on salinity:

- *Stenocypria, Cyprinotus, Cypridopsis, Ilyocypris, Darwinula* and *Candona* characterize the oligohaline environments (0.5–8 ‰ of NaCl) and indicate a shallow, coastal part of river mouths or in swamps. They occurred in the lowest parts of the Pannonian and in the Upper Pontian.
- *Hungarocypris, Thaminocypris, Propontoniella, Cypria, Serbiella, Camptocypria, Zalanyiella, Typhlocyprella, Pontoleberis,* etc. represent the dominant group of the caspibrackish–mesohaline habitats (8–18 ‰). All of them are related to the entire Pannonian–Pontian and lived in shallow infralittoral environments covered by water plants.
- Assemblages with *Cyprideis, Amplocypris, Leptocythere*, *Hemicytheria, Loxoconcha* and *Xestoleberis* represents more meso- to polyhaline (18–30 ‰) habitats and these associations occupied most of the southern Pannonian estuary (the Kolubara Basin, the Velika Morava Bay, eastern Serbia). Estuaries are semi-enclosed coastal waterbodies in which there is a salinity gradient from fully marine (35 ‰) to fresh water. The salinity varies due to tidal and seasonal influences.
- Ornamented forms of ostracodes lived in the coastal parts and the sculpture is a reaction to adaptation.
- Increases of ionic concentrations resulted in increased diversity (for ex. mostly of Upper Pannonian ostracodes)
- A deficiency of oxygen and a low Mg/Ca ratio in the water can eliminate sculptured morphotypes.
- Nodose ostracodes from the Upper Pontian (*Amnicythere, Ilyocypris*) lived under conditions of low salinity and increased organic matter.

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Резиме

Млађе миоценске остракоде Србије: морфолошка и палеоеколошка разматрања

Пре око 11,5 милиона година, тектонска издизања у Карпатима су довела до одвајања Панонског простора од остатка Паратетиса. То је резултирало дискорданцијом између сарматских, бракичних и панонских, каспибракичних наслага. Почетком плиоцена, промене географских прилика, хидролошких услова и формирање ослађене водене средине, довеле су до потпуног изумирања морских организама. Само неколико еврихалинских форми као и оних који су настањивали приобалне делове успело је да се прилагоди и преживи. Код остракода, слатководни облици попут кандонина, све више настањују такво велико језеро-море док неки филогенетски низови показују постепене измене. Старије панонска, слабије разноврсна остракодска фауна еволуира у неке ендемичне облике током млађег панона. Горњи панон је време процвата остракода, како по броју врста тако и по броју јединки. То је период последњег појављивања родова *Aurila, Cytheridea*, *Propontoniella* односно време првог појављивања родова *Zalanyiella, Serbiella, Camptocypria, Sinegubiella*. За време понта, запажени су миграциони процеси на овом простору и сматра се да многи облици који живе у источном Паратетису имају панонско порекло.

Остракоде које су настањивале Панонску провинцију, а посебно њене маргиналне делове, делимично су се разликовале од оних које су живеле у Дакијској провинцији. Основни разлози леже у чињеници да су те две провинције у појединим етапама током старијег горњег миоцена – панона, биле међусобно одвојене. Свака биопровинција је имала своје посебне карактеристике. Панонска је била више изолована и формирала је временом специфичну остракодску заједницу. Старије асоцијације су биле сиромашније јер су егзистовале у једној новој средини у односу на дотадашње услове. То се посебно добро види на примеру из Колубарског басена. Млађе панонске асоцијације су много више разноврсне и имају много више јединки. Основни разлог је довољно дуго време адаптације и касније повољни животни услови. Појављују се потпуно нови родови као одговор на већ консолидоване животне услове. Током горњег панона десиће се прави процват у еволуцији остракода на панонском простору. То се посебно односи на неке таксоне као што су кандониде и хемицитериде које доживљавају експанзију. С друге стране, у Дакијској провинцији која је у исто време више комуницирала са црноморским басеном, присутне су друге групе остракода које указују на ту везу, а посебно лептоцитерине. Такође, има и потпуно другачијих таксона којих нема у Панонском басену (*Getocytheria*, *Stanchevia*). Интересантно је рећи да род *Cyprideis* има врло малу заступљеност за разлику од Панонске провинције где је један од руководећих облика.

Посебно је добро проучен род *Hemicytheria* са свим својим врстама (20) и који показује све поменуте трендове у развоју остракодске фауне који су владали током панона и понта.

Са палеоеколошког аспекта посматрано, током млађег миоцена на простору обе провинције, егзистовало је неколико различитих типова средине у којима је живела остракодска заједница. Прву карактерише присуство родова који насељавају олигохалинске (< 8 ‰), плитке обалске делове речних ушћа и мочвара: *Stenocypria, Cyprinotus, Cypridopsis, Ilyocypris, Darwinula, Candona*. Присутне су током старијег панона и млађег понта. Друга, доминантна заједница (*Hungarocypris, Thaminocypris, Propontoniella, Cypria, Serbiella, Camptocypria, Zalanyiella, Typhlocyprella, Pontoleberis*) представља каспибракичну, мезохалинску средину (< 18 ‰) односно инфралиторал обрастао воденом вегетацијом. Трећа остракодска асоцијација у којој су представници *Cyprideis, Amplocypris, Leptocythere*, *Hemicytheria, Loxoconcha* и *Xestoleberis* (> 18 ‰) одговара

мезо и полихалинском биотопу односно најчешће већини тадашњих панонских и дакијских естуара (Колубарски басен, Великоморавски залив, и други заливи у источној Србији).

У вези са претходним, могуће је донекле успоставити међусобну зависност биотопских услова са изгледом и саставом остракодске љуштуре. Примећено је да, на пример, нодозне форме настањују средине које имају низак ниво растворене соли односно повећан проценат органске материје (родови *Ilyocypris* и *Amnicythere* у Колубарском басену). Сматра се и да смањен ниво кисеоника односно низак однос Mg/Ca у води, може довести до елиминације орнаментисаних форми остракода.

ГЕОЛОШКИ АНАЛИ БАЛКАНСКОГА ПОЛУОСТРВА ANNALES GÉOLOGIQUES DE LA PÉNINSULE BALKANIQUE	67	101–108	БЕОГРАД, децембар 2006 BELGRADE, December 2006

Spectroscopic study of barite from the Kremikovtsi deposit (Bulgaria) with implication for its origin

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Abstract. Different genetic types (endogene and supergene) of barite from the Kremikovtsi deposit (Bulgaria) were studied by Laser-induced time-resolved luminescence (LITRL), Infrared (IR) and Raman spectroscopy. The IR spectra of the endogene barites are quite similar to those reported in the literature and do not show appreciable differences among them. The IR spectra of the supergene barites are almost identical to those of the endogene ones in respect to the positions of the vibrational modes ν_1, ν_2 and ν_4 of SO_4^{2}, except for a shift of 3 cm^{-1} for the ν_3 band. They displayed a presence of additional bands, which are close to the ν_3 and ν_1 modes of CO_3^{2-} in calcite. The Raman studies support the suggestion that the supergene barite contains traces of calcite.

The modern LITRL technique allowed the detection of several luminescent centers in the endogene barite. Eu^{3+} luminescence was identified for the first time in barite. The different emission spectra at 266 and 532 nm excitations suggest there are at least 2 structural positions for Eu^{3+} in the barite crystal lattice. The luminescent spectra also revealed a rather unusual violet-blue Nd^{3+} emission, which usually occurs in the IR spectral range, as well as emissions of Ce^{3+}, Eu^{2+}, Tb^{3+}, Ag^{+}, Sn^{2+}(?) and UO_2^{2+}.

The oxidation state of cations isomorphically present in the barite crystal lattice suggests the endogene barite in the Kremikovtsi deposit precipitated from reduced fluids supposedly subjected to cooling (conductive/convective) and oxidation (mixing with seawater).

Key words: barite, UV Time-resolved Luminescence, IR spectroscopy, Raman spectroscopy, Kremikovtsi deposit, Bulgaria.

Апстракт. Различити генетски типови барита (ендогени и супергени) из кремиковачког лежишта у Бугарској проучавани су спектроскопским методима LITRL, IR и Раман. Инфрацрвени спектри ендогених барита слични су спектрима из литературе и не показују међусобне разлике. IR спектри супергених барита су скоро идентични спектрима ендогених барита у погледу положаја вибрационих пикова ν_1, ν_2 и ν_4 SO_4^{2-} осим за помак од 3 cm^{-1} код ν_3. Спектри су приказивали присуство додатних трака које су блиске пиковима ν_3 и ν_1 CO_3^{2-} у калциту. Раманова спектроскопска проучавања иду у прилог наговештаја да супергени барит садржи трагове калцита.

Савремена техника LITRL омогућава откривање неколико луминесцентних центара у ендогеним бариту. По први пут је у бариту утврђена луминесценција Eu^{3+}. Различити емисиони спектри при побуђивању од 266 и 532 nm указују да постоје бар два структурна положаја Eu^{3+} у кристалној решетки барита. Луминесцентни спектри су такође открили необичну љубичасто-плаву емисију Nd^{3+}, која се обично јавља у инфрацрвеном опсегу спектра, као и емисије Ce^{3+}, Eu^{2+}, Tb^{3+}, Ag^{+}, Sn^{2+}(?) и UO_2^{2+}.

Степен оксидације катјона изоморфно присутних у кристалној решетки барита указује да је ендогени барит у лежишту Кремиковци наталожен из редукованих флуида за које се претпоставља да су били изложени хлађењу (кондуктивно односно конвективно) или оксидацији (мешањем са морском водом).

Кључне речи: барит, ултравиолентна луминисценција, инфрацрвена спектроскопија, Раман спектроскопија, лежиште Кремиковци, Бугарска.

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Introduction

A large share of the known and mined reserves of various metals (Pb, Zn, Cu, Ag, Hg, Sb, less Fe and Mn) are concentrated in carbonate-hosted polymetallic deposits of the sedimentary exhalative (SEDEX) type. A large Phanerozoic deposit of this type, the Kremikovtsi iron(+Mn)-barite-sulphide deposit in Bulgaria, which has been mined for iron, also contains large reserves of barite ore (29 million tons of barite ore and over 60 million tons of $BaSO_4$). Investigations of this deposit have mainly been focused on the iron ores (DAMYANOV, 1998, and the references therein). There are just a few studies on the mineralogy and geochemistry of barite (ATANASSOV & VASSILEVA, 1987; ZLATEV & MLADENOVA, 1997; VASSILEVA *et al*., 2001; DIMOVA, 2006) and only one of them (ATANASSOV & VASSILEVA, 1987) presents a brief spectroscopic (IR and thermoluminescence) characterization of the Kremikovtsi barite. All these approaches, however, are based on routine conventional techniques (X-ray diffractometry, emission spectroscopy). In order to gain more insight into the barite structure and cation valence with implications for its origin, a set of modern methods (LITRL, IR and Raman spectroscopy) was used. Here, spectroscopic data for barite from this deposit, with emphasis on the results obtained using the laser-induced time-resolved luminescence technique, are reported.

Geological setting

The Kremikovtsi deposit (Fig. 1) lies in the southernmost part of the Kremikovtsi–Vratsa ore district, located in the eastern part of the Western Balkanides, which belong to the northern branch of the global Alpine–Hymalayan collisional orogenic belt on the Balkan Peninsula. The lithology of the region is presented by Paleo-, Meso- and Neozoic sedimentary rocks (Fig. 1). A major tectonic element is the Kremikovtsi thrust. The deposit is hosted in Middle Triassic dolomitic limestones in the western part of the Kremikovtsi thrust sheet. It consists of stratiform and lenticular iron formations and barite orebodies subparallel to the allochton bedding plane and subvertical (pipe-like) bodies of low-grade sulfide mineralization (DAMYANOV, 1998).

Two main genetic types of barite were found in the Kremikovtsi deposit – endogene and supergene (ATANASSOV & VASSILEVA, 1987), and 3 main morphological types of endogene barite bodies were distinguished: veins and lenses, veinlets and nests, impregnations (DIMOVA, 2006). Supergene barite occurs as colloform

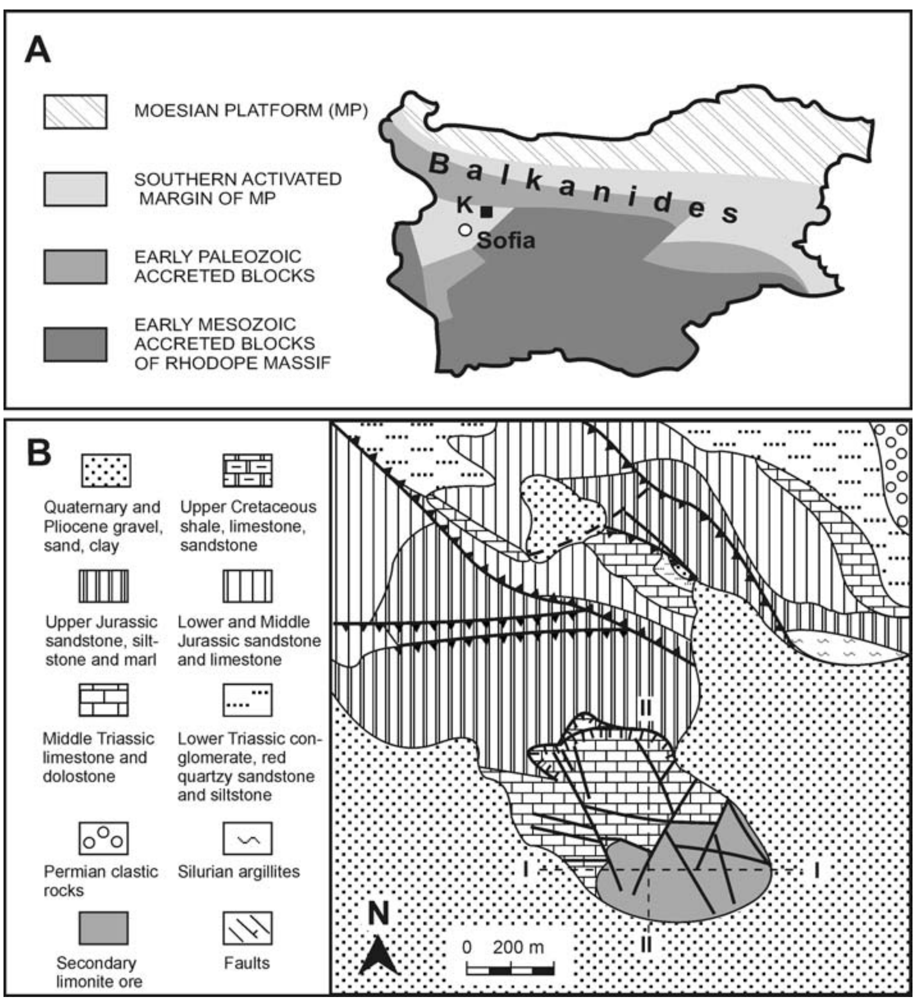

Fig. 1. Location (A) and geological map (B) of the Kremikovtsi ore field (after DAMYANOV, 1998).

crusts and crystal aggregates (ATANASSOV & VASSILEVA, 1987).

Material and methods

Isomorphic substitutions in barite were studied in 38 samples by Infrared Spectroscopy (Perkin Elmer Spectrum One fourier transform infrared spectrophotometer, transmission mode, KBr/sample = 300mg/1mg pellets) and 7 samples by Raman Spectroscopy (SPEX Raman Spectrometer, Ar^+ laser excitation at 488.0 nm, P=150 mW, step 1 cm^{-1}, integration time 1s, powder sample in capillary tube).

The luminescence spectra of 7 barite samples were investigated under 2nd, 3rd and 4th YAG harmonics (532, 355 and 266 nm, correspondingly) pulsed lasers excitations. The spectra observed at the geometry of 90° were analyzed by INSTASPEC equipment, enabling time-resolved spectra acquisition with the following facilities: delay times and strobe pulse duration 20 ns – 9 ms, spectral detection range 300–900 nm (1200 channels, spectral resolution 0.5–1 nm, gratings with 300 and 600 lines/mm), detector type – intensified CCD matrix. The luminescence spectra were measured at room temperature (300 K).

X-Ray powder diffraction (Philips PW1710 diffractometer, Cu K_α, U=45 kV, I=40 mA, 2–70° 2θ, step 0.02° 2θ, 2 s/step; DRON M3, Co K_α, U=40 kV, I=40mA, 2–70° 2θ, step 0.05° 2θ) was used to control the purity of the barite samples.

Results and discussion

Barite has an orthorhombic structure (2/m 2/m 2/m), where the S is situated in tetrahedral coordination with O and the Ba is surrounded by 12 oxygens of 7 SO_4 tetrahedra (JAMES & WOOD, 1925). The BaO_{12} polyhedra and the SO_4 tetrahedra are edge-bound. The BaO_{12} polyhedra are irregular: six of the Ba–O distances are 2.77–2.81 Å, and the other 6 – 2.91–3.32 Å, which suggests a "sheet" structure parallel to {001}.

IR and Raman Spectroscopy

The sulfate group has 4 fundamental vibrational modes: one nondegenerate (ν_1), one doubly degenerate (ν_2), and two triply degenerate (ν_3 and ν_4). The IR spectrum of barite exhibits several significant bands: 2 strong bands corresponding to asymmetric stretching and bending (ν_3 and ν_4), and 2 weak ones – to symmetric stretching and bending (ν_1 and ν_2). The IR spectra of the studied endogene barites from the 3 main morphological types of bodies and from different mineral associations (Fig. 2) are very similar each other and to that reported by OMORI (1968; Table 1). Microprobe analyses show that Sr is the main isomorphic substitution for Ba in barite structure (SrO 0–4.5%; DIMOVA, 2006). ADLER & KERR (1965) found spectral shifts of the stretching modes (ν_3 and ν_1) to lower frequencies with increasing cation mass, such as the case of substitution Ba for Sr. The IR spectra of the studied endogene barites with different Sr contents (up to 4.5 % SrO) do not show any appreciable spectral shifts.

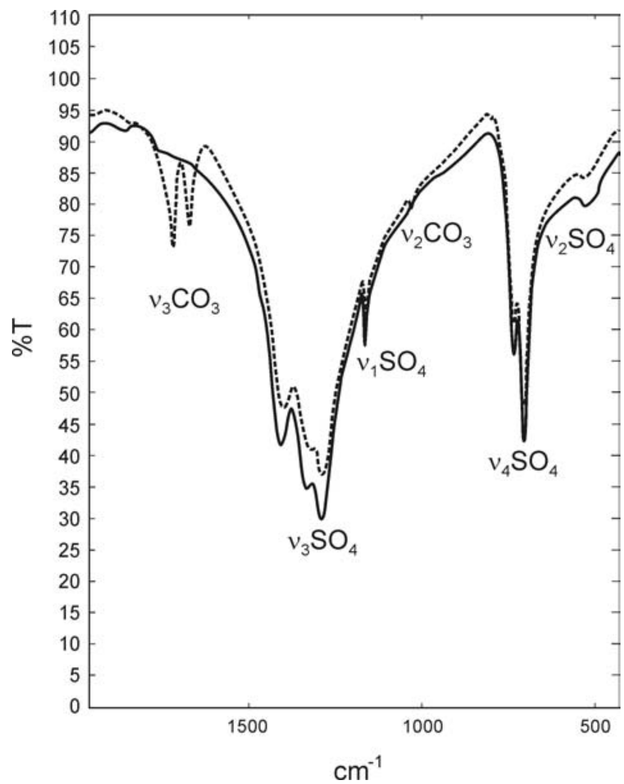

Fig. 2. IR spectra of endogene (bold line) and supergene (dashed line) barite from the Kremikovtsi deposit.

The IR spectra of the supergene barite (Fig. 2) are almost identical to those of the endogene ones in respect to the positions of the vibrational peaks, corresponding to the modes ν_1, ν_2, ν_4, except for a shift of 3 cm^{-1} for ν_3 (Table 1). A significant difference in the IR spectra of the supergene barite in comparison with the endogene one is the presence of additional bands at 1437, 1400 and 874 cm^{-1}, which correspond to the ν_3 and ν_1 modes of CO_3^{2-} in calcite (Fig. 2; Table 1). This suggests that the supergene barite has traces of calcite, undetectable by XRD (<2%).

All the Raman spectra of the studied barite samples are dominated by an intense ν_1 band (symmetric stretching of SO_4 tetrahedra) at 988 and 984 cm^{-1} for endogene and supergene barite, respectively (Fig. 3). The other characteristic bands, ν_2, ν_3 and ν_4, reported in the literature, are also present (Fig 3; Table 2). The Raman spectra of the supergene barites show additional bands at 1054, 710 and 270 cm^{-1} (Fig. 3; Table 2). The Raman studies support the suggestion that the supergene barite contains traces of calcite: ν_1(1086 cm^{-1}), which coincides with ν_3 of the SO_4 group and ν_4 (710 cm^{-1}) bands.

Table 1. Peak positions (cm^{-1}) of the Infrared modes of barite and calcite.

IR modes of SO_4^{2-}	Endogene barite, Kremikovtski deposit	Supergene barite, Kremikovtski deposit	Barite (OMORI, 1968)	IR modes of CO_3^{2-} in calcite (NAKAMOTO, 1997)
ν_1	982	982	980	
ν_2	467	468	470, 439	879
ν_3	1179, 1118, 1083	1176, 1115, 1182	1180, 1120, 1080	1429-1492
ν_4	610	610	633, 608	706
Additional bands		1437, 1400, 874		

Table 2. Peak positions (cm^{-1}) of the Raman modes of barite and calcite.

Raman modes of SO_4^{2-}	Endogene barite, Kremikovtski deposit	Supergene barite, Kremikovtski deposit	Barite (OMORI, 1968)	Raman modes of CO_3^{2-} in calcite (NAKAMOTO, 1997)
ν_1	988	984	987	1087
ν_2	462, 453	460, 454	460, 451	
ν_3	1167, 1140, 1084	1134, 1086	1167, 1140, 1083	1432
ν_4	647, 618	644, 618	646, 630, 617	714
Additional bands	1104	1054, 710, 270		

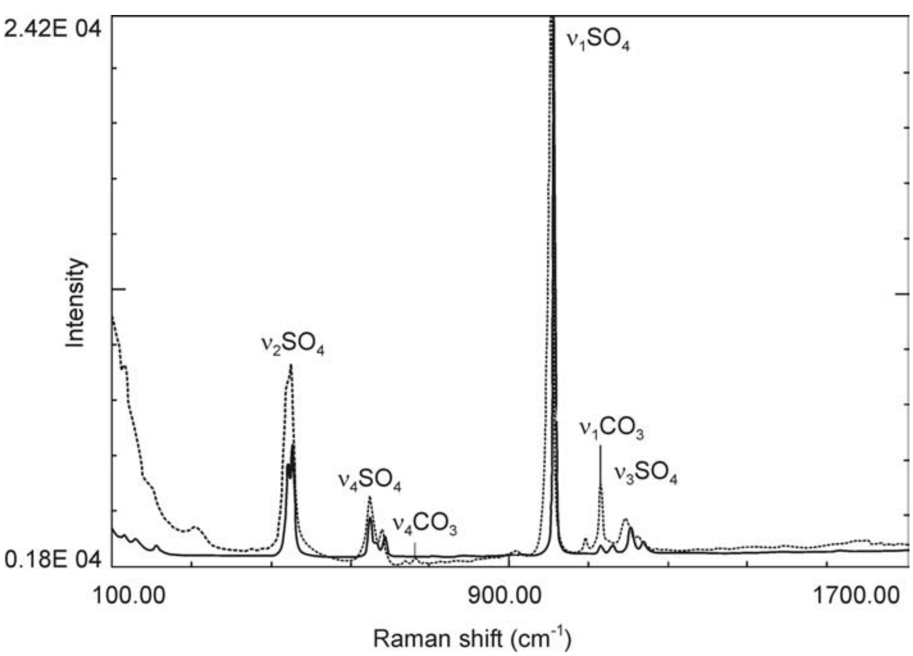

Fig. 3. Raman spectra of endogene (bold line) and supergene (dashed line) barite from the Kremikovtsi deposit.

Laser-induced time-resolved luminescence

Barite is one of the first luminescent materials from which the famous "Bologna stone" was obtained. It has been known for a long time that some barite specimens are fluorescent under UV exposure and emit white, yellow, green or orange light. In order to understand the nature of this phenomenon, the luminescence spectra of barite have been examined via UV, thermal and X-ray excitations. These studies allow the detection of the appearance of different luminescence bands from the UV to the red part of the spectrum.

Laser-induced time-resolved luminescence is a modern technique, which allows discrimination between centers with emission in the same spectral range, but with different decay times. The method involves recording the intensity in a specific time gate at a given delay after the excitation pulse, whereby both the delay and the gate width have to be carefully chosen. Such manipulation allows to be recorded separately the emissions corresponding to different decay times and to avoid the overlapping of the emissions produced from different centers. Laser-induced time-resolved luminescence of barites have detected and identified luminescence centers of Bi^{3+}, Bi^{2+}, Ag^{+}, Cu^{+}, REE^{3+} (Gaft *et* *al*., 2001a; GAFT *et al*., 2005) in addition to UO_2^{2+} and Eu^{2+} revealed by Steady-State Photoluminescence (TARASHCHAN, 1978; GAFT *et al*., 1985; GOROBETS & ROGOJINE, 2001). Thus the information about the redox state of the different cations in the barite crystal lattice could throw more light on the origin of the barite.

The luminescence spectrum (excitation of 266 nm, without delay, broad gate of 9 ms) of the studied endogene barite contains 2 relatively narrow ultraviolet bands: one peaking at 306 nm and the other at 375 nm (Fig. 4A). The first band has a very short decay time and disappears after D = 50–100 ns. Such a combination of spectrum and decay time parameters is evidence that the luminescence is connected with Ce^{3+}. The emission of Ce^{3+} corresponds to transitions between $5d^1$ and $4f^1$ electronic configurations. The second band has a longer decay time of approximately 1 μs and belongs to Eu^{2+} (GAFT *et al*., 2005). The Emission spectra of Eu^{2+} result from electronic transitions between $4f^7$ and $4f^65d^1$ electronic configurations. After a delay of several μs, the Eu^{2+} emission becomes much weaker and very weak narrow lines appear, peaking at 488, 544 and 615 nm (Fig. 4B). These lines are connected with trivalent rare-earth elements, which are characterized by relatively long decay times of hundreds of μs: the first 2 lines certainly belong to Tb^{3+} and the last one is principally typical for Eu^{3+} (GAFT *et al*., 2005). While Eu^{2+} luminescence is common, Eu^{3+} emission is here detected for the first time in barite. Under excitation of 532 nm, a luminescence line at 615 nm dominates the spectrum, accompanied by several lines near 700 nm (Fig. 4C). Such a behavior confirms that Eu^{3+} is responsible for these luminescence lines. The emission of Eu^{3+} corresponds to f–f transitions – from the excited $^5D_0$ level to the ^7F_j (j=0, 1, 2, 3, 4, 5, 6) levels of the $4f^6$ configuration.

Some samples do not show Eu^{3+} luminescence. The relative intensities of Ce^{3+}, Eu^{2+} and Eu^{3+} in different samples are different: Ce^{3+} emission could be stronger than that of Eu^{2+}, while the luminescence of Eu^{3+} is relatively intensive. The different emission spectra at excitations at 266 and 532 nm suggest at least 2 structural positions for Eu^{3+} in the barite crystal lattice (Fig. 4C, D). Under excitation of 355 nm, a very broad orange-red band is detected (Fig. 4E), which was previously ascribed to Ag^+ luminescence (GAFT *et al*., 2005). One of the samples showed a relatively strong Ag^+ luminescence dominating the spectrum even with an excitation of 266 nm, which is not optimal for this emission (Fig. 4F). The emission bands of Ag^+ result from d^9s–d^{10} transitions.

Under 266 nm excitation, without delay and with a broad gate of 9 ms, the luminescence spectrum contains 2 relatively narrow ultraviolet bands: one peaking at 320 nm and another at 375 nm (Fig. 4G). The latter band belongs to Eu^{2+}, while the origin of the first one is difficult to suggest. A similar emission has been found in synthetic barite artificially activated by Sn (GAFT *et al*., 2005), but such an interpretation needs further support. The rather unusual narrow lines (at 370 and 391 nm) which appear in the luminescence spectrum with a longer delay of several μs (Fig. 4H) belong to trivalent rare-earth elements. They have been preliminary ascribed to violet-blue emission of Nd^{3+}, but this identification should be further clarified. The weak broad green band (at around 500 nm) may be related to uranyl emission, well known in barite (Fig. 4H).

The LITRL study of supergene barite did not show any luminescence. This could be connected with the lower impurity level in supergene minerals in general. A thermo-luminescence study of barite (KRIVOVICHEV, 1971) showed that the intensity of luminescence depends on the Sr concentrations in barite. The available data on the chemical composition of the Kremikovtsi supergene barite (ATANASSOV & VASSILEVA, 1987) showed very low Sr contents, which accounts for the absence of luminescence. Another possible explanation is that the luminescence is quenched by components with high-energy phonons, such as water or organic matter (GAFT *et al*., 2005).

The main prerequisite needed for a mineral to display luminescent properties, in the case that the luminescent centers are minor elements, is a similarity of the ionic radii and charges of the host and isomorphic elements. It is known that the luminescent centers Eu^{2+} (1.24–1.40 Å), Ce^{3+} (0.88–1.02 Å), Nd^{3+} (0.99–1.15 Å), Tb^{3+} (0.89–1.09 Å), Ag^+ (1.13–1.26 Å), Sn^{2+} (0.93 Å) substitute for Ba^{2+} (1.35–1.44 Å) or Sr^{2+} (1.10–1.27 Å), which are in 12-fold coordination in the barite structure (GOROBETS, 2002; GAFT *et al*., 2005; all ionic radii are for the 6-coordination form). A possible accommodation for the established in this study Eu^{3+} (0.97–1.13 Å) is also isomorphic substitution for Ba^{2+} or Sr^{2+}. The presence of uranyl molecules in barite is considered to be a result of chemical adsorption (GOROBETS, 2002).

Samples from both morphological types of endogene barite (veins and lenses, and veinlets and nests) fall into 2 groups: (1) barite with Eu^{2+} and Sn^{2+}(?), or Eu^{2+} and Ce^{3+}; (2) barite with Eu^{2+}, Eu^{3+} and Ce^{3+}. Barite samples from the first group contain isomorphic cations in their reduced form (Eu^{2+}, Sn^{2+}, Ce^{3+}), which implies that the barite precipitated from reduced fluids. A possible manner of this precipitation is conductive/convective cooling of the transporting fluid, which reaches the point of barite saturation with no substantial oxidation. The barite from the second group has reduced (Eu^{2+}, Ce^{3+}) as well as oxidized (Eu^{3+}) cations. This suggests that the barite from these samples precipitated from reduced transporting fluid subjected to oxidation. It can be speculated that both morphological types of barite are the result of conductive/convective cooling and mixing of hydrothermal fluid with seawater. This corroborates the most recent submarine hydrothermal model for the formation of the Kremikovtsi deposit (DAMYANOV, 1996a; DAMYANOV, 1998): sub- and on-seafloor precipitation upon cooling and mixing of hydrothermal fluid with seawater.

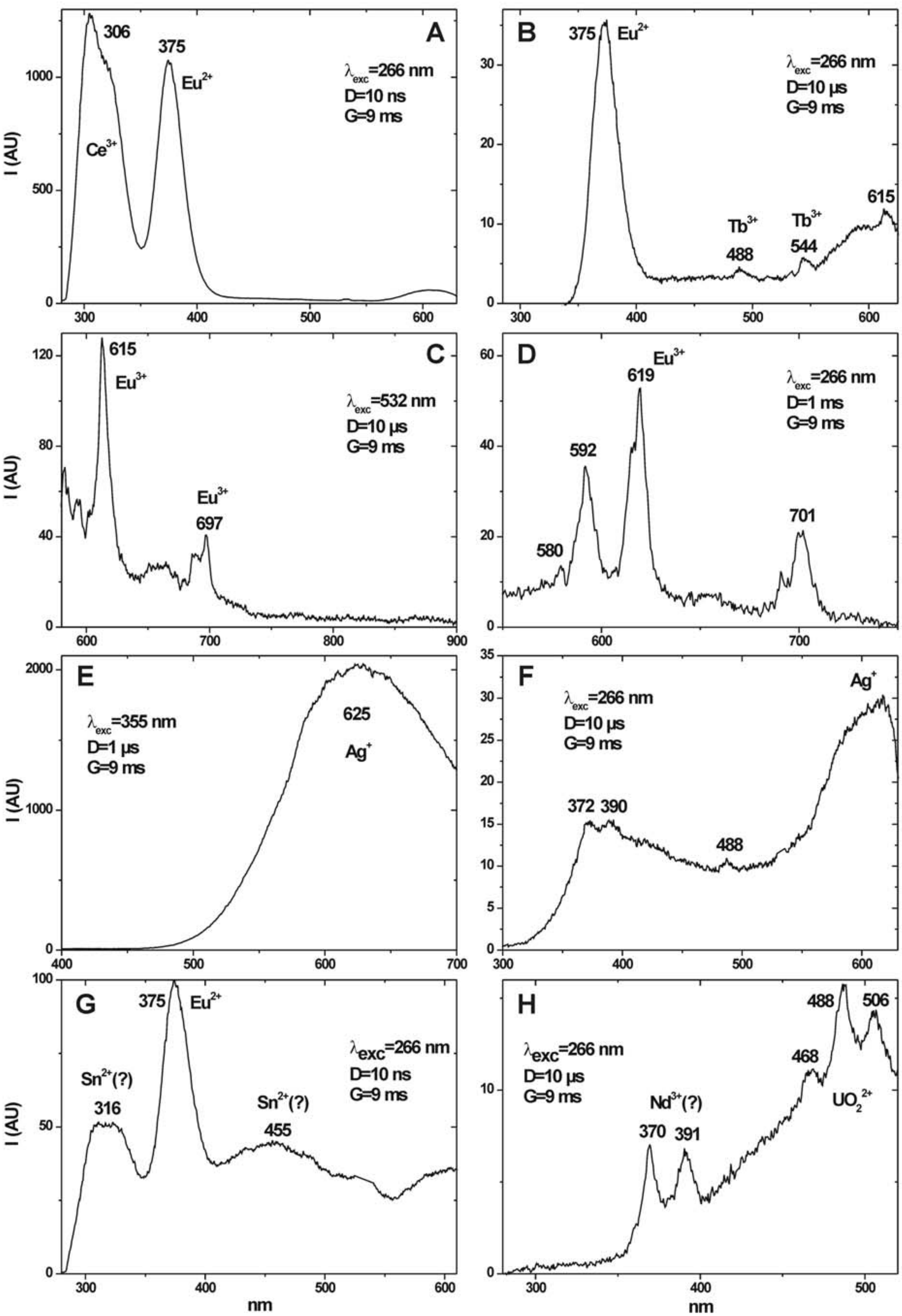

Fig. 4. Time-resolved luminescence spectra of endogenic barite from the Kremikovtsi deposit demonstrating different emission bands: (A) Ce^{3+}, Eu^{2+}; (B) Eu^{2+}, Tb^{3+}; (C) Eu^{3+}; (D) Eu^{3+}; (E) Ag^{+} (F) Ag^{+} (G) Eu^{2+}, Sn^{2+}; (H) Nd^{3+}, UO_2^{2+}.

Conclusions

The data obtained in the present study allow the following conclusions to be drawn:

(1) There is no structural difference depending on the varying Sr content (0–4.5 wt.%) in all the morphologic types of endogene barite, according to the IR and Raman studies. Supergene barite shows IR and Raman spectra identical to those of the endogene one with the only difference being the presence of traces of calcite.

(2) The laser-induced, time-resolved luminescence technique is a suitable tool for the identification of rare-earths (undetectable with conventional methods) in barite and the discrimination of their oxidation states.

(3) Along with the common Eu^{2+} luminescence, the emission of Eu^{3+} was detected for the first time in barite. There are at least 2 structural positions for Eu^{3+} in the barite crystal lattice.

(4) It seems that the endogene barite in the Kremikovtsi deposit was precipitated from reduced fluids subjected to cooling (conductive/convective) and oxidation (mixing with seawater).

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Резиме

Спектроскопско проучавање барита из лежишта Кремиковци (Бугарска) са импликацијама његовог порекла

Лежиште гвожђа(+Mn)-барита-сулфида Кремиковци у Бугарској садржи различите метале и велике резерве руде барита. Пошто се лежиште експлоатисало углавном због гвожђа, претежно су вршена испитивања гвоздене руде. Постоји само неколико минералошких и геохемијских студија барита. Циљ овог проучавања је боље упознавање са структуром и катјонском валентношћу барита са импликацијама његовог порекла. Различити генетски (ендогени и супергени) и морфолошки (жице и сочива, као и жилице и гнезда) типови барита испи-

тивани су применом спектроскопских метода ласерски редуковане луминесценције (LITRL), инфрацрвене анализе (IR) и Рамонове анализе.

Инфрацрвени спектри ендогеног барита сасвим су слични спектрима објављеним у литератури. Не постоји структурна разлика која зависи од променљивог садржаја Sr (0–4,5 теж.%) ни у једном морфолошком типу ендогеног барита. Инфрацрвени спектри супергеног барита скоро су идентични спектрима ендогеног барита у погледу положаја вибрационих пикова ν_1, ν_2 и ν_4 SO_4^{2-}, осим за помаке од 3 cm^{-1} код ν_3. Ти спектри су показивали присуство додатних трака, које су блиске пиковима ν_3 и ν_1 CO_3^{2-} у калциту. Раманова проучавања иду у прилог наговештаја да супергени барит садржи трагове калцита.

Савремена техника LITRL, као погодан начин утврђивања ретких земаља (које се не могу открити класичним методима) и разликовања њихових степена оксидације, омогућила је утврђивање неколико центара луминесценције у ендогеном бариту. Луминесценција Eu^{3+} је по први пут утврђена у бариту. Различити емисиони спектри при побуди од 266 и 532 nm указују на присуство бар два структурна положаја Eu^{3+} у кристалној решетки барита. Луминесцентни спектри су такође открили доста необичну љубичасто-плаву емисију Nd^{3+}, која се обично јавља у опсегу инфрацрвеног спектра, као и емисије Ce^{3+}, Eu^{2+}, Tb^{3+}, Ag^{+}, Sn^{2+}(?) и UO_2^{2+}.

Степен оксидације катјона изоморфно присутних у кристалној решетки барита указује да је ендогени барит у лежишту Кремиковци наталожен из редукованих флуида за које се претпоставља да су били изложени хлађењу (кондуктивно односно конвективно) и оксидацији (мешањем са морском водом).

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Crystallite size distribution of clay minerals from selected Serbian clay deposits

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Abstract. The BWA (Bertaut-Warren-Averbach) technique for the measurement of the mean crystallite thickness and thickness distributions of phyllosilicates was applied to a set of kaolin and bentonite minerals. Six samples of kaolinitic clays, one sample of halloysite, and five bentonite samples from selected Serbian deposits were analyzed. These clays are of sedimentary, volcano-sedimentary (diagenetic), and hydrothermal origin. Two different types of shape of thickness distribution were found – lognormal, typical for bentonite and halloysite, and polymodal, typical for kaolinite. The mean crystallite thickness (T_{BWA}) seams to be influenced by the genetic type of the clay sample.

Key words: kaolinite, bentonite, halloysite, BWA technique, Serbia.

Апстракт. Мерење просечне дебљине кристалита филосиликата и њихове дистрибуције извршено је на узорцима каолинских и бентонитских минерала помоћу BWA (Bertaut-Warren-Averbach) метода. Проучено је шест узорака каолинитских глина, један узорак халојзита и пет узорака бентонита из изабраних лежишта у Србији. Те глине су седиментног, вулканогено-седиментног (дијагенетског) и хидротермалног порекла. Утврђена су два различита облика дистрибуције дебљине кристалита – логнормална типична за бентоните и халојзит, и полимодална типична за каолинитске глине. Просечна дебљина кристалита (T_{BWA}) изгледа да зависи од генетског типа узорака глине.

Кључне речи: каолинитске глине, бентонит, халојзит, BWA метод, Србија.

Introduction

The size distributions of crystallites can be measured by powder X-ray diffraction (XRD) because the widths of the XRD peaks broaden as the crystallite size decreases, if the influence of associated components on the degree of disorder of clay minerals (as presented for kaolinite by Galan *et al*., 1994) is eliminated by adequate sample preparation. The interpretation of distribution and the shapes of crystallite thicknesses, measured by the Bertaut-Warren-Averbach (BWA) method, can then be related to crystal-growth mechanisms according to the theoretical approach of Eberl *et al*. (1998a).

The BWA technique has been applied to the measurement of illite particle thickness (Eberl *et al*., 1998b), to measure the crystallite size distribution of kaolin minerals (Šucha *et al*, 1999), to explore crystal growth mechanisms for illite and smectite (Środoń *et al*., 2000; Mystkowski & Środoń, 2000), to study the diagenetic evolution of the crystallite thickness distribution of illitic material (Kotarba & Środoń, 2000), weathering processes which affected smectite and illite/smectite (Šucha *et al*., 2001), and crystallite-size changes of pyrophyllite during grinding (Uhlik *et al*., 2000). Eberl *et al*. (1998a) studied the growth mechanism of minerals based on the shapes of the crystal size distribution.

Different clay deposits in Serbia have been explored and studied for many decades (Simić, 2001, 2004; Simić & Jović, 1997; Radosavljević *et al*., 1994; Stangačilović, 1970a, 1970b), but the crystallite size of the clay minerals has never been determined.

The main goal of this study was to measure the thickness and thickness distribution of kaolinite and smectite crystallites by the BWA technique and to compare the results with those obtained for similar clays from Slovakia and some other world deposits, and to

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check if the mean crystallite size depends on the origin of the clay.

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Materials and methods

Twelve samples of kaolinites, halloysite, and smectites from selected deposits in Serbia were used for this study. The kaolinites were collected from the Vrbica (sample VRB), Ćirinac (CIR-Z), Lazine (L-1), and Košarno (KOS-5A) deposits (Aranđelovac basin), the Rudovci (RUD-3) deposit (Kolubara basin) and the Jasenovac coal mine, the halloysite was from the Novo Brdo deposit, and the smectites were from the bentonite deposits or occurrences Popovac (POP-1), Mečji Do (MD), Bogovina coal mine (BOG-I), Bivolica (BIV), and Drmno coal mine (D-3). These deposits were selected on the basis of their different clay minerals, genetic types and parent rocks.

Prior to analyses, < 2 mm fractions were separated from the bulk samples by sedimentation. Separated fine fractions were used for X-ray diffraction (XRD) analysis of oriented specimens. The oriented specimens were prepared by sedimentation of the clay suspension (10 mg/cm^2) onto glass slides. All specimens were analysed by XRD using a Philips PW 1710 diffractometer equipped with Cu radiation with a graphite monochromator. The step size was 0.02° 2Θ with a counting time of 5s for the oriented specimens.

The resulting basal reflections of the clay minerals were used for the determination of the mean crystallite thickness (crystallite = X-ray scattering domain) and thickness distribution by means of the BWA techniques (DRITS *et al.*, 1998) using the MudMaster program (EBERL *et al.*, 1996). The XRD method of crystallite size determination is based on the observation that XRD peaks broaden regularly as a function of decreasing crystallite size. The first basal reflection of all samples was subjected to BWA analysis in the recommended two theta intervals between 6 and 13° for the kaolinite (Fig. 1) and 2.5 to 7.5, for the smectites. All kaolinite samples, except the halloysite sample NB, contain illite in the clay fraction. Therefore, the illite peaks were chopped by the program PkChopr (Fig. 2). A longer XRD exposition time (5 s) was used to obtasin smooth XRD patterns for the analysis.

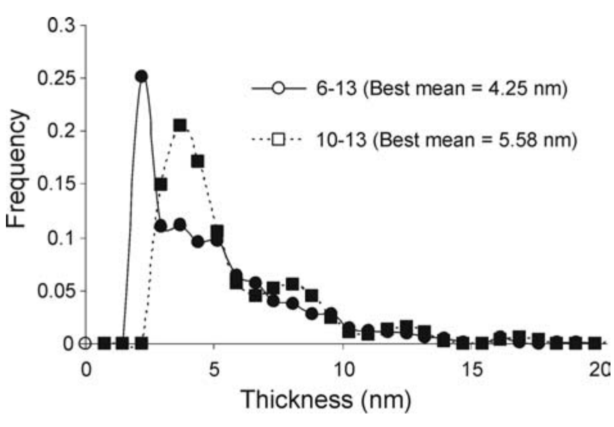

Fig. 1. Changes in the distribution and mean thickness of halloysite (sample NB) after using the incorrect analysed area (10–13° 2θ) in comparison with the recommended area (6–13° 2θ).

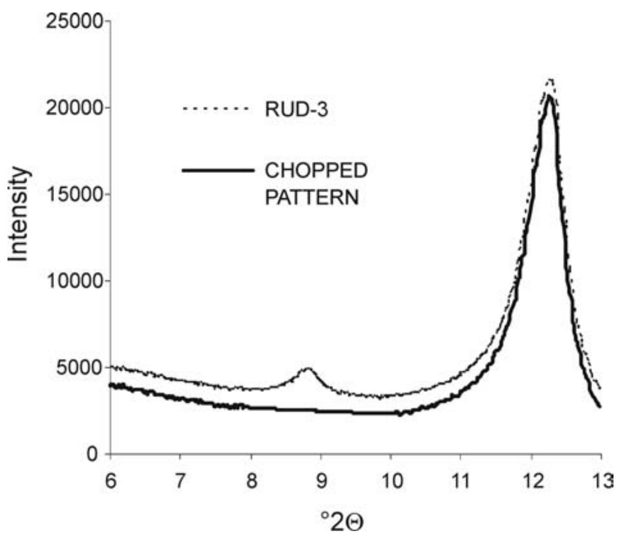

Fig. 2. Example of the modification of an XRD pattern before BWA-analysis the by PkChopr program.

Scanning electron images were taken from fresh rock chips coated with gold using a Jeol JXA 840 scanning electron microscope (SEM).

Geological features of the studied deposits

Samples of 6 kaolinites, 1 halloysite and 5 smectites from deposits in three different geological environments and origin were used for this study. Kaolinites and smectites from sedimentary (originating in a weathering crust and transported into sedimentary basins), volcano-sedimentary (formed by diagenesis of volcanic ash in a subaqual and subarial environment) and of hydrothermal origin were studied. The geological setting of each sample is indicated in Table 1. The analysed samples represent a selected collection of kaolinitic clays and bentonites from the economically most important deposits in Serbia, one sample of halloysite and one sample of Miocene tonstein, recently discovered in eastern Serbia.

Table 1. Basic geological features of the studied clays.

Sample	Genetic type	Age	Clay mineral	Basin	Deposit
Kaolinite					
VRB	Sedimentary	Miocene	Kaolinite	Aranđelovac	Vrbica
CIR-Z	Sedimentary		Kaolinite		Ćirinac
L-1	Sedimentary		Kaolinite		Lazine
KOS-5	Sedimentary		Kaolinite		Košarno
RUD-3	Sedimentary	Pontian	Kaolinite	Kolubara	Rudovci
JAS-5A	Volcano-sedimentary	Miocene	Kaolinite	Krepoljin	Jasenovac
Halloysite					
NB	Hydrothermal	Oligocene-Miocene	Halloysite (7Å)		Novo Brdo
Smectite					
POP-1	Volcano-sedimentary	Lower Miocene	Smectite	Paraćin	Popovac
MD	Volcano-sedimentary	Lower Miocene	Smectite	Zaplanje	Mečji Do
BOG-1	Sedimentary (?)	Miocene	Smectite	Bogovina	Bogovina
BIV	Sedimentary (?)	Lower Miocene	Smectite	Svrljig	Bivolica
D-3	Sedimentary	Pontian	Smectite	Kostolac	Drmno

The sedimentary kaolinitic clays were deposited in different basins, but in similar lacustrine settings. The kaolinitic clays from the Aranđelovac basin (Vrbica, Ćirinac, Lazine, and Košarno deposits) were formed by weathering and redeposition of materials from Bukulja granite (Simić, 2004). Kaolinite is the dominant clay mineral, with small amounts of illite. The clay from the Košarno deposit also has subordinate smectite. The parent rocks for the clays from the Rudovci deposit (Kolubara basin) are dacitic rocks and their pyroclastics. Kaolinite is also the most abundant mineral, accompanied by small amounts of smectite and traces of illite (Simić, 2004). The length of transport in both the Aranđelovac and Kolubara basins ranged from several hundred meters to 2–3 km, hence crystal disintegration during transport may have some influence on the crystallite size and thickness. Halloysite from the Novo Brdo deposit is of hydrothermal origin (Maksimović & Nikolić, 1978). The kaolinitic clay from the Jasenovac coal mine is a typical tonstein, formed by the diagenetic alteration of volcanic tuff (Životić & Simić, 2003, unpublished report).

The smectite samples are also of different origin. Both Popovac bentonites, interbedded in marlstone in the quarry near the Paraćin Town and the Mečji Do deposit near the Vlasotince Town, are typical volcano-sedimentary rocks formed as a result of “in situ” subaqual alteration of the volcanic tuff. The bentonites from the Bogovina coal mine (East field) and the Bivolica deposit, near the Svrljig Town, are most probably the products of reworking of the weathering crust of andesitic rocks. The bentonite from the Drmno deposit (Kostolac coal basin) is of sedimentary origin (Simić *et al*., 1997), but the primary source of clay minerals has not yet been established.

Results and discussion

Typical XRD patterns of each genetic type of clay are shown in Fig. 3, and the results of the BWA measurements of the kaolinite, halloysite and smectite samples in Table 2.

The T_{BWA} value of the sedimentary kaolinites studied varies between 5.55 and 7.91 nm, with an average value of 6.48 nm. The curves of all five samples are polymodal (Fig. 4), indicating that the samples consist of two or more generations of crystals with different thickness. The average T_{BWA} of the Serbian sedimentary kaolinites is slightly higher than the T_{BWA} of Slovakian sedimentary kaolinites, but, at the same time, significantly smaller than the T_{BWA} of selected world kaolinites (Table 3).

The BWA measurements confirmed the previously obtained geological, mineralogical and geochemical data that the weathering conditions during the Upper Oligocene–Lower Miocene did not lead to the origin of a well-developed kaolinitic weathering crust, neither in Serbia (Maksimović & Nikolić, 1978; Simić, 2004), nor in Slovakia (Kraus, 1989).

The halloysite sample of hydrothermal origin has a rather small mean crystallite thickness of 4.25 nm and a polymodal distribution pattern (Fig. 4). The T_{BWA} values of the Serbian and Slovakian halloysites are very similar, indicating a similar stage of hydrothermal alteration of the primary rocks. The distribution shapes of

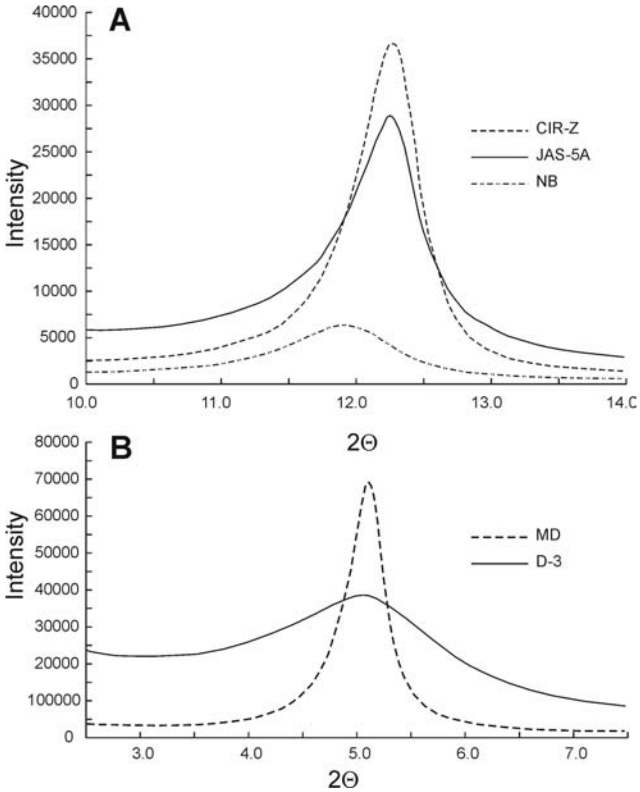

Fig. 3. Typical XRD patterns of the studied samples. A) Sedimentary kaolinite (CIR-Z), volcano-sedimentary kaolinite (JAS-5A), and hydrothermal halloysite (NB). B) Volcano-sedimentary smectite (MD), and sedimentary smectite (D-3).

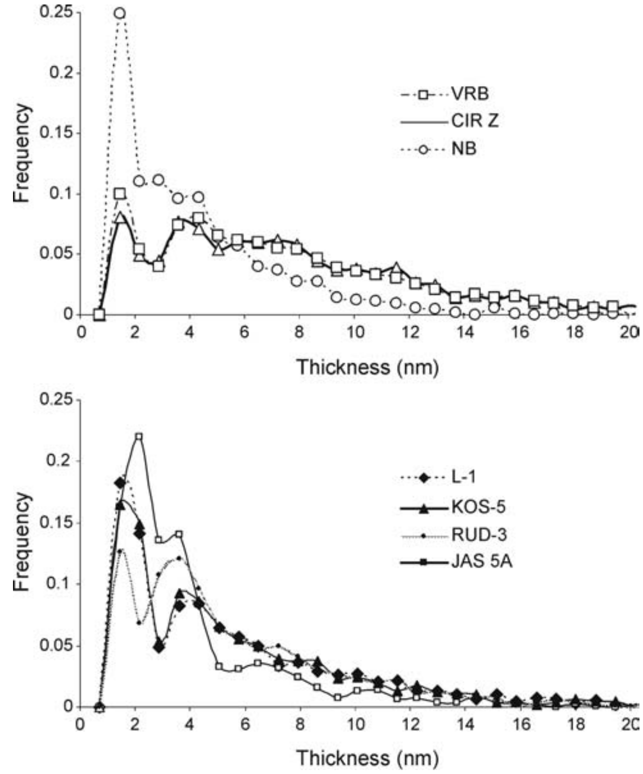

Fig. 4. Crystallite size distribution of kaolinites obtained by the BWA technique.

Table 2. List of clays used for BWA-analysis and the input and output data.

Sample	Genetic type	Position of peak maximum (θ)	d-spacing (Å)	Analysed area (θ)	Best mean (nm; extrapolated; area-weighted)
Kaolinite					
VRB	Sedimentary	12.27	7.21	6–13	7.53
CIR-Z	Sedimentary	12.29	7.20	6–13	7.91
L-1	Sedimentary	12.21	7.24	6–13	5.64
KOS-5	Sedimentary	12.30	7.19	6–13	5.55
RUD-3	Sedimentary	12.25	7.22	6–13	5.75
JAS-5A	Volcano-sedimentary	12.28	7.20	6–13	4.32
Halloysite					
NB	Hydrothermal	11.89	7.44	6–13	4.25
Smectite					
POP-1	Volcano-sedimentary	5.14	17.18	2.5–6	9.00
MD	Volcano-sedimentary	5.11	17.29	2.5–6	10.12
BOG-1	Sedimentary (?)	5.15	17.15	2.5–5.36	5.67
BIV	Sedimentary (?)	5.13	17.20	2.5–5.32	5.79
D-3	Sedimentary	5.07	17.41	2.5–4.88	5.21

Table 3. Average mean crystallite thickness (T_{BWA}) of Serbian, Slovakian and selected world kaolinites and halloysites. Values for the Slovakian and selected world kaolinites are from ŠUCHA *et al*. (1999).

Country	Genetic type	Average T_{BWA} (nm)
Kaolinites		
Serbia	Sedimantary	6.48
Slovakia	Sedimantary	4.81
World (selected)	Sedimantary	13.83
Serbia	Volcano-sedimantary	4.32
Halloysites		
Serbia	Hydrothermal	4.25
Slovakia	Hydrothermal	3.50

lognormal (Fig. 4). The tonstein from the Jasenovac mine is generally weakly crystallized according to the XRD (Fig. 5) and at least two generations of kaolinitic minerals can be observed on the SEM image (Fig. 6), confirming the polymodal distribution shape.

The smectites from the volcano-sedimentary type have higher mean crystallite thickness with an average value of 9.56 nm than the smectites from the sedimentary bentonites with an average value of 5.56 nm. The crystallite size distributions for the volcano-sedimentary samples are lognormal (Fig. 7). Their shapes are quite different from the sedimentary types. The volcano-sedimentary smectites have identical distribution shapes with a theoretical lognormal distribution (Fig. 8A). The distribution of smectites from the sedimentary bentonites is different from the theoretical lognormal shape (Fig. 8B).

The mean thickness of smectites from selected world volcano-sedimentary bentonites varies from 6 to 9 nm (MYSTKOWSKI & ŚRODOŃ, 2000; MOL, 2001). The relatively wide range of T_{BWA} values of volcano-sedimentary smectites does not support the idea of using it to

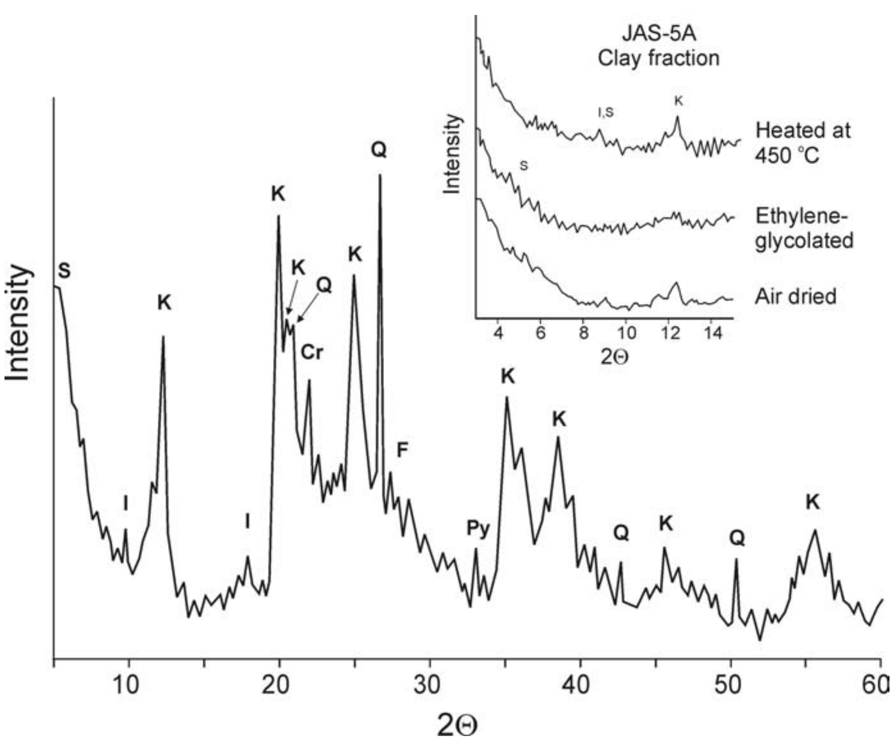

Fig. 5. XRD pattern of the kaolinite sample JAS-5A.
K – kaolinite,
S – smectite,
I – illite,
Q – quartz,
Cr – crystobalite,
F – feldspar,
Py – pyrite.

these two hydrothermal halloysites are different, as the Slovakian sample has an asymptotic shape and the Novo Brdo halloysite a polymodal one. The polymodal distribution of the Novo Brdo halloysite seems to be a combination of one lognormal and one asymptotic distribution. The asymptotic distribution is typical for samples with small T_{BWA} and could be characteristic for early stages of formation (EBERL *et al*., 1998a).

The tonstein sample of volcano-sedimentary origin also has a small mean crystallite thickness of 4.32 nm with a polymodal distribution pattern, but similar to distinguish the origin in general. However, the measurement of T_{BWA} has sense for the differentiation of the origin of a bentonite in smaller regions, as was observed for the Serbian bentonites. A similar difference was found for in situ volcano-sedimentary and transposed bentonites from middle Slovakia (both types were characterized by ŠUCHA *et al*., 1996). Smectites originating from the in situ alteration of andesitic volcanoclastics have higher T_{BWA} values (up to 7 nm) in comparison with smectites originating by the redeposition of alteration products (5.5 nm).

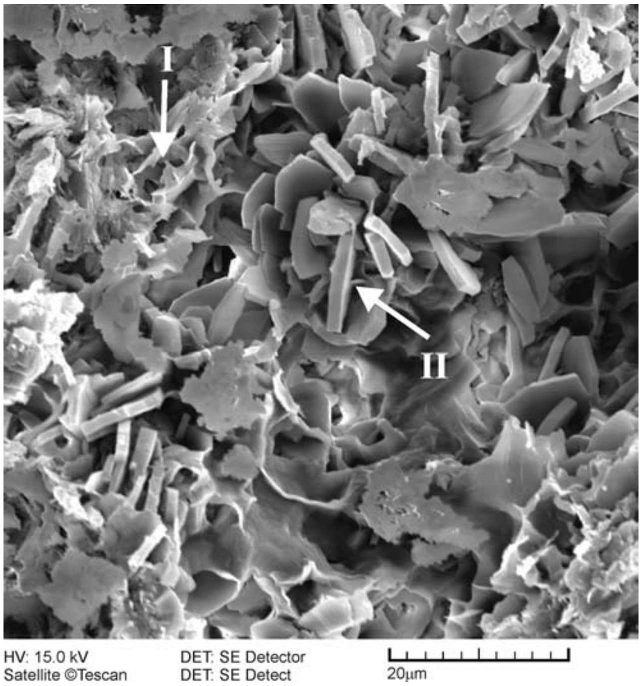

Fig. 6. SEM image of the kaolinite sample JAS-5A, showing two different particle generations (I, II).

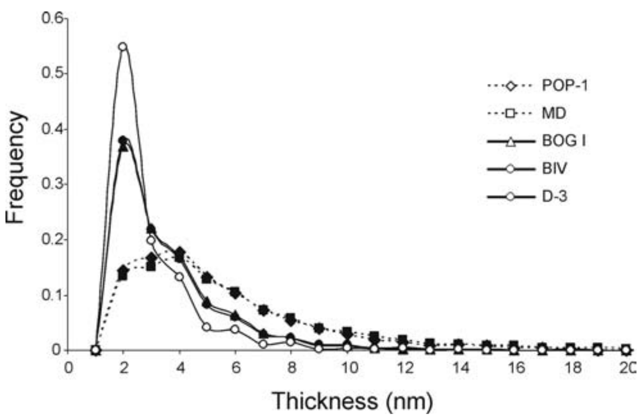

Fig. 7. Crystallite size distribution of the smectites obtained by the BWA technique.

Conclusions

Sedimentary kaolinites from five deposits in Serbia have a low mean crystallite thickness indicating a poorly developed kaolinitic weathering crust from which these clays were redeposited, a situation similar to Slovak kaolin deposits. The role of crystal disintegration during transport may also influence the crystallite size. The shape of the crystal size distribution is polymodal for all samples, most probably as a result of the presence of different kaolinite generations.

Volcano-sedimentary (diagenetic) tonstein from the Jasenovac coal mine has a very low mean crystallite thickness, typical for a weakly crystallized material, and a polymodal distribution shape, due to at least two generations of kaolinite particles.

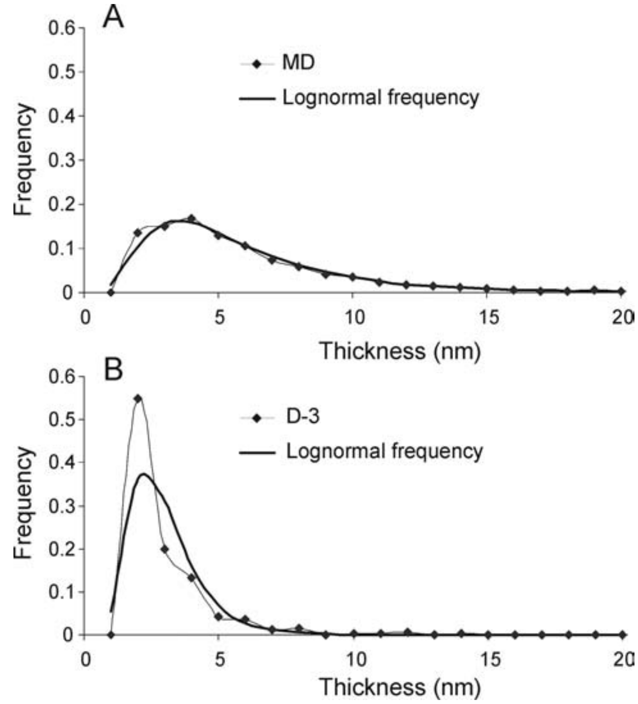

Fig. 8. Comparison of the measured (BWA) and the theoretical lognormal distributions of smectite particles. A) volcano-sedimentary type, B) sedimentary type.

Hydrothermal Novo Brdo halloysite also has a very low mean crystallite thickness and a polymodal distribution.

Two diverse shapes of the theoretically lognormal distributions were observed for the smectites. They correspond to different genetic types of bentonites – sedimentary and volcano-sedimentary. The mean crystallite thickness is also different in the sedimentary and volcano-sedimentary bentonites, with an average T_{BWA} of 5.56 and 9.56 nm, respectively. This means that “in situ” alteration of volcanic ash under subaqual conditions led to the formation of well-crystallised smectite with thicker crystallites.

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Резиме

Дистрибуција дебљине кристалита минерала глина из изабраних лежишта глина Србије

У овом раду измерене су дебљине кристалита каолинита и смектита и њихова дистрибуција методом BWA на узорцима из лежишта у Србији. Након извршених проучавања направљена је компарација са сличним глинама из Словачке и из неких светских лежишта.

Репрезентативни узорци 6 каолинитских глина, једног халојзита и 5 бентонита из лежишта ствараних у различитим геолошким условима: седиментним лежиштима глина (створених у корама распадања а затим транспортована у седиментне басене), вулканогено-седиментним лежиштима (насталим дијагенезом вулканског пепела у подводним или приповршинским условима) и хидротермалним лежиштима. Генетски тип лежишта и основне геолошке информације приказане су у табели 1.

Седиментни каолинити из пет проучаваних лежишта Србије одликују се малом дебљином кристалита, што указује на слабо развијен тип кора распадања из којих су ти минерали глина преталожени, као и на утицај уситњавања честица приликом транспорта. Таква ситуација је веома слична као код лежишта каолина у Словачкој. Облик криве расподеле дебљине кристалита је код свих узорака полимодални, највероватније као последица присуства различитих генерација каолинита.

Вулканогено-седиментни (дијагенетски) тонштајн из лежишта угља Јасеновац показује веома малу дебљину кристалита, типичну за слабо искристали-

сали материјал, и полимодални облик дистрибуције захваљујући присуству најмање две генерације каолинитских честица.

Хидротермални халојзит из лежишта Ново Брдо такође се одликује веома малом дебљином кристалита и полимодалним обликом расподеле.

Код испитиваних бентонита утврђено је присуство два различита типа теоретски логнормалне расподеле дебљине кристалита, које одговарају различитим генетским типовима бентонита – седиментном и вулканогено-седиментном. Средња дебљина кристалита је такође различита код седиментних и вулканогено-седиментних бентонита, са просечним T_{BWA} од 5,56 и 9,56 nm.

ГЕОЛОШКИ АНАЛИ БАЛКАНСКОГА ПОЛУОСТРВА ANNALES GÉOLOGIQUES DE LA PÉNINSULE BALKANIQUE	67	117–122	БЕОГРАД, децембар 2006 BELGRADE, December 2006

IN MEMORIAM

Проф. др Предраг Николић
(1928 – 2005)

Прошле године преминуо је Предраг Николић, доктор геолошких наука, редовни професор у пензији, дугогодишњи Декан Рударско-металуршког факултета у Бору и Декан заједничког Рударско-геолошко-металуршког факултета Београд-Бор Универзитета у Београду.

То су само најосновнији подаци из блиставе каријере примерног човека, врхунског професора и научног радника, који је много тога оставио по чему ће га се сећати генерације студената, његови сарадници, колеге и пријатељи.

Немерљив је допринос Професора Николића за формирање Рударско-металуршког факултета у Бору и његов развој. Мање су познате и велике заслуге за развој Рударско-геолошког факултета у Београду на коме је Професор Николић провео другу половину своје каријере. По мишљењу многих колега био је један од најбољих, а можда и најбољи Председник Државне комисије за оверу минералних резерви. Поред тога Професор Николић нам оставља вредан научни опус од 146 објављених научних радова, 6 уџбеника и 4 монографије. Написано већ довољно говори о изузетној личности професора Николића. Простор нам не дозвољава детаљан приказ животног пута и дела професора Николића па ће он бити скроман, управо онакав какав је био профеоср.

Професор Николић је рођен 31. јануара 1928. године у Горњем Дреновцу код Прокупља, где је завршио гимназију. На геолошко-палеонтолошкој групи Природно-математичког факултета Универзитета у Београду дипломирао је 1952. године, а докторирао 1962. године. Радну каријеру је почео 1953. године као руднички геолог и руководилац геолошко-рударских истраживања у руднику угља "Добра срећа" код Књажевца, затим у рудницима ватросталних глина – Аранђеловац и књажевачким, односно тимочким рудницима угља "Књажевац". Од 1962. године ради на Рударско-металуршком факултету у Бору као наставник, и то најпре као доцент, затим као ванредни професор и од 1969. године као редовни професор. Од 1980. године је у радном односу на Рударско-геолошком факултету у Београду. Био је 11 година руководилац Рударско-металуршког факултета у Бору, напре као продекан, затим у континуитету као декан. Био је две године заменик декана јединственог Рударско-геолошко-металуршког факултета Београд-Бор и две године декан истог факултета. Остаће упамћен и његов рад као Председника одбора за "Геонауке" у Министарству за науку и технологију Републике Србије. Био је дугогодишњи Главни и Одговорни уредник научног часописа Зборник радова Рударско-металуршког факултета и Института за бакар у Бору. Руководио је и Одбором за високо школство у Заједници усмереног образовања и био члан Председништва исте заједнице. За свој успешан рад стизала су и признања. Прво, 1967. године, Октобарска награда Града Бора, а затим 1977. године Орден рада са златним венцем.

Научни и стручни опус професора Николића је веома обиман и разноврстан па га није лако и једноставно приказати. У основи, био је геолог (стратиграф, тектоничар), али је врхунске резултате остварио и у домену истраживања лежишта минералних сировина, посебно угљева. Слободни смо да кажемо, ако је прва геолошка љубав професора Николића била Тимочка зона, онда је друга љубав угаљ.

Незаобилазан је и велики допринос професора Николића за сагледавање геолошке грађе и тектонског склопа, али и природне потенцијалности наших Карпато-балканида. Посебно се то односи на једну од најинтересантнијих и најсложенијих геолошких јединица у литератури познатој као Тимочка зона. Почев од докторске дисертације у којој је на оригиналан начин приказао стратиграфске односе, посебно горњокредних и палеогених творевина, затим тектонски склоп и магматизам једног дела ове зоне. Потом, следе десетине радова у којима професор Николић шири своја истраживања на целу зону. На крају, све то обједињује у једну врхунску монографију "Тимочка зона Источне Србије – геологија и минералне сировине". Довољно је само набројати поглавља из ове изузетне монографије па да се сагледа њена свеобухватност и значај. У првом поглављу је детаљан приказ стратиграфије, структурних односа и тектонике, као и критички осврт на досадашња истраживања ове зоне. Друго поглавље обрађује лежишта угља и уљних шкриљаца у јужном делу ове зоне, детаљно по локалитетима – рудницима. Приказ обухвата од геологије до резерви. У трећем поглављу детаљно су обрађена лежишта бакра у северном делу Тимочке зоне. Бројни су радови у којима је обрађивао лежишта угљева у Источној Србији. Довољно је поменути Влашко поље, Добра срећа, Подвис, Лубница, Звездан др. Као врхунски истраживач, сва своја, и истраживања својих сарадника, обједињује у три вредне монографије о угљевима. Професор Николић је један од најзаслужнијих аутора за објављивање дванаестотомене едиције "Геологија Србије" и десетотомног енциклопедијског речника "Геолошка терминологија и номенклатура".

Посебно издвајамо као непревазиђен монографски рад "Тектоника Карпато-балканида Србије", који је професор Николић објавио заједно са својим, по нашем мишљењу, најближим колегом и пријатељем, покојним професором Милодрагом Анђелковићем. Реч је о најдетаљнијем приказу стратиграфије и тектонике наших Карпато-балканида. То је незаобилазна литература за наше, али и и за геологе суседних земаља.

Научни опус професора Николића повезује једна лепа и вредна дивљењу научна нит. Основне проблеме које је у почетку своје каријере почео да ради, после вишегодишњих истраживања је обједињавао и сублимирао у монографијама.

Наставни рад за професора Николића био је светиња. Наставник је дужан да обезбеди уџбеничку литературу – био је његов став. Имао је неколико издања универзитетског уџбеника Основи геологије и Опште геологије и први уџбеник на нашем језику из Геотектонике.

Све то говори да је професора Николића одликовала огромна енергија, вредноћа, упорност, креативност и систематичност, па ето одговора за сјајну професорску, научно-истраживачу и људску каријеру.

Нама који смо имали привилегију да са њим пијемо кафу, а понекад и нешто жешће, и причамо не само о геологији, ово написано није потребно, оно је уписано у нама, али ради млађих и оних који долазе, ради Рударско-геолошког факултета и српске геологије име професора Предрага Николића треба да буде уписано крупним – најкрупнијим словима.

Проф. др Јован Јанкичевић
Проф. др Драгоман Рабреновић

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BOOK REVIEW:

Mittelmiozäne Ostracoden aus dem Wiener Becken (Badenium/Sarmatium, Österreich)

[Middle Miocene Ostracods from the Vienna Basin (Badenian/Sarmatian, Austria)]

by MARTIN GROSS

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This book is a typical paleontological work concerning the Middle Miocene ostracodes from the Vienna Basin and their taxonomy and biostratigraphy. It consists of the following chapters: (1) Introduction, (2) Regional Geology, (3) Material and Sample Preparation, (4) Systematic part, (5) Biostratigraphy and (6) References. Technically, it is a correctly prepared book and illustrated with very high quality figures (6), tables (4) and plates (55).

All the samples originate from the area of Bad Deutsch Altenburg – Hainburg/Donau (eastern margin of the Vienna Basin, 40 km ESE from Vienna). 64 taxa (species) are described and illustrated on 55 plates with 591 SEM-microphotographs. It represents 37 genera and 15 families of the Order Podocopida. Very good quality, high-resolution SEM pictures document the intraspecific variability, juvenile forms and sexual dimorphism of these species as well as the carapace/valve ornamentation.

The terms and morphological features of the ostracodes use here are based on MOORE (1961), MORKHOVEN (1962), HARTMANN (1966), OERTLI (1985) and HINZ-SCHALLREUTER & SCHALLREUTER (1999). Paleoenvironmental and paleobatimetric interpretations were made on the basis of criteria by MORKHOVEN (1963), HARTMANN (1975), LIEBAU (1980), GRAMANN (2000) and MEISCH (2000). The systematic part was based on LIEBAU (1975) and MADDOCKS & STEINER (1987), as well as HARTMANN & PURI (1974) and MEISCH (2000).

Based on this study, the author demonstrates that some earlier known ostracodes have a wider stratigraphic range (for example, *Callistocythere postvallata* and *Hemicytheria omphaloedes*). Likewise, *Aurila hispidula*, *Xestoleberis tumida* and *Tenedocythere sulcatopunctata* were discovered for the first time from the Lower Sarmatian.

From the (paleo)ecological point of view, the ostracodes association are grouped into four taphocoenosis and the first three correspond to epineritic, epineritic/phytal taphocoenosis and the last one to epi/mesoneritic taphocoenosis.

In comparison to the foraminifer fauna, most of the ostracod samples (59) belong to the Upper Badenian and only 7 samples are assigned to the Lower Sarmatian. In the chapter of Biostratigraphy (5), one comparative biostratigraphical review of the Middle Miocene (Badenian and Sarmatian) of Central Paratethys is given based on the ostracodes and foraminifers biozonation (after JIRICEK & RIHA, 1991; ZELENKA, 1990). The author distinguished eight ostracod biozones (NO 7 – NO 14), which correspond to the six-foraminifer biozones. This study of ostracodes is complementary to the early-adopted model of ostracod development in the Vienna Basin.

Finally, the very detailed and wide-ranging list of references (341) shows that the author employed both classic papers (MUENSTER, 1830; ROEMER, 1838; REUSS, 1850; BOSQUET, 1852, etc.) as well as modern literature.

At the end of this review, a few important remarks can be given:

This book represents an important contribution to study of ostracodes of the Middle Miocene of the Vienna Basin, as well as of the Central (Western) Paratethys area. It is a very high quality, distinct article, both professionally and technically, with numerous SEM-microphotographs which give this book a high professional level. Eventually, some paleo(environmental) interpretations and conclusions are discussed. The absolutely competent approach to the research of fossil ostracodes, as well as the results given here, make this monograph a new upgrades for future taxonomic and biostratigraphic studies of the Middle Miocene of Paratethys.

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AGER, D.V., 1963. *Principles of Paleoecology*. McGraw-Hill, New York, 318 pp.

OWEN, E.F., 1962. The brachiopod genus *Cyclothyris*. *Bulletin of the British Museum (Natural History), Geology*, 7 (2): 2–63.

RABRENOVIĆ, D. & JANKIČEVIĆ, J., 1984. Contribution to the study of Albian near Topola. *Geološki anali Balkanskoga poluostrva*, 48: 69–74 (in Serbian, English summary).

SMIRNOVA, T.N., 1960. About a new subfamily of the Lower Cretaceous dallinoid. *Paleontologicheskij Zhurnal*, 2: 116–120 (in Russian).

SULSER, H., 1996. Notes on the taxonomy of Mesozoic Rhynchonellida. *In*: COOPER, P. & JIN, J. (eds.), *Brachiopods*, 265–268. Balkema Press, Rotterdam.

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A **summary** (up to 15% of the paper) is published in Serbian and should contain the essence of all new data and the conclusions.

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ГЕОЛОШКИ АНАЛИ БАЛКАНСКОГА ПОЛУОСТРВА
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