SARMATIAN PALEOENVIRONMENT AND BIOEVENTS IN THE DOBROGEA REGION (SE ROMANIA)

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Abstract. This paper presents investigation carried out on two sections containing successions of the middle Sarmatian *s.l.* (Bessarabian) and upper Sarmatian *s.l.* (Khersonian). Both substages are mainly characterized, from lithological point of view, by the presence of chalky limestones, argillaceous limestones, oolithic limestones and coquinas. The boundary between the two substages is marked by coquinas mainly containing small-sized specimens of the bivalve *Cardium* spp. The upper Bessarabian is characterized by the *Plicatiforma fittoni* bivalve zone, while in the Khersonian substage the *Mactra caspia* bivalve zone, followed by *Mactra bulgarica* biozones are present. The Techirghiol section contains no calcareous nannofossils, while in the Limanu section a few specimens assigned to the genus *Noelaerhabdus* were discovered in the upper Bessarabian. This finding indicates a possible connection of the South Dobrogea (part of the Euxinian-Caspian domain) with the Central Paratethys, during the middle Sarmatian *s.l.* (Bessarabian).

Key words: Middle Miocene, Euxinian-Caspian domain, lithology, macrofaunas, calcareous nannoplankton.

1. INTRODUCTION

During the Paleogene, the tectonic movements of the Alpine chain led to the separation of the Tethyan Realm into two domains, *i.e.* the Mediterranean and the Paratethyan realms. These newly established domains periodically disconnected and reconnected since the Oligocene (Papp *et al.*, 1974; Rögl, 1998, 1999; Steininger & Wessely, 2000; Popov *et al.*, 2004, Piller *et al.*, 2007).

The regional Middle Miocene stage Sarmatian encloses significant paleogeographic and paleobiotic changes, being also one of the most debated stratigraphically units of the Paratethys. The Sarmatian term was coined by Suess (1866), who used it for the designation of Sarmatian Stage in the Vienna Basin. Later, scientists have agreed that the initial definition of the Sarmatian stage encloses different stratigraphic intervals in the Central European regions and, respectively in the Eastern ones. At the beginning of the 20th Century, the Sarmatian was divided by Simionescu (1903) into three substages (oldest first), such as the Volhynian, Bessarabian and Khersonian. In the Central Paratethys, following the concept of Suess (1866), the stage of the Sarmatian *senso stricto* (*s.s.*), stratigraphically placed between the Badenian and the Pannonian stages, comprises two substages, the Volhynian and the lower part of the Bessarabian (Papp *et al.*, 1974; Piller *et al.*, 2007) spanning an interval of 1.1 Ma between 12.7 Ma and 11.6 Ma, which corresponds to the late Serravallian, in term of global stages (Harzhauser & Piller, 2004; Piller & Hartzhauser, 2005).

The Paratethys divided in several domains such as the Central Paratethys, the Eastern Paratethys and the Euxinian-Caspian one (Papp *et al.*, 1974; Popov *et al.*, 2004; Piller *et al.*, 2007), as a consequence of the major tectonic uplift of the Carpathians (Maţenco *et al.*, 2003) during the late Sarmatian *senso lato* (*s.l.*). The latter two above-mentioned domains largely communicated, while the circulation pattern with the Euxinian-Caspian realm was mostly restricted (Popov *et al.*, 2004). Different paleobiotic evolution of the aforementioned domains has led to the occurrence of the endemic taxa (synthesis of data in Papp *et al.*, 1974). Hence, in the Central Paratethys, the stage is referred as Sarmatian *s.s.*, while in the Eastern Paratethys, as in the Euxinian-Caspian domain, the Sarmatian *s.l.* is in use. The three substages, Volhynian, Bessarabian and Khersonian of the Sarmatian *s.l.* correspond to three development intervals of the endemic macrofaunas (Sinzov, 1883; Cobălcescu, 1883; Ionesi & Ionesi, 1973; Neveskaia *et al.*, 1986; Papaianopol, 1997, Ionesi *et al.*, 2005 among many others). Additionally, Laskarev (1903) identified in the Buglovka River basin (Podolia), based on macrofaunas, a depositional interval that comprises the transition between the marine setting of the Badenian upper part and the progressively shift towards brackish one within the Sarmatian. This depositional interval was described by the above-mentioned author as 'The Buglovian Strata', from which derived the stage Buglovian. This stage was largely used in the extra-Carpathians areas of Romania, ex. in the Moldavian Platform (Atanasiu, 1945; Ionesi, 1968; Macarovici *et al.*, 1970; Ionesi *et al.*, 2005). A transition interval between the Badenian and Sarmatian stages, with mixed marine and brackish faunas was recently reported from outcrops and drillings in Romania (Moldavian Platform) and Republic of Moldavia (Dumitriu *et al.*, 2017).

During the Sarmatian, the territory of Romania was situated in distinct Paratethyan domains: (i) the Central Paratethys, including the intra-Carpathian areas, such as the Transylvanian region, (ii) the Eastern Paratethys, which encloses the extra-Carpathian regions, described under the name of the Dacian Basin, and (iii) the Euxinian-Caspian Basin (Andrusov, 1917; Marinescu, 1978; Popov *et al.*, 2004; Brânzilă & Chira, 2005; Jipa & Olariu, 2009, 2013).

In the Romanian Eastern Paratethyan domain, *i.e.* the Dacian Basin, the top of the Sarmatian was placed, based on paleomagnetic data of various sections located in the Eastern Carpathian Foredeep, between 9.02 Ma and 8.07 Ma (Vasiliev *et al.*, 2004). Recently, Andreescu (2008) showed, based on paleomagnetic data, that in the Dacian Basin the Sarmatian stage is comprised between 13.65 Ma (the base of the stage, i.e., the Badenian-Sarmatian boundary) and 8.06 Ma, the top of the stage, i.e. the Sarmatian-Maeotian boundary (Fig. 1).

Recently, Palcu *et al.* (2015) indicated that in the Carpathian Foredeep basin of Romania the BSEE (Badenian-Sarmatian Extinction event) that took place within the Badenian-Sarmatian boundary interval is situated at 12.65 Ma. They conclude that the extinction event took place in less than 10 kyr, being probably synchronous across the Central Paratethys.

Good outcrops of the Sarmatian have been described from the southern extremity of the Romanian Dobrogea region (Atanasiu, 1940; Chiriac, 1960; Chiriac, 1967; Ionesi & Ionesi, 1971), placed during those times in the western part of the Paratethyan Euxinian Domain. The aim of this paper is to characterize from litho- and biostratigraphic points of view the Sarmatian successions of the aforementioned region. A comparison with similar exposures situated in N Bulgaria and comprises in the same domain, *i.e.* the Euxinian one, is also presented herein.

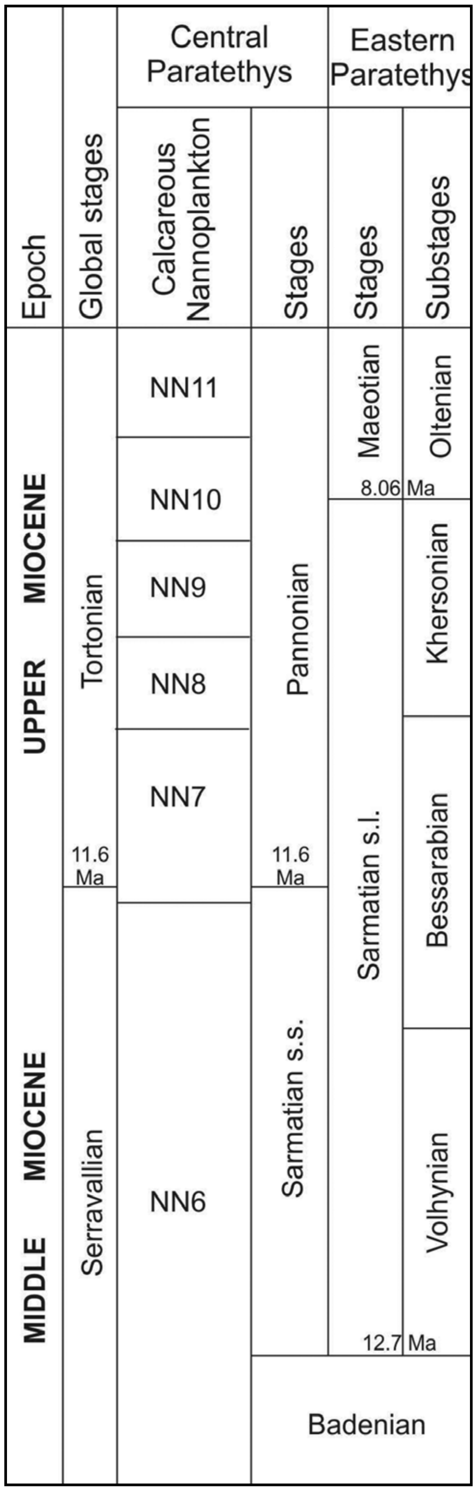

Fig. 1. Correlation of global Middle Miocene stages with the Central Paratethyan and Eastern Paratethyan stages and calcareous nannoplankton zones, after Hartzhauser & Piller, 2004 and Piller *et al.* 2007; the base of the Sarmatian *s.l.* and the base of the Sarmatian *s.s.* after Piller & Hartzhauser (2005); the top of the Sarmatian *s.l.* after Andreescu (2008).

2. GEOLOGICAL SETTING

During the Sarmatian, the SE extremity of the present-day Romanian territory was placed in the western part of the Euxinian-Caspian basin (Laskarev, 1924; Popov *et al.*, 2004). The Sarmatian deposits of the South Dobrogea, tectonically included in the eastern Moesian Platform, extend south from the Capidava-Ovidiu Fault (Fig. 2). The Sarmatian transgressively covers Lower Cretaceous sediments (Barremian to Albian), Upper Cretaceous deposits, as well as Paleogene ones, *i.e.* Eocene and Miocene (Chiriac, 1960; Ianovici *et al.*, 1961).

Lithologically, the Sarmatian of the South Dobrogea is mainly characterized by the deposition of sands, rudites, organogenic limestones, oolitic limestones, clays and marls (Macarovici, 1957; Chiriac, 1960; Ionesi & Ionesi, 1971 and 1973). The macrofaunal (mainly bivalve) assemblages of the study area (Papaianopol, 1997) are indicative of an emerged land during the lower Sarmatian (Volhynian). Within the boundary interval between the lower Sarmatian and the middle Sarmatian, i.e. between the Volhynian and Bessarabian substages, the paleoenvironment changed; a shallow semi-enclosed sea with brackish faunas covered the Dobro-

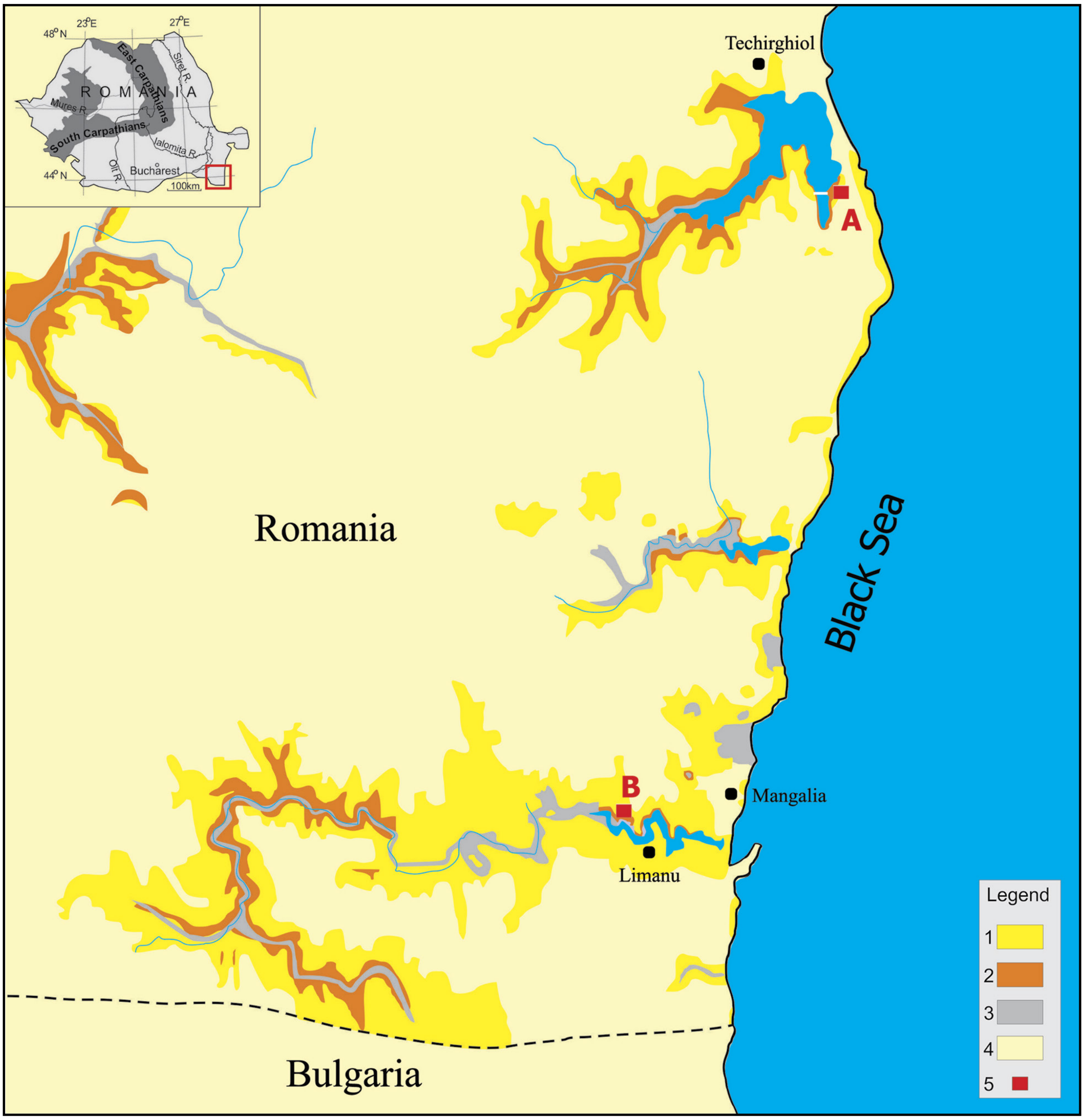

Fig. 2. (**1**) Location of studied area in the SE Romanian territory; (**2**) Occurrence of the Sarmatian deposits in the South Dobrogea (modified after Chiriac, 1967) and location of the investigated outcrops. **Legend**: 1- upper Sarmatian (Khersonian); 2 - middle Sarmatian (Bessarabian); 3 - Pleistocene; 4 - Holocene; 5 - Studied sections; A - Techirghiol section; B - Limanu section (Stănescu & Brustur, 2018).

gea region (Tătărîm *et al.*, 1977; Ion *et al.*, 2001), characterized by temporary connections with open marine basins (Fig. 3). According to the above-mentioned authors, the brackish paleosetting progressively shifted to a continental-lacustrine one in the late Sarmatian.

3. MATERIAL AND METHODS

Two sections exposing Sarmatian sediments in the southern Dobrogea (Romania) are investigated. The northern studied section (latitude 44º01'24.1032" N and longitude 28º38'31.1424" E), is located on the SE bank of the Techirghiol Lake (Figs. 2 and 4), in the vicinity of the Techirghiol locality and nearby the Black Sea coast. The southern investigated section (latitude 43º48'56.1816" N and longitude 28º30'55.5660" E) is located on the NW bank of the Limanu Lake, in the vicinity of the Limanu locality (Figs. 2, 5 and 6).

The sections have been investigated from a lithological and a paleontological (macrofaunas and calcareous nannoplankton) points of view. Samples for calcareous nannoplankton analysis were collected at each 10 cm in both investigated outcrops. For preserving the original composition, smear-slides were prepared from the untreated material. A small amount of sediment was scraped onto a glass coverslip and diluted with distilled water. The suspension was smeared with a flat-sides toothpick along the coverslip that was fixed by using Norland Optical Adhesive. Examinations were carried out by using an Olympus LM (light microscope) at a magnification of x1600.

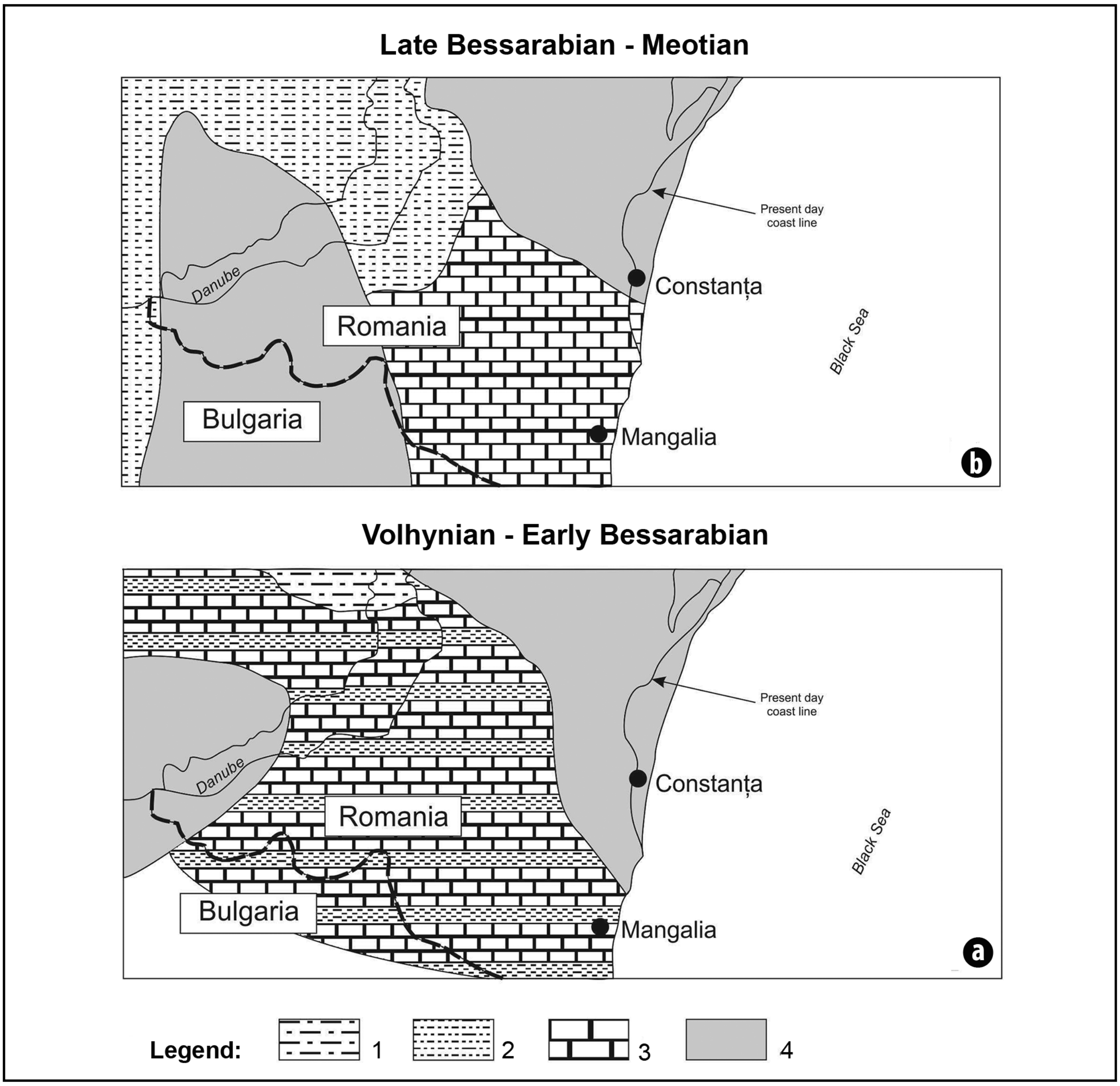

Fig. 3. Lithofacies maps of the Southern Dobrogea, SE Romania (modified after Ion *et al.*, 2011); (**a**) Volhynian-early Bessarabian; (**b**) late Bessarabian-Maeotian. **Legend**: 1 – siltstones; 2 - marls; 3 - limestones; 4 – emerged land.

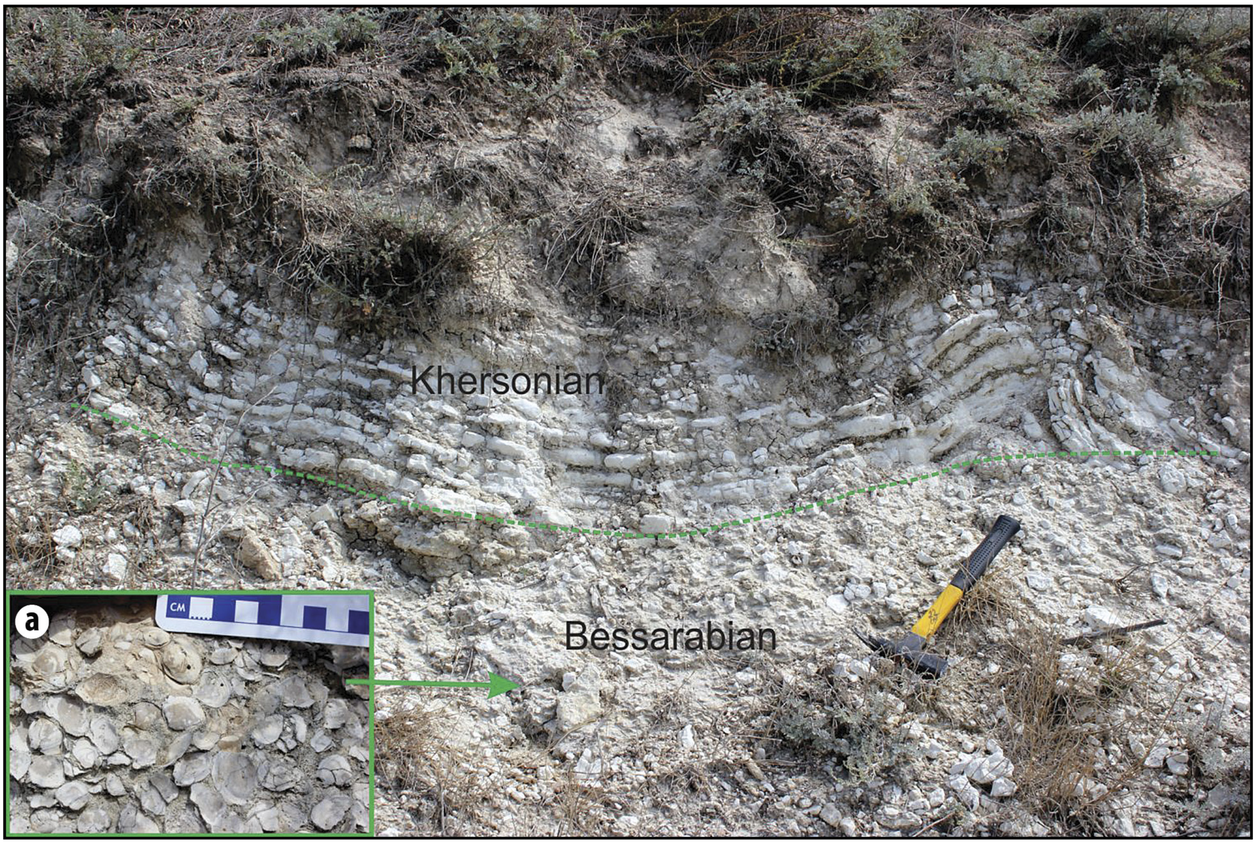

Fig. 4. The Techirghiol section that comprises upper Bassrabian oolithic limestones and coquinas in the lower part, and lower Khersonian chalky limestones at the upper part; A: Detail of the upper Bessarabian oldest part of the section containing coquinas, mainly constituted by *Obsoletiforma* spp (Stănescu & Brustur, 2018).

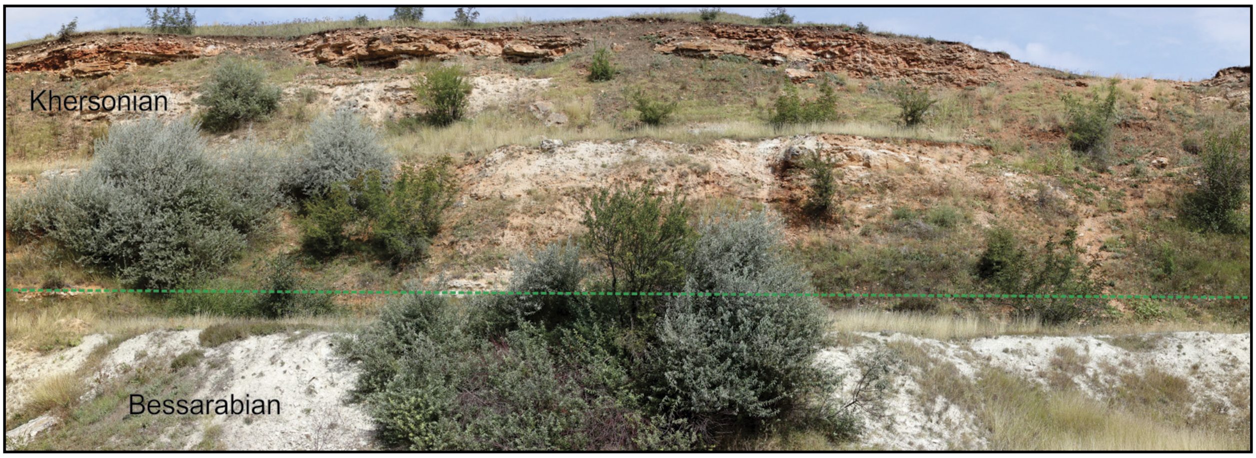

Fig. 5. Panoramic view of the Limanu section, showing the Bessarabian deposits with limestones and coquinas in the lower part and Khersonian limestones in the upper part.

4. RESULTS

4.1. Lithology

The Techirghiol section shows two distinct lithological units (Figs. 4 and 7): (i) The lowermost unit, 2.8 m thick, which consists of oolithic limestones, hard micritic limestones and coquinas; a 10 cm thick coquina level was also noticed at the top of this unit; (ii) The uppermost unit, up to 50 cm in thickness, is made by cm thick chalky limestones (Figs. 4 and 7).

The outcrop from the NW bank of the Limanu Lake has a total stratigraphic thickness of almost 20 m. As the Techirghiol section, the Limanu section exposed two distinct lithological units. The oldest unit, 3.2 m in thickness, contains micritic

Fig. 6. (**a**) Detail of the Khersonian deposits that crop out in the Limanu section. (**b**) Detail of the lower part of the section, enclosing coquinas with *Mactra* spp.

and argillaceous limestones, as well as chalky limestones and oolithic ones. A coquina bed, 80 cm thick, was also observed at the top of the oldest unit. The youngest unit is made by 13.7 m of yellowish-white limestones, alternating with coquinas, oolithic limestones and argillaceous limestones. Towards the upper part of the Limanu section, frequently karstified stromatolites occur (Figs 5, 6 and 7).

4.2. Macrofaunas

The macrofaunas identified in the oldest unit of the Techirghiol section is represented by bivalves, belonging to the taxa: *Plicatiforma fittoni* (d'Orbigny), *Abra alba* Sok., *Obsoletiforma obsoleta* (Eichwald), *Obsoletiforma sarmatica* Koles and *Cardium* spp. (Figs. 4 and 7).

The species of the genus *Obsoletiforma* represent around 70% of the total assemblages found. Additionally, specimens of *Mactra vitaliana* d'Orbigny and *M. pallasi* Baily, as well as few specimens assigned to the *Cardium* and *Gibbula* genera, badly preserved, are present. Towards the top of this biozone, a 15 cm thick coquina level, mainly containing small-sized specimens of *Cardium*, is present.

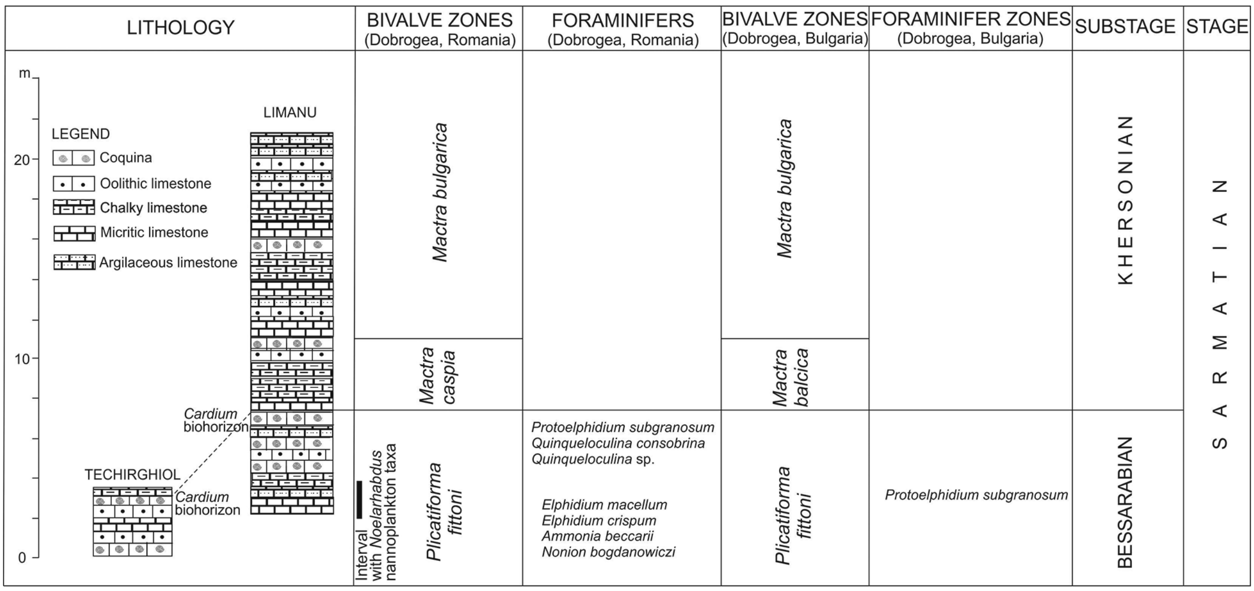

Fig. 7. Litho- and biostratigarphy of the studied sections; foraminiferal assemblages after Ionesi and Ionesi (1971); bivalve biozones for Bulgaria after Nikolov (2009) and Nikolov *et al.* (2013); foraminiferal zones for Bulgaria after Kojumdgieva *et al.* (1989).

The youngest unit of the Techirghiol section contains commonly but badly preserved macrofaunas, i.e. *Mactra caspia* Eichwald, *Mactra balcica* Macarovici and *Mactra bulgarica* Toula. Few specimens of *Helix toulai* (Kojumdgieva) are also present in the mollusk assemblages.

Within the oldest unit of the Limanu section, the macrofaunal assemblages are similar with those recorded in the Techirghiol section. Bivalve taxa, such as *Plicatiforma fittoni* and *Obsoletiforma* spp. are present, along with a coquina level, 80 cm in thickness, towards the top of the oldest unit, enclosing small-sized cardiids. Within the younger unit exposed in the Limanu section, high abundance of the taxa belonging to the bivalve genus *Mactra*, i.e. *M. caspia*, *M. balcica* and *M. bulgarica* are present (Figs. 5, 6 and 7).

In both studied sections, the above-mentioned species of *Mactra* occur in the assemblages from the base of the youngest lithological units, but with a variable abundance: *Mactra caspia* is dominant (over 60% of bivalve assemblages) in the lower part, followed by an increased frequency of *Mactra bulgarica* (over 70% in the upper part); concerning *Mactra balcica*, its specimens are around 10-15% of total assemblages.

4.3. Calcareous nannofossils

Samples from the Techirghiol section, from both lithological units as described above yielded no calcareous nannoplankton, *in situ* or reworked. In the studied smear slides, only ascidian spicules were observed (Plate 1). In the samples collected from the Limanu section, abundant ascidian spicules are present, especially in the upper part of the investigated succession. Besides, in the samples from the older unit, below the level containing high abundance of cardiid bivalve, few specimens of the calcareous nannoplankton species *Noelaerhabdus bojinovicae* Jerković are present (Plate 1).

5. DISCUSSION

5.1. Biostratigraphy

The oldest unit, identified both in the Techirghiol and Limanu sections, contain bivalve assemblages that characterize the *Plicatiforma fittoni* zone, which extends within the late Bessarabian (Chiriac, 1960; Ionesi & Ionesi, 1971, 2004) in the investigated region of the Euxinian-Caspian domain, *i.e.* the South Dobrogea (SE Romania).

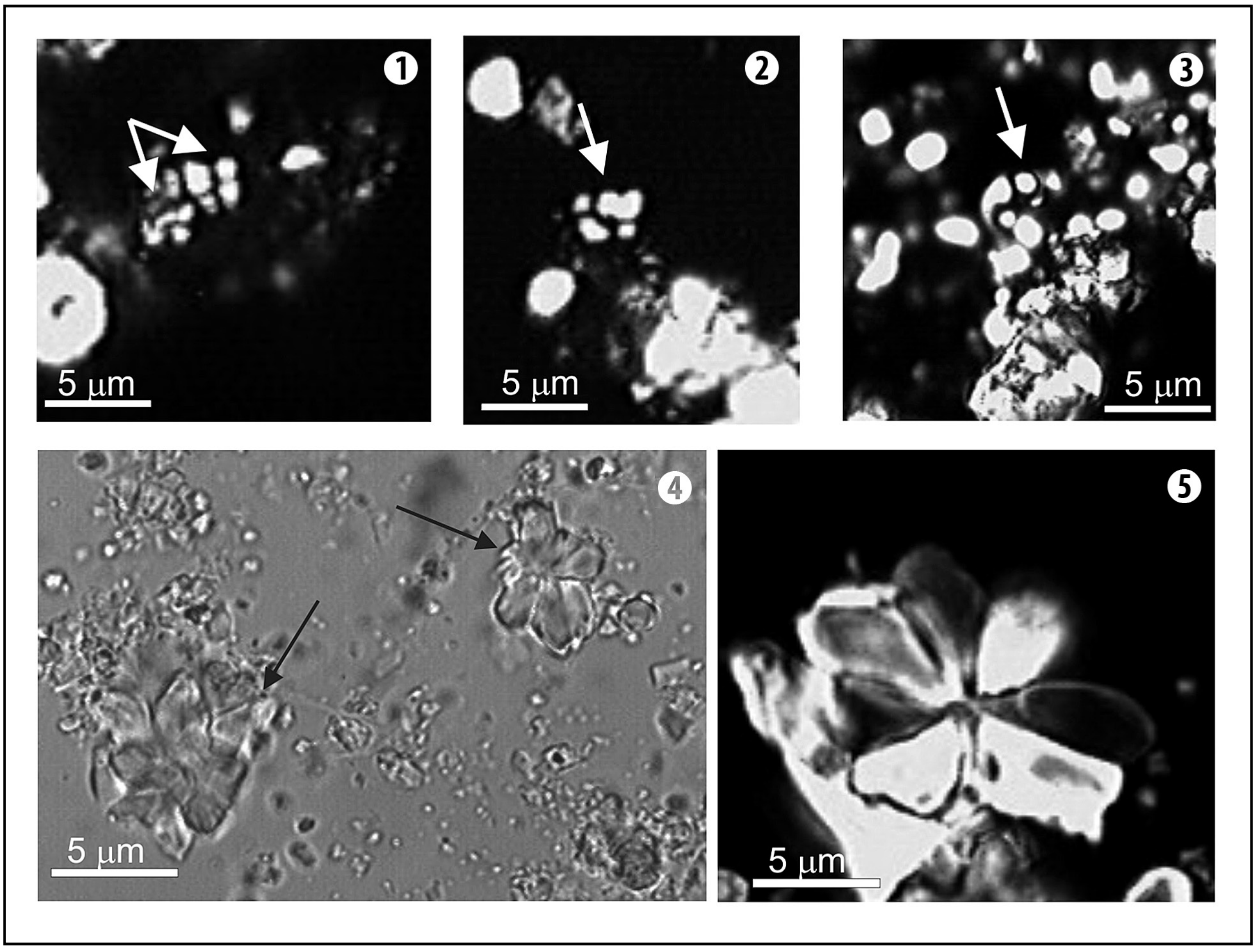

Plate 1. All the microphotographs at LM (Light microscope), at N+ (crossed nicols), except 4, NII (polarized light); **1-3** – *Noelarhabdus bozinovicae* Jerković (Site Limanu, upper Bessarabian); **4-5** – Ascidian Spicules; 4 – Site Techirghiol (lower Khersonian); 5 – Site Limanu (lower Khersonian).

Toward the top of the *Plicatiforma fittoni* bivalve zone, a cm-thick coquina level containing abundant small-sized specimens of *Cardium* was observed. Ionesi and Ionesi (1971) reported the presence of this biohorizon (reaching a maximum stratigraphic thickness of 4.5 m), described by them as the 'Limanu Limestone', at the top of the middle Sarmatian *s.l.* (Bessarabian) in several sections of the South Dobrogea, such as Albeşti and western part of the Limanu Lake.

The base of the Khersonian is pointed out, in the studied sections, by the disappearance of the coquina beds rich in small-sized cardiids, along with the appearance of small-sized specimens belonging to the *Mactra* genus (Ionesi & Ionesi, 1971; Ionesi & Ionesi, 2004). From the base of the Khersonian, the dominant taxon of the genus *Mactra* is *M. caspia*, followed by an interval of *M. bulgarica* increased abundance. Based on these findings, the base of the Khersonian was assigned, in the S Dobrogea, to the *Mactra caspia* bivalve zone, followed by the *Mactra bulgarica* bivalve zone.

In terms of the calcareous nannoplankton, taxa belonging to the *Noelaerhabdus* genus are present, in the upper Bessarabian deposits of the *Plicatiforma fittoni* bivalve zone. So far, taxa of *Noelaerhabdus* were reported only from the Central Paratethys. Since the discovery of this genus with three species, i.e. *Noelaerhabdus bozinovicae*, *N. bekei* and *N. braarudi* by Jerković (1970) in the Pannonian sediments of Belgrad area (Serbia), *Noelaerhabdus* taxa were reported from Hungary, in the sediments with *Congeria banatica* from Mecsek Mountain (Bona & Gal, 1985), in Romania, in the intra-Carpathian area, Transylvanian Basin (Mărunţeanu, 1997, 1998; Chira *et al.*, 2000; Chira & Malacu, 2008), in Austria, Styrian Basin (Ćorić & Gross, 2004), as well as in Croatia, in two distinct areas, such as the Hrvatsko Zagorje and the North Croatian basins (Galović & Young, 2012). The later authors indicate the presence of the genus *Noelaerhabdus* within the interval covered by the NN7 up to the lower part of the NN10 calcareous nannoplankton zones, corresponding to the Sarmatian *s.s.* (including the Badenian-Sarmatian boundary interval) up to the lower Pannonian from the Central Paratethys. Galović & Young (2012) indicate that only one species, *N. bozinovicae* JERKOVIĆ 1970, is valid, while the other taxa of *Noelaerhabdus* represent stages of incomplete growth and dimorphism; additionally, the diagentical processes, leading to the occurrence of broken specimens and overgrowth are very numerous and might hinder the specific identification.

Concerning the stratigraphic position of *Noelaerhabdus* taxa present in the upper Bessarabian of the Limanu section, this is in accordance with previous findings of Ćorić & Gross (2004), who identified this calcareous nannoplankton genus in the lower part of the Pannonian stage from the Central Paratethys, corresponding to the upper part of the middle Sarmatian s.*l*., the Bessarabian (Piller *et al.*, 2007).

5.4. Correlation

The bivalve zones identified in the Bessarabian and Khersonian deposits of Dobrogea (SE Romania) are well correlated with those from NE Bulgaria, territory enclosed during the Sarmatian times also in the Euxinian-Caspian domain. Hence, the upper part of the Bessarabian is characterized by the presence of the *Plicatiforma fittoni* bivalve zone, in Bulgaria (Nikolov, 2009; Nikolov *et al.*, 2013), as in SE Romania (Fig. 7). Additionally, the upper Bessarabian foraminifera assemblages identified in NE Bulgaria (Kojumdgieva *et al.*, 1989) are similar with those described from SE Romania (Ionesi & Ionesi, 1971; 2004), mainly containing taxa of the genera *Protoelphidium*, *Elphidium*, *Porosononion*, *Nonion*, *Ammonia* and *Quinqueloculin*a, and attributed to the *Protoelphidium subgranosum* foraminiferal zone.

Taking into account the bivalve assemblages found in the foreland of the Southern Carpathian, where abundant *Mactra* spp., i.e. *Mactra caspia*, *Mactra balcica* and *Mactra bulgarica*, were recorded from the base of the Khersonian (Papaianopol, 1997; Macaleţ & Munteanu, 2008), no difference is to note between the bivalve zonation of the Dacian Basin (included in Eastern Paratethys) and that from the SE extremity of the Romanian territory (belonging to the Euxinian-Caspian domain).

To observe also the presence of ascidian spicules, encountered with higher frequency in the Khersonian than in the Bessarabian studied sediments. In the Sarmatian of the Moldavian Platform, NE Romania (included in the Dacian Basin, Eastern Paratethys), the high frequency of the ascidian spicules is associated with significantly high abundance of the calcareous nannoplankton species *Braarudosphaera bigelowii* (Brânzilă & Chira, 2005), indicative of the salinity decrease in a marine environment, which was probably a very shallow one.

6. CONCLUSIONS

The two studied sections situated in S Dobrogea (SE Romania) exposed Bessarabian and Khersonian deposits, representing the middle and upper Sarmatian *s.l.* The boundary between the Bessarabian and Khersonian stages could be placed above the disappearance of biohorizons rich in small-sized cardiid coquinas. The base of the upper Sarmatian *s.l.* (= the Khersonian stage) is characterized by the presence of abundant small-sized *Mactra*, among which *M. caspia* is the most abundant species, followed by a stratigraphic interval where *Mactra bulgarica* prevails in the bivalve assemblages.

The bivalve zones recognized in SE Romania are well correlated with those from NE Bulgaria, both areas being included in the western part of the Euxinian-Caspian domain. The single difference is the presence of *Mactra balcica* bivalve zone in NE Bulgaria in the oldest Khersonian deposits, and *Mactra caspia* bivalve zone in SE Romania, in the same depositional interval.

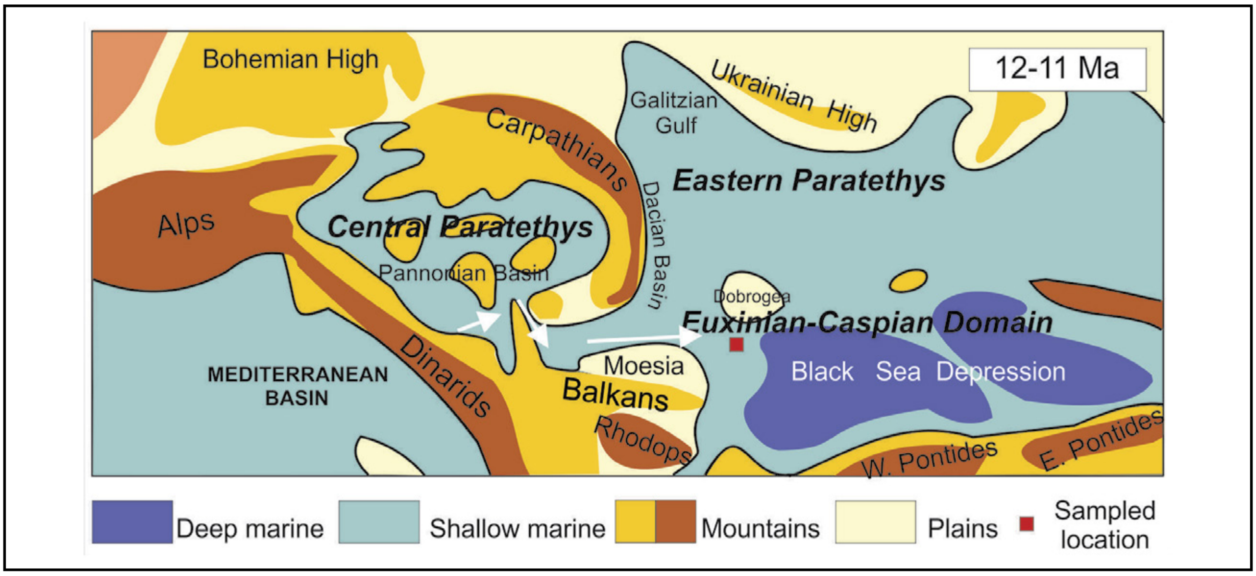

Fig. 8. Paleogeographic of the Central Paratethys, Eastern Paratethys and Euxinian-Caspian domains during the middle and late Sarmatian *s.l.* (Bessarabian-Khersonian interval), and early Pannonian, respectively (simplified after Popov *et al.* 2004); white arrows indicate the possible connection between the Central Paratethys and the Euxinian-Caspian Domains.

To note the first identification in the Euxinian-Caspian domain of specimens assigned to the calcareous nannoplankton species *Noelaerhabdus bozinovicae*, described so far only from the Pannonian deposits of the Central Paratethys domain. This presence is possibly linked to a transgressive event towards the upper part of the Bessarabian, implying a connection between the western part of the Euxinian-Caspian domain (*i.e.* today territories of SE Romanian and NE Bulgaria) and the Central Paratethys (extending up to the today Serbian territory) – Fig. 8.

Possibly, from the Khersonian a regressive phase took place, as strongly karstified sediments were observed. This karstification might mirror the early Khersonian regressive event, evidenced in the NE part of Bulgaria (Popov and Kojumdgieva, 1987).

The presence of ascidian spicules in both the Bessarabian and Khersonian stages indicates a shallow marine environment during the middle and upper Sarmatian. As the calcareous nannoplankton taxa *Noelaerhabdus* are present only in the middle Sarmatian (upper Bessarabian), it is to assume that the salinity progressively shifted from the middle Sarmatian to the upper Sarmatian (Khersonian) interval.

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