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assemblages in Upper Jurassic carbonates  
of the eastern Getic Carbonate Platform  
(Southern Carpathians, Romania)

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# Exceptionally preserved calcified sponge assemblages in Upper Jurassic carbonates of the eastern Getic Carbonate Platform (Southern Carpathians, Romania)

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## ABSTRACT

A rich poriferan assemblage was identified within the easternmost part of the Getic Carbonate Platform of Romania (Grădiștei Gorges). The excellent preservation state of most poriferans here led to the discovery of a new species (*Neuropora gigantea* Pleș & Schlagintweit, n. sp.) and to the identification of previously unknown diagnostic features in some species (*Sarsteinia babai* Schlagintweit & Gawlick, 2006 emend., *Neuropora lusitanica* Termier, 1985, *Sphaeractinia steinmanni* Canavari, 1893). *Calciagglutispongia yabei* Reitner, 1992, *Sarsteinia babai* and *Sphaeractinia steinmanni* are reported

**KEY WORDS**

Calcified sponges, microencrusters, carbonate platforms, Intra-Tethyan realm, reef zonation, palaeoenvironments, palaeoecology, taphonomy, Kimmeridgian-Tithonian, new species.

**MOTS CLÉS**

Éponges calcifiées, micro-organismes encroûtants, plateformes carbonatées, domaine intra-téthysien, zonation récifale, palaeoenvironments, palaeoecologie, taphonomie, Kimmériidgien-Titonique, espèce nouvelle.

for the first time from the Upper Jurassic carbonates of the Getic Carbonate Platform. The sedimentary input fluctuations and the nutrient competition had an important role in understanding the morphological adaptations of the analysed species. The existing palaeoecological and palaeoenvironmental conditions generated different distribution patterns towards the reef profile and also preferential adaptations to a specific Tethyan domain. As opposed to the poriferan assemblages from the northern Tethyan shelves, these organisms formed sponge-coral-microencruster boundstones at the margins and fore-reefal zones of isolated carbonate platforms within the intra-Tethyan realm. The importance of calcified sponges in reef-zonation is highlighted by the establishment of a general zonation model. Three zones can be distinguished: 1) *Cladocoropsis-Milleporidium* zone (back-reef area); 2) *Bauneia-Chaetetopsis-Parastromatopora* zone (central reef area); and 3) *Sphaeractinia-Ellipsactinia-Neuropora* zone for the fore-reef area. In the absence of a true reef framework these calcified sponges developed typical morphologies, environmental adaptations and partnerships with other biotic groups which strongly influenced the carbonate production throughout the intra-Tethyan domain.

**RÉSUMÉ**

*Assemblage d'éponges calcifiées exceptionnellement conservées dans les carbonates du Jurassique supérieur de la plateforme géotique carbonatée orientale (Carpates méridionales, Roumanie). Implications paléontologiques et paléoécologiques, caractéristiques taphonomiques et aperçu sur la zonation récifale.*

Un assemblage riche en spongiaires a été identifié dans la partie la plus orientale de la plateforme géotique carbonatée de Roumanie (gorges Gradistei). L'excellent état de conservation de la plupart des spongiaires a conduit à la découverte d'une nouvelle espèce (*Neuropora gigantea* Ples & Schlagintweit, n. sp.) et à l'identification de caractéristiques diagnostiques, jusque-là inconnues, dans certaines espèces (*Sarsteinia babai* Schlagintweit & Gawlick, 2006 emend., *Neuropora lusitanica* Termier, 1985, *Sphaeractinia steinmanni* Canavari, 1893). *Calciagglutispongia yabei* Reitner, 1992, *Sarsteinia babai* et *Sphaeractinia steinmanni* ont été signalées pour la première fois dans les carbonates du Jurassique supérieur de la plateforme géotique carbonatée. Les fluctuations des apports sédimentaires et la composition en éléments nutritifs ont eu un rôle important dans la compréhension des adaptations morphologiques des espèces analysées. Les conditions paléoécologiques et palaeoenvironnementales existantes ont généré différents patrons de distribution vers le profil récifal et aussi des adaptations préférentielles vers un domaine téthysien spécifique. Contrairement aux assemblages de spongiaires des hauts-fonds nord-téthysiens, ces organismes ont formé des boundstones éponge-coraill-élément microencroûtant, aux marges et dans les zones d'avant-récif de plateformes carbonatées isolées au sein du domaine intra-téthysien. L'importance des éponges calcifiées dans la zonation récifale a été soulignée par l'établissement d'un modèle général de zonation. Trois zones peuvent être distinguées : 1) zone à *Cladocoropsis-Milleporidium* (zone d'arrière-récif) ; 2) zone à *Bauneia-Chaetetopsis-Parastromatopora* (zone récifale centrale) ; et 3) zone à *Sphaeractinia-Ellipsactinia-Neuropora* (zone d'avant-récif). En l'absence d'une vraie construction récifale, ces éponges calcifiées ont développé des morphologies typiques, des adaptations environnementales et des partenariats avec d'autres groupes biologiques, qui ont fortement influencé la formation des carbonates dans tout le domaine intra-téthysien.

**INTRODUCTION**

Calcified sponges (e.g. “stromatoporoids”) played an important role in the development and evolution of intra-Tethyan platform margin reef systems during the Late Jurassic (e.g. Turnšek *et al.* 1981; Leinfelder *et al.* 2005; Rusciadelli *et al.* 2011). Together with corals and encrusting organisms, they formed specialized bioconstructed frameworks which produced and consolidated the shallow-water sediments of numerous isolated carbonate platforms. Even though many studies focused on anthozoan distribution (Turnšek *et al.* 1981; Kołodziej 2015) or encrusting organisms (Schlagintweit & Gawlick 2008; Pleş *et al.* 2013; Kaya & Altiner 2015), little is known about species diversity, morphostructural adaptations and palaeoecological significance of the associated sponge assemblages (Leinfelder *et al.* 2005).

The present study focuses on the description and analysis of a rich and exceptionally preserved poriferan assemblage discovered in the Dâmbovicioara region (eastern part of the Getic Carbonate Platform, Romania) in order to highlight new palaeontological, palaeoecological and palaeoenvironmental features. The poriferan response to the palaeoenvironment is reflected by their growth patterns (low-domical, encrusting, and rarely, cylindrical). Moreover, the sedimentary input fluctuations and the nutrient competition had an important role in understanding the morphological adaptations of some sponges here. The existing palaeoecological and palaeoenvironmental conditions generated different distributional patterns towards the reef profile and also preferential adaptations to specific Tethyan domains. All of these can be used to establish a general distribution model which may emphasize relationships or discrepancies with synchronous reef types

in the Tethyan realm. Moreover, the obtained data can serve as a supplementary proxy in understanding the zonation pattern of such bioherms.

#### CALCIFIED SPONGE ASSEMBLAGES WITHIN THE UPPER JURASSIC TETHYAN REEF SYSTEMS. A SHORT OVERVIEW

It is well known that Upper Jurassic Tethyan reef systems vary in structural morphology, biotic content and spatial distribution (Leinfelder *et al.* 1994, 2002; Wood 1999; Leinfelder 2001). A valuable amount of data regarding poriferan-dominated reefs comes from the northern Tethyan carbonates of Portugal (Termier *et al.* 1985; Nose & Leinfelder 1997), Spain (Leinfelder *et al.* 1994), France (Olivier *et al.* 2004; Leinfelder *et al.* 2005) or southern Germany (Leinfelder 1993). They are defined most commonly by siliceous sponge-microbialite mud-mounds (mostly during Oxfordian-Kimmeridgian) or by massive coral reefs (framestones) associated with stromatoporoids (Leinfelder 2001; Leinfelder *et al.* 2005). As opposed to these northern Tethyan reefs, the analysed sponge assemblage is associated with corals and various amounts of encrusting morphotypes and syndepositional early cements characterising smaller bioherms developed in epicontinental agitated seas within the intra-Tethyan realm. In the geological literature of the last decade, such deposits are generally known as “microencruster-cement boundstones” (with associated “stromatoporoids”) (*sensu* Schlagintweit & Gawlick 2008) or “coral-stromatoporoid-microencruster boundstones” (*sensu* Pleş *et al.* 2016).

Concerning the “stromatoporoid” skeletal organization of these sponges, it is true that most analysed taxa share such features, but without critical taxonomic elements (e.g. spicules), terms such as “calcareous sponges” or “calcified sponges” are more suitable. The majority of Jurassic poriferans (with or without a stromatoporoid bauplan) are now considered hypercalcified demosponges (West 2011). The chambered sponges are included in the Sphinctozoa group, while those without chambers are part of the Inozoa group of the demosponges (Senowbari-Daryan & Rigby 2011). More details on this topic can be found in the studies of Reitner (1992), Leinfelder *et al.* (2005) or West (2011).

#### GEOLOGICAL SETTING

The Pietra Craiului-Dâmbovicioara region is situated in the eastern part of the Southern Carpathians between the Iezer-Păpuşa (west) and Bucegi and Leaota massifs to the east/south-east. The eastern part of this region comprises a sedimentary sequence made up of Lower-Middle Triassic, Middle-Upper Jurassic and Cretaceous deposits known in the Romanian literature as the “Braşov Series” (Patrulius 1969; Pleş *et al.* 2013; Mircescu *et al.* 2016). The studied area is located in the southeastern part (Fig. 1) where only Jurassic and Cretaceous deposits are outcropping. Lithologically,

the mid-Jurassic deposits (Bajocian-?lower Callovian) are represented by a condensed sequence of sandstones, microconglomerates, marls, sandy and bioclastic limestones with frequent hardground surfaces (Bucur *et al.* 2011; Lazăr *et al.* 2013; Grădinaru *et al.* 2016; Mircescu *et al.* 2016). The mid-upper Callovian-Oxfordian is defined by the presence of fine layered limestones with radiolarians and cherty nodules (Beccaro & Lazăr 2007). On top of these deposits, a regressive succession is recorded starting with the Kimmeridgian up to the lower Valanginian characterized mainly by shallow-water carbonates. It corresponds with the eastern domain of the Getic Carbonate Platform comprising platform-margin deposits (slope, fore reef and coral-microencruster buildups) which gradually shift upward into inner-platform carbonates (Bucur 1978; Panaiotu *et al.* 1997; Dragastan 2010; Bucur *et al.* 2011; Pleş *et al.* 2013; Mircescu *et al.* 2016). Starting with the middle Valanginian up to the ?upper Valanginian, a regional discontinuity (hardground) surface is reported from several zones within the Dâmbovicioara area (Patrulius 1969; Patrulius & Avram 1976; Ungureanu *et al.* 2015, 2017; Grădinaru *et al.* 2016). Upper Valanginian hemipelagic carbonates (Cetatea Neamţului Member) are transgressively overlying the middle Valanginian discontinuity followed by uppermost Valanginian-Hauterivian marls with ammonites (Dealul Sasului Member) (Patrulius 1976; Bucur *et al.* 2011; Grădinaru *et al.* 2016). The Lower Cretaceous sedimentary sequence continues with Barremian-lower Aptian cephalopod rich marls supporting in the lower part bioconstructed levels (patch-reefs) with corals, calcified sponges, calcareous algae and rudists (Valea Muierii Member) (Patrulius 1969; Bucur *et al.* 2011). The whole upper Valanginian-lower Aptian succession with all of the three members (Cetatea Neamţului Member, Dealul Sasului Member and Valea Muierii Member) was described as Dâmbovicioara Formation (Patrulius 1969, 1976; Patrulius & Avram 1976). At the end of the Lower Cretaceous the region is covered by upper Aptian and uppermost Albian-Cenomanian polymictic conglomerates (Patrulius 1969; Ungureanu *et al.* 2017). The sponge assemblage described here, was found in Upper Jurassic carbonates belonging to the Giuvala Formation (Urdăriţa Member) of the Dâmboviţa Group (Dragastan 2010).

#### SAMPLED SECTION AND METHODOLOGY

The sponge assemblage was identified in a small outcrop located in the central part of the Grădişteii Gorges touristic complex (Braşov County) (GPS: 45°27'2.993"N, 25°17'46.363"E; altitude: 1257 m) (Fig. 1). The outcrop is represented by a thick pile of massive white-yellowish carbonates (in some parts fractured or breccified) with an impressive palaeontological content characterized by a variety of calcified sponges and coral fragments (Fig. 2A-F). The excellent taphonomical conditions of most sponge specimens allowed selective sampling and macroscopical observations (biometric features, high resolution photographs). A number of 65 samples were collected from

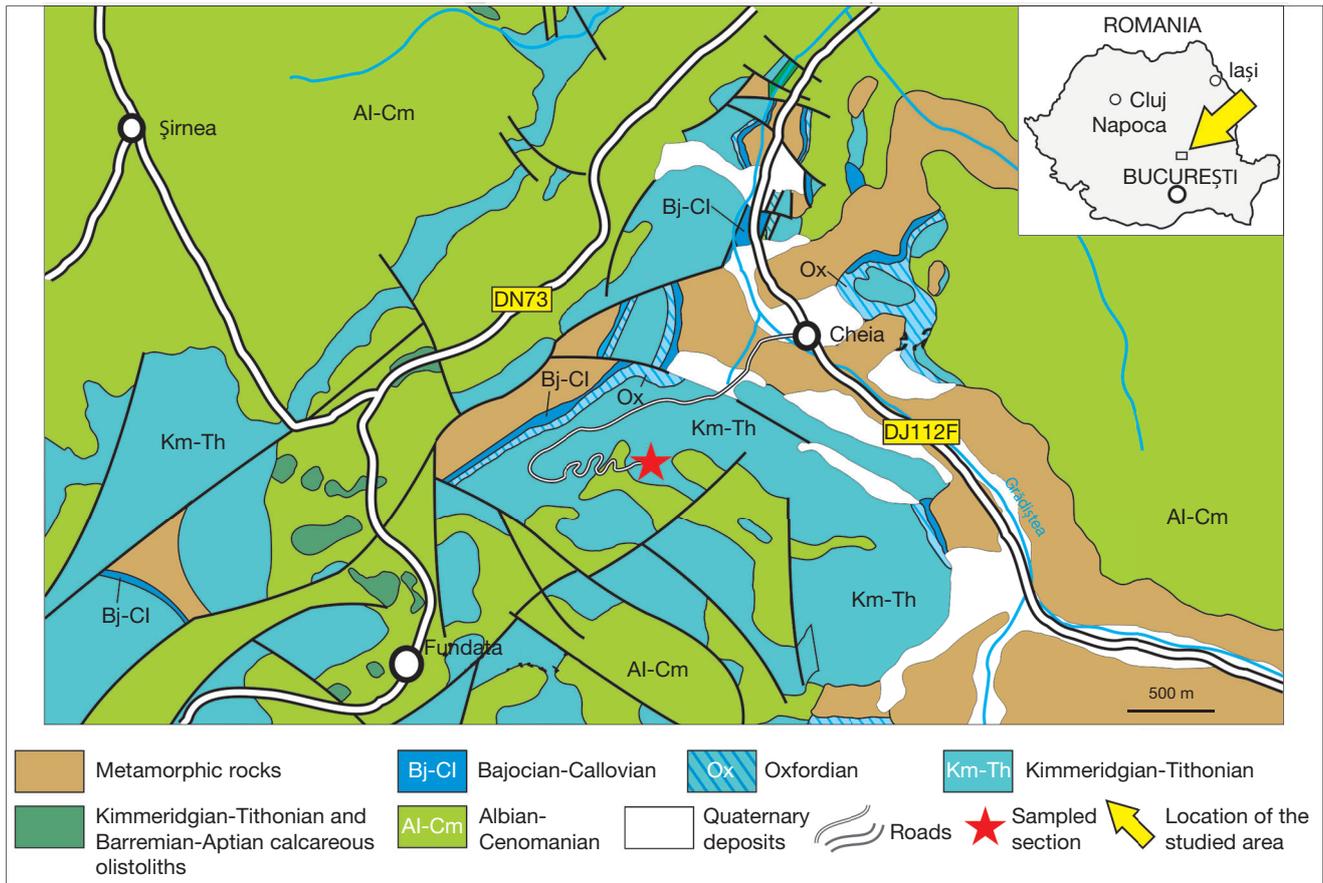


Fig. 1. — Geological map of the studied region based on Dimitrescu *et al.* (1971, 1974), Patruşius *et al.* (1971).

this outcrop from which more than 100 thin-sections were made. The samples containing well preserved specimens were cut in different planes (longitudinal, oblique, cross, tangential) in order to obtain a three-dimensional perspective of the skeletal inner-architecture, microstructural features and also for understanding the depositional palaeoenvironment. The description, nomenclature and systematics of the calcareous sponges follows Milan (1969), Wood (1987), Reitner (1992), West (2011), Senowbari-Daryan & Rigby (2011) and West *et al.* (2013). The classification of the microfacies traits follows Dunham (1962), Embry & Klován (1971) and Flügel (2010). The thin-sections used for illustrations are stored at the Geology-Paleontology Museum, Department of Geology, Babeş-Bolyai University in Cluj-Napoca under repository numbers 24127-24155.

## RESULTS

### AGE CONSTRAINTS

Based on the biotic content and lithological traits (e.g. massive appearance) the sampled carbonates from Grădiştei Gorges Complex can be described as Upper Jurassic “Štramberk”-type limestones (*sensu* Ciborowski & Kołodziej 2001) or “Plassen”-type limestones (*sensu* Schlagintweit & Gawlick 2008). Their age, Kimmeridgian-Tithonian, was established

in respect with the existing palaeontological assemblage (calcareous algae, benthic foraminifera, calcified sponges and encrusting microorganisms) corroborated with biostratigraphic data from other studies on similar deposits in this region (Patruşius 1969; Dragăstan 2010; Bucur *et al.* 2011; Mircescu *et al.* 2016).

Concerning these, the identified palaeontological assemblage consists of the following taxa: foraminifera – *Mohlerina basiliensis* (Mohler, 1938), *Coscinophragma cribrosa* (Reuss, 1846), *Lituola baculiformis* Schlagintweit & Gawlick, 2009, *Lenticulina* sp. –; green algae – *Salpingoporella pygmaea* (Gümbel), *Nipponophycus ramosus* Yabe & Toyama, *Griphoporella* sp. –; calcified sponges – *Neuropora lusitanica* Termier, 1825, *Sphaeractinia steinmanni* Canavari, 1893, *Ellipsactinia* sp., *Sarsteinia babai* Schlagintweit & Gawlick, 2006 emend., *Perturbatacrusta leini* Schlagintweit & Gawlick, 2011, *Thalamopora lusitanica* Termier, Termier & Ramalho, 1985, *Calcistella jachenhausenensis* Reitner, 1992, *Calciagglutispongia yabei* Reitner, 1992, *Cylicopsis verticalis* Turnšek, 1968, *Tubuliella* sp. –; microencrusters – *Crescentiella morronensis* (Crescenti, 1969), *Labes atramentosa* Eliášová, 1986, *Radiomura cautica* Senowbari-Daryan & Schäfer, 1979, *Koskinobullina socialis* Cherchi & Schroeder, 1979, *Thaumatoporella parvovesiculifera* (Raineri, 1922) and *Lithocodium*-type structures –; annelid tubes – *Terebella lapilloides* Münster, 1833.



FIG. 2. — Field pictures from the Grădiștei Gorges touristic complex: **A-C**, massive white-yellowish bioclastic limestones with calcareous sponges and corals; **D**, coral fragments (**white arrows**) in reef debris deposits; **E**, large *Neuropora gigantea* Pleş & Schlagintweit, n. sp. agglomeration (**white arrows**) and microbial crusts (upper-right side of the picture); **F**, bioclastic rudstone with *Neuropora* Bronn, 1825 (**white arrows**), *Sphaeractinia* Steinmann, 1878 (**yellow arrow**), bivalves and small coral fragments.

*Mohlerina basiliensis* (Fig. 3A) and *Lituola baculiformis* represent two widely distributed foraminifera species in the Upper Jurassic (Kimmeridgian-Tithonian) intra-Tethyan shallow-water carbonates of Europe (Săsăran *et al.* 2001; Schlagintweit *et al.* 2005; Săsăran 2006; Krajewski & Olszewska 2006; Schlagintweit & Gawlick 2008, 2009; Bucur *et al.* 2011; Schlagintweit 2012; Pleş *et al.* 2013; Mircescu *et al.* 2014, 2016; Pleş *et al.* 2016; Atasoy *et al.* 2018). Regarding the calcareous algae, *Salpingoporella pygmaea* (Fig. 3B), *Nipponophycus ramosus* (Fig. 3C) and *Griphoporella* (Fig. 3D) represent also cosmopolitan species in Kimmeridgian-Tithonian deposits of the Tethyan realm (Granier & Deloffre 1993; Bucur 1999; Schlagintweit & Ebli 1999; Bucur & Săsăran 2005; Schlagintweit 2011). Also, the rich calcified sponge assemblage associated with the microencruster consortium confirms a Kimmeridgian-Tithonian age (details regarding the stratigraphic range of the main poriferan species are given in the description chapter). Even if some sponges and microencrusters – e.g. *Crescentiella morronensis* (Fig. 3I), *Labes atramentosa* (Fig. 3F), *Radiomura cautica* (Fig. 3G), *Thaumatoporella parvovesiculifera* (Fig. 3E) have a wider stratigraphic range (Schlagintweit *et al.* 2005 and Pleş *et al.* 2013, 2017 for details), an acme period in the Upper Jurassic is given by most authors (Ivanova *et al.* 2008; Schlagintweit & Gawlick 2008; Kaya & Altiner 2015). The annelid *Terebella lapilloides* was identified in Kimmeridgian-Tithonian deposits from northern Turkey (Kaya & Altiner 2014).

#### MICROFACIES AND PALAEOENVIRONMENT

Bio-intraclastic grainstone/rudstone (MFT1) and sponge-coral-microencruster boundstone (MFT2) represent the main microfacies types for the studied carbonates. Details regarding the main components, diagenetic features and other microfacies features are given in Table 1.

Based on the main microfacies traits (Table 1), an agitated platform margin (upper slope/fore-reef) palaeoenvironment is considered. Concerning the bio-intraclastic grainstones/rudstones (MFT1), these deposits represent most probably small debris-flows composed of abraded particles from the bioconstructed framework generated by a relatively high hydrodynamic regime. This is supported by the diversified microencruster consortium and syndimentary cement crusts (fibrous or radiaxial cements) which are known to be abundant in these parts of a carbonate platform (Schlagintweit & Gawlick 2008; Flügel 2010). Moreover, poriferan species such as *Ellipsactinia*, *Sphaeractinia*, *Neuropora* and the foraminifer *Lenticulina* are preferring such environments (Leinfelder *et al.* 2005; Rusciadelli *et al.* 2011; Pleş *et al.* 2015). The sponge-coral-microencruster boundstone (MFT2) is represented by small buildups without a true reef framework alternating with skeletal debris levels (MFT1). Such peculiarity is typical for the Upper Jurassic intra-Tethyan platform margin reef settings. Here, these bioconstructions did not achieve a high topographic relief (displaying mostly patch-reef characteristics), but the encrusting potential of most of the main components helped to enforce and stabilize the upper slope carbonates.

#### SYSTEMATIC PALEONTOLOGY

This chapter focuses on the description of the main calcified sponge taxa which were observed within the Grădişteii Gorges Complex carbonates. Prior to biostratigraphic and diagenetic processes in most of the fossil hypercalcified sponges only the calcareous skeleton is preserved and, in some cases, spicules (West 2011). Considering the present agitated palaeoenvironment (fore-reef) the overall preservation state of the sponge skeletons is highly favourable for numerous insights regarding both external and internal morphostructural features, growth patterns and diagnostic traits. As known from previous studies on similar associations (Reitner 1992; Leinfelder *et al.* 2005; West 2011), Upper Jurassic stromatoporoid- and chaetetid-type poriferans rarely display preserved spicules or did not possess them at all. Based on this statement, it is hard in some species to place an exact phylogenetic position since the spicules represent a critical systematic trait (Wood 1987; Reitner 1992; West 2011). Comments on this topic are given for each analysed species.

Genus *Neuropora* Bronn, 1825

*Neuropora lusitanica* Termier, 1985  
(Fig. 5A, B)

*Neuropora lusitanica* Termier *et al.*, 1985: 207, pl. 5, figs 1-2. — Krajewski & Schlagintweit 2018: 9, fig. 6a-f.

#### GENERAL DESCRIPTION

The internal morphology of *Neuropora lusitanica* is related to a central tubular system (with more or less parallel longitudinal tubes) from which bifurcating radially arranged tubules are developing perpendicular (or bended) towards the skeleton outer wall. In longitudinal sections, the lateral elements (tubules) resemble a conically superimposed arrangement divided by thin tabulae (Fig. 5A). According to Termier *et al.* (1985) the septate walls are developing at relatively specific intervals and the peripheral openings of the lateral tubes are characterized by a “crown of spiculous tubercles”. In analogy with other *Neuropora* species, *N. lusitanica* can possess asterothizae/stellate-type or mamelonar microstructures at the surface of the skeleton (West *et al.* 2013). The skeleton has a fibrous microstructure best observed in longitudinal and oblique/longitudinal sections.

#### REMARKS

This calcified sponge represents a cosmopolitan species among the Upper Jurassic-Lower Cretaceous shallow water reefal and peri-reefal biotic communities of the Getic Carbonate Platform (Pleş *et al.* 2013, 2016) and throughout synchronous rimmed carbonate platforms of the Tethyan domain (Schlagintweit & Ebli 1999; Leinfelder *et al.* 2005; Schlagintweit & Gawlick 2008). Termier *et al.* (1985) observed two morphologies in the type-material: 1) an “encrusting” (massive) form with an undifferentiated thickened outer (external) part; and 2) a much

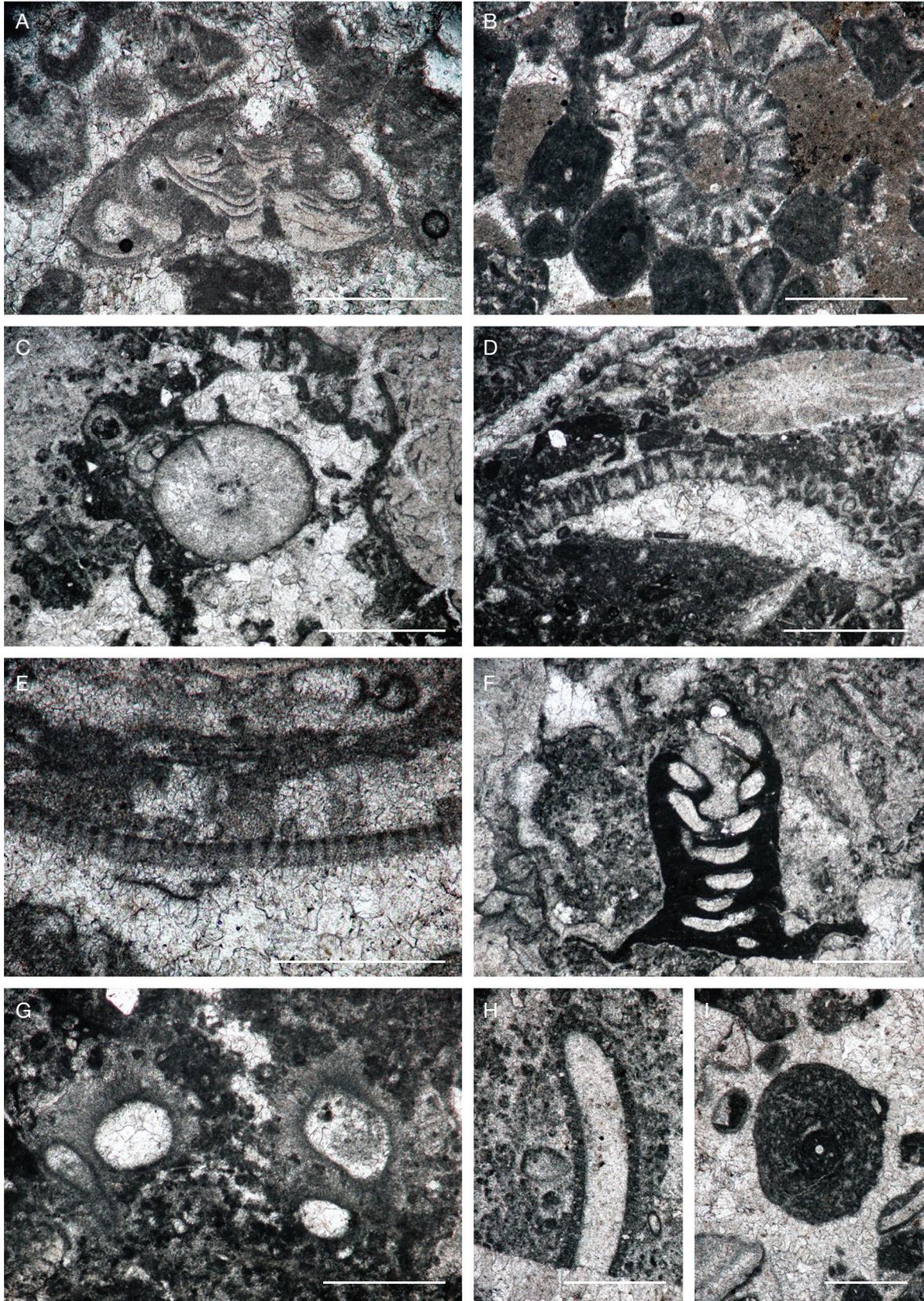


FIG. 3. — Benthic foraminifera, calcareous green algae, terebellid worm tubes and microproblematic organisms from Grădiștei Gorges: **A**, *Mohlerinia basilien-sis* (Mohler, 1938) (sample 15092D); **B**, *Salpingoporella pygmaea* (Gümbel) (sample 15092D); **C**, *Nipponophycus ramosus* Yabe & Toyama (sample 15092L); **D**, *Griphoporella* sp. (sample 15092H); **E**, *Thaumatoporella parvovesiculifera* (Raineri, 1922) (sample 15092H); **F**, *Crescentiella*-type encrusting microstructure (*Labes atramentosa* Eliášová, 1986) (sample 15092I); **G**, *Radiomura cautica* Senowbari-Daryan & Schäfer, 1979 (sample 15092C<sub>1</sub>); **H**, *Terebella lapilloides* Münster, 1833 (sample 15092R); **I**, *Crescentiella morronensis* (Crescenti, 1969) (sample 15092W). Scale bars: 0.5 mm.

TABLE 1. — Description of the main microfacies types (MTF) for the Upper Jurassic carbonate succession from the Grădişteţ Gorges.

Main microfacies type (MTF)	Main components					Microfacies features	Environment
	Calcareous sponges	Corals	Encrusting microorganisms	Other biota	Non-biotic components		
MFT1 - Bio-intraclastic grainstone/rudstone	<p><i>Neuropora gigantea</i> Pleş &amp; Schlagintweit, n. sp. and <i>Sphaeractinia steinmanni</i> centimeter-sized fragments. Isolated <i>Thalamopora lutanica</i> specimens and <i>Calcastella</i> crusts on coral fragments or small intraclasts are observed.</p>	<p>Large sized (1-5 cm) and smaller broken fragments of placoid-type small colonies highly encrusted by <i>Lithocodium</i>-type structures.</p>	<p>High abundance of <i>Crescentiella morronensis</i> specimens and associated morphotypes (<i>Labes atramentosa</i>, <i>Koskinobullina socialis</i> and <i>Radulomura cautica</i>). Serpulinid worm tubes encrusting sponge skeletons or mollusk fragments. Bacinellid-type structures are frequently observed within the broken coral fragments. In many cases the encrusting microorganisms are associated with cement crusts.</p>	<p>Benthic foraminifera (<i>Litula baculiformis</i>, <i>Leonticulina</i> sp.). Calcareous algae (<i>Sarpiropora</i>, <i>Gyrophoporella</i>). Gastropod, bivalve and brachiopod fragments encrusted by thin cyanophycean rims. Echinoid spines and skeletal fragments. Bryozoan fragments.</p>	<p>Angular and sub-angular different sized intraclasts (from 5 mm to several centimeters). Terrigenous material is absent.</p>	<p>Early diagenetic cements (mostly fibrous-radial). In some cases dissolution cavities might appear being filled with 2-3 granular cements (mosaic/drusy). Incipient dolomitization is frequent. Scarce syntaxial overgrown cements can be noticed on echinoid fragments (small plates). Fissures are common.</p>	<p>Mostly allocthonous Platform margin environment (upper slope/fore-reef)</p> <p>Diversified micro-encruster consortiums represented by clotted and agglutinated stromatolitic-type microstructures. Abrasion and fragmentation features on most of the main components.</p>
MFT2 - Sponge-coral-micro-encruster boundstone	<p><i>Neuropora</i>, <i>Sphaeractinia</i> and <i>Ellipsactinia</i> bioconstructed levels associated with other calcified sponges (<i>Perturbatacrusta</i>, <i>Calcastella</i>, <i>Calciagglutispongia</i>, <i>Sarsteinia</i>, <i>Cylindrocopsis</i>), corals and encrusting morphotypes. Crustose patterns generated by low domical, sphaerical growth forms and erect/upright morphologies in <i>Neuropora</i> clusters. Different sponge species agglomerations are developing encrusting features supporting the small bioconstructions.</p>	<p>Mainly placoid morphotypes and massive (in some cases) forming small bioconstructions associated with calcified sponges and encrusting organisms. Branching and phaceloid forms are very rare. Borings and perforations are frequently observed within these bioconstructions. Generally the corals are subordinated to the calcified sponge consortium.</p>	<p>Encrusting foraminifera (<i>Coscinophragma cribrata</i>). <i>Lithocodium</i>-type structures and <i>Crescentiella morronensis</i> are developing crusts mostly on coral and sponge fragments.</p>	<p>Calcareous algae (<i>Nipponophycus</i>). Terebellid agglutinated worm tubes (<i>Terebella lapilloides</i>). Rare agglutinated microbial mesostructures.</p>	<p>Sydepositional cement crusts intergrown within the sponge-microencruster framework. These cement crusts are represented by fibrous-radial cements. Late generation cements (mosaic/drusy-type). Neomorphic features are present. Micritization is common (abraded debris).</p>	<p>Small buildups, agglomerations and clusters. No large rigid framework. Crustose fabrics and highly biogenic encrustations. Perforation structures (<i>Gastrochaenolites</i>- and <i>Entobia</i>-type). Geopetal structures and cavities are common. The internal sediment is micritic with small particles (abraded debris).</p>	

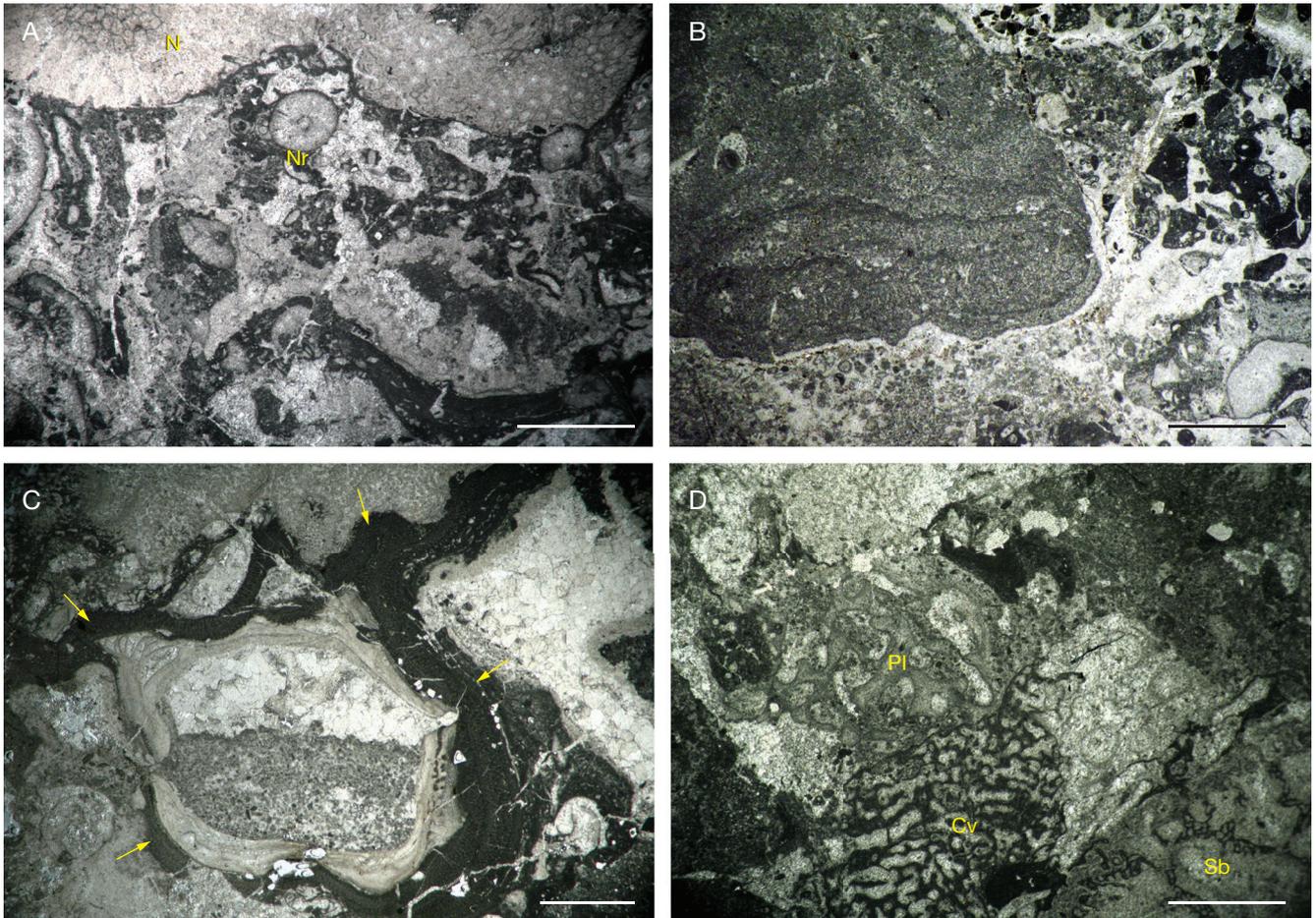


FIG. 4. — Main microfacies types from Grădiștei Gorges: **A**, sponge-microencruster boundstone (MFT2) with *Neuropora gigantea* Pleş & Schlagintweit, n. sp. (**N**), *Nipponophycus ramosus* Yabe & Toyama (**Nr**), *Crescentiella morronensis* (Crescenti, 1969) and numerous cement crusts (sample 15092C<sub>1</sub>); **B**, coarse bio-intraclastic rudstone (MFT1) with a large microbial mesostructure (agglutinated microbialite) (sample 15092W); **C**, reef boundstone with cement crusts and encrusting calcified sponges (**yellow arrows**) (sample 15092G); **D**, crustose poriferan boundstone with *Perturbatacrusta leini* Schlagintweit & Gawlick, 2011 (**PI**), *Cylicopsis verticalis* Turnšek, 1968 (**Cv**) and *Sarsteinia babai* Schlagintweit & Gawlick, 2006 emend. (**Sb**) (sample 15937). Scale bars: 1 mm.

larger branching morphotype which is the most common one. In the studied material, all observed specimens develop tubular (cylindrical) growth patterns or appear as abraded fragments encrusted by *Lithocodium*-type crusts within the fore-reef carbonates. It is quite possible that some fragments might have originated from branching-type specimens since such forms were frequently reported from Buila-Vânturarița or Piatra Craiului massifs (Pleş *et al.* 2013: fig. 7g) as close integrating sedimentary zones of the Getic Carbonate Platform. Well preserved branching specimens were also described recently by Krajewski & Schlagintweit (2018) from Upper Jurassic reefs from the Crimena Peninsula. On the other hand, the proposed “encrusting” forms of Termier *et al.* (1985) can be explained by the following:

1) In the generic description of *Neuropora*, Termier *et al.* (1985) stated that “This genus presents a double behavior: encrusting in the young ontogenetic stages, then starting to be branched”. Taking this into account, the “encrusting” *N. lusitanica* forms represent an incipient development stage in the ontogeny of this sponge rather than a general morphostructural feature.

2) As known from the initial growth stages of chaetetids (Kershaw & West 1991; West 2011) the selective or inconsistently emergence of a growth center (or centers) of tubules represents a key factor in the morphological development of the skeleton. Therefore it can be deduced that more advanced ontogenetic stages of *N. lusitanica* can have a slightly different growth patterns. According to Kershaw (2012) specimens of the same species can develop different growth morphologies if they died before achieving an advanced ontogenetic stage.

3) It is well known that environmental conditions serve as the main controlling element of the growth phases and external morphological variations in many calcified sponges. Considering the present agitated environment, some adult *N. lusitanica* specimens might develop encrusting patterns when found in clusters (agglomerations) with other encrusting sponges such as *Sarsteinia babai* or *Perturbatacrusta leini*.

#### COMMENTS ON THE SYSTEMATIC POSITION

The genus *Neuropora* represents even today the subject of numerous debates regarding its systematic placement among the complex hierarchy of the calcified sponges phylogeny.

In a broad perspective, some *Neuropora* morphotypes can be compared (in terms of structural organization and external morphology) with other groups of invertebrates (anthozoans, bryozoans) thus the presumption for a bryozoan nature stood for decades (Walter 1969). Moreover, Schlagintweit & Ebli (1999) observed that *N. lusitanica* might share the same palaeoecological niches with bryozoans and can exhibit a similar “light honey-coloured appearance”. The bryozoan origin of *Neuropora* was placed under a question mark by Hillmer (1971) while studying the Cretaceous bryozoans from western Germany. Soon after, Brood (1971) temporarily assigned this genus to the stromatoporoids. The first irrefutable evidence for a sponge affinity of *Neuropora* was presented by Kaźmierczak & Hillmer (1974) based on the discovery of monoaxonoid spicules within the fibrous skeleton of the type species *Neuropora pustulosa* Roemer, 1839. The observed morphostructural similarities (spicules, basal skeleton and external features-mamelonar microstructures) between *N. pustulosa* and *Ceratoporella nicholsoni* (Hickson, 1911) encouraged Kaźmierczak & Hillmer (1974) to place *Neuropora* in the “Ceratoporellidae” family of the sclerosponge group. Even if a chaetetid feature was recognized by Termier *et al.* (1985) in the encrusting morphotypes of *Neuropora*, the authors established the “Neuroporidae” family to comprise this genus. In his substantial work on coralline sponges, Reitner (1992) noticed also a typical chaetetid architecture of *N. pustulosa* basal skeleton with ceratoporellid-type features in some specimens. Even if the overall development of the skeleton points to a chaetetid affinity, Termier *et al.* (1985) and Reitner (1992) stated that in advanced ontogenetic phases *Neuropora* specimens are often displaying an immature or partial organization. Following West *et al.* (2013), the genus *Neuropora* belongs to an uncertain family of hypercalcified chaetetid-type demosponges.

#### STRATIGRAPHIC RANGE

The known stratigraphic distribution of *Neuropora lusitanica* ranges between the upper Oxfordian (Termier *et al.* 1985) and the lower Aptian (Pleş *et al.* 2017) with an acme period during the late Kimmeridgian-Tithonian interval (Schlagintweit & Ebli 1999; Leinfelder *et al.* 2005; Schlagintweit & Gawlick 2008; Pleş *et al.* 2013).

### *Neuropora gigantea* Pleş & Schlagintweit, n. sp. (Fig. 5C–E; 6A, B)

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DERIVATION OF NAME. — The name of this species comes from the latin word *gigas* (giant, large) due to the large size of its skeleton.

MATERIAL. — One longitudinally sectioned specimen (holotype, sample 15092A), two transversely sectioned specimens (sample 15092B), one bifurcated specimen (sample 15092C1), three transversely sectioned individuals (samples 15092C1 and 15092D), one large individual (sample 15092H) and three transversely sectioned specimens (sample 15092L) together with numerous oblique/transverse sectioned specimens and several fragments (more than thirty specimens).

MEASUREMENTS. — The holotype is 4.3 cm high, 0.7 cm in diameter; 0.026–0.028 mm – the size of the tubule walls. The smallest individual is 3.2 cm in height and 0.5 cm in diameter, while the largest individual is 7.2 cm in height and 1.3 cm in diameter. Most of the measured specimens have the height of the skeleton between 4–5 cm with a diameter of 0.6–0.9 cm.

HOLOTYPE. — The longitudinally sectioned specimen from Figure 5E (sample 15092A, repository number 24127).

DEPOSITORY. — The holotype and other used thin-sections are stored at the Museum of Geology-Paleontology (Babeş-Bolyai University) under repository number 24127–24154.

TYPE LOCALITY. — **Romania.** The Grădiştei Gorges touristic complex (Braşov County).

TYPE LEVEL. — Upper Jurassic (Kimmeridgian-Tithonian) carbonates of the Giuvala Formation (Urdăriţa Member).

DIAGNOSIS. — Large sized poriferan (more than seven centimeters in height) with a cylindrical erect skeleton (sometimes bifurcated) and a pale yellow color. Both transverse and longitudinal sectioned specimens shows a fibrous pattern of the skeleton microstructure (Fig. 5C). A group of densely packed primary tubules with thin walls is forming a rigid axial zone of the skeleton. In transverse section, it can be observed that some of the main tubules possess small septa developed perpendicularly on tubule wall. Secondary elongated tubules are diverging from these central elements towards the peripheral zones of the skeleton (Fig. 5C, E). They are segmented by very thin tabulae. Some specimens can bear perforation marks. Spicules were not observed so far.

#### REMARKS

These large *Neuropora* specimens are dominating the sponge assemblage from Grădiştei Gorges. They can develop agglomerations or clusters (up to ten specimens) massively encrusted by cyanophyceans and *Lithocodium*-type crusts. Often they are associated with *Sphaeractinia*/*Ellipsactinia* and coral fragments. The assignment of this calcified sponge to the genus *Neuropora* was made based on the general diagnostic traits highlighted by Termier *et al.* (1985). Despite the fact that *Neuropora gigantea* Pleş & Schlagintweit, n. sp. shares some morpho-structural affinities with *N. lusitanica* (axial tubules from which lateral tabulated tubes are diverging towards the margins of the skeleton), detailed thin-section analysis have evidenced discrepancies between both taxa. As opposed to *N. lusitanica*, transverse sections of *Neuropora gigantea* Pleş & Schlagintweit, n. sp. show a much denser packing of the axial tubules. In addition, *N. gigantea* Pleş & Schlagintweit, n. sp. possesses thinner tubule walls (0.026–0.028 mm) displaying crude septal projections (Fig. 5D). Moreover the section of these tubes is rather irregular than circular as in *N. lusitanica*. Regarding the tabulae system within the lateral tubes, *Neuropora gigantea* Pleş & Schlagintweit, n. sp. have much larger segments between the tabulae developing a “bamboo”-type appearance in longitudinal sections rather than a “cone-in-cone” pattern as in *N. lusitanica* (Fig. 5A). Also the distance between the tabulae seems to be constant (as noticed by Termier *et al.* 1985) in *N. lusitanica* (see Schlagintweit & Ebli 1999: pl. 7, figs 10, 11 for comparison) as opposed to *Neuropora gigantea* Pleş & Schlagintweit, n. sp. where the distance increases progressively towards the peripheral zone

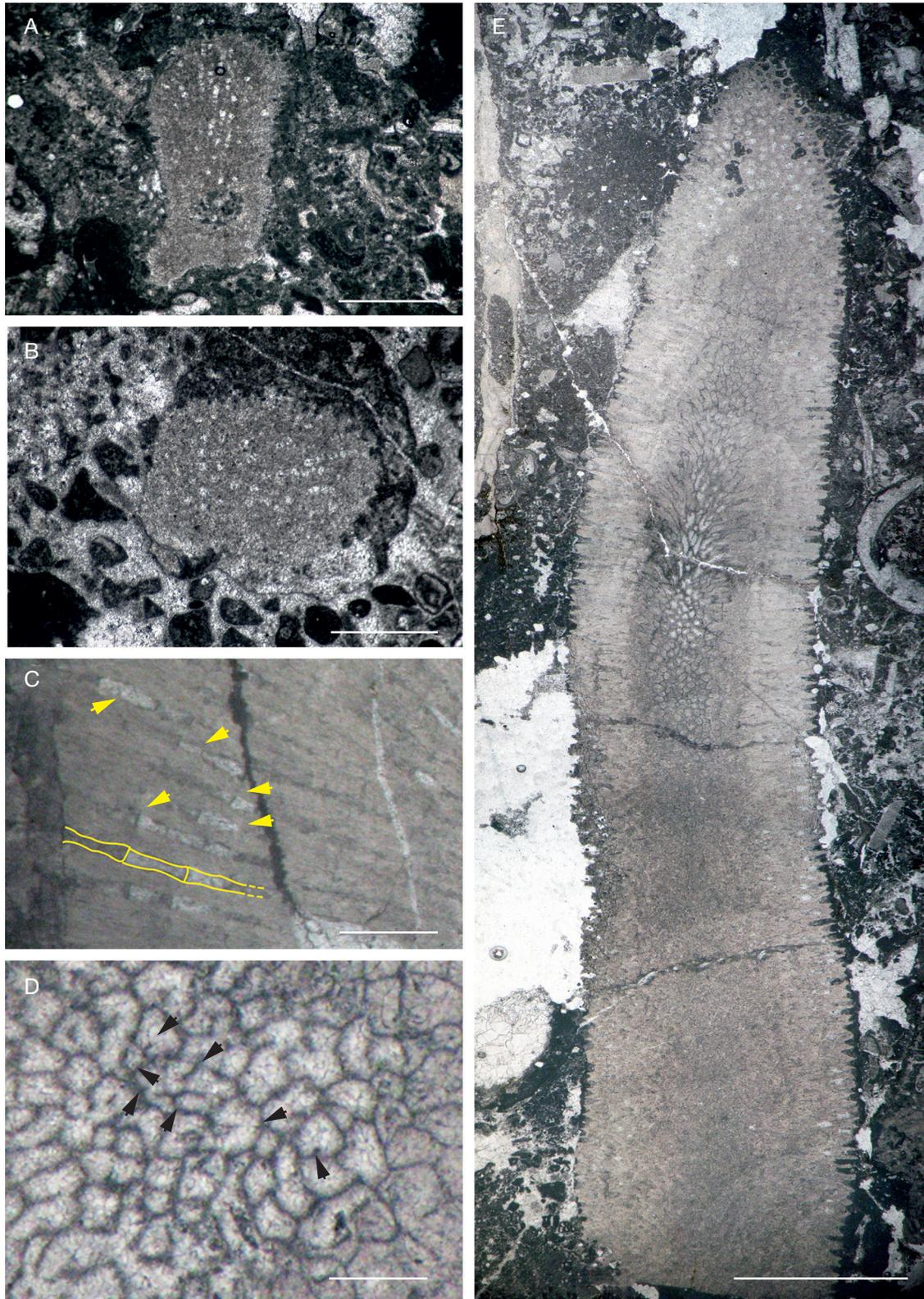


FIG. 5. — **A**, *Neuropora lusitanica* Termier, 1985 with a small perforation cavity within the lower part of the skeleton; notice the conically superimposed arrangement of the small tubules (sample 15092L); **B**, *Neuropora lusitanica* (sample 15092P); **C**, *Neuropora gigantea* Pleş & Schlagintweit, n. sp. longitudinally/oblique sectioned specimen; note the elongated tubules segmented by very thin tabulae (**yellow arrows**) developing a “bamboo”-type appearance; the yellowish fibrous pattern of the skeletal microstructure is also visible (sample 15092C-); **D**, cross-sectioned axial zone of *Neuropora gigantea* Pleş & Schlagintweit, n. sp. skeleton showing the closely packed axial tubules with thin septal projections (**black arrows**) (sample 15092B); **E**, *Neuropora gigantea* Pleş & Schlagintweit, n. sp. holotype; note the secondary elongated tubules diverging from the central elements (primary tubes) towards the peripheral zones of the skeleton (sample 15092A). Scale bars: A-C, 1 mm; D, 0.5 mm; E, 0.5 cm.

of the skeleton (Fig. 5C). Field observations have revealed that some of these large sponges have small bulbs or lumpy microstructures on the surface of the skeleton. Astrorhizae-type structures or stellate patterns were not observed. It is possible that *Neuropora gigantea* Pleş & Schlagintweit, n. sp. and *N. lusitanica* specimens might possess such structures similar to *N. pustulosa* (West *et al.* 2013) but due to the abrasion and intense fracturing (generated by the agitated environment) they were not preserved here. Last but not least the size of *Neuropora gigantea* Pleş & Schlagintweit, n. sp. (more than 7 cm in height and 1.3 cm in diameter) can represent a distinctive feature in comparison with *N. lusitanica* (average height 1–2 cm; diameter 3–3.5 mm) (Termier *et al.* 1985).

#### COMMENTS ON THE SYSTEMATIC POSITION

Based on the general morphostructural traits of its skeleton, a chaetetid-type bauplan is recognized for *Neuropora gigantea* Pleş & Schlagintweit, n. sp. However, the lack of spicules from the analysed specimens makes the assignment to a specific order or family of calcified sponges very difficult.

Genus *Sphaeractinia* Steinmann, 1878

*Sphaeractinia steinmanni* Canavari, 1893  
(Figs 6C; 7A–C, E)

*Sphaeractinia steinmanni* Canavari, 1893: 52, table 5, fig. 4. — Milan 1969: 169, table 12, figs 1, 2.

#### GENERAL DESCRIPTION

Large sized colonial calcified sponge (up to 5–6 cm in diameter) with a spherical/subspherical skeleton (“coenosteum” *sensu* Milan 1969) and a radial growth pattern. The main morphostructural features of *Sphaeractinia steinmanni* are represented by a series of superimposed arched micritic lamellae (becoming thinner towards the peripheral zones of the skeleton) connected through numerous short pillars (Figs 6C; 7A, C, E) and a radially developed canal system composed of spar filled tubules (sometimes developing astrorhizae-like structures [Fig. 7C]). The lamellar spaces possess numerous different-sized pores, best visible in the so called “parent lamella” (Fig. 7B) *sensu* Russo & Morsilli 2007. The canal system is not regularly developed throughout the skeleton thus the lamellar spaces appear more or less interrupted (in some parts of the skeleton) (Milan 1969). Where bundles of interconnected developed tubules are present (Fig. 6C; 7E), the lamellar spaces are very thin and therefore the skeletal structure appears as possessing a reticulated pattern (“dry-stone wall” *sensu* Russo & Morsilli 2007). Monoaxon spicules are rarely observed.

#### REMARKS

*Sphaeractinia steinmanni* represents an abundant species in the Upper Jurassic deposits from Grădiștei Gorges Complex. It may develop clusters (micro-colonies) most commonly with *Neuropora*, *Calcistella* and possibly *Ellipsactinia*. It is worth mentioning the fact that this species was identified

due to the very good preservation conditions which allowed insights into the inner- and outer architecture of its skeleton. Both *Ellipsactinia* and *Sphaeractinia* share common traits thus the differences between both genera are difficult to observe without well preserved specimens at hands. As opposed to the *Ellipsactinia*, *Sphaeractinia* possesses a much higher number of pillars connecting the interlamellar spaces (Fig. 7A) and interconnected tubules (or bundle of tubules) forming in the outermost parts of the skeleton astrorhizae-like canals (Fig. 7C). These are the most important diagnostic traits which can be observed by comparing both taxa (Milan 1969; Russo & Morsilli 2007). Also, the size of *Sphaeractinia* is much smaller than *Ellipsactinia* (Russo & Morsilli 2007). It is highly possible that *Ellipsactinia* specimens might be present here. This argument is supported by the fact that some fragments resemble *Ellipsactinia* microstructure but it is hard to determine if those fragments are part from *Ellipsactinia* skeletons or fragments of different growth stages of *Sphaeractinia*. Concerning other Upper Jurassic sphaeractinids, *S. steinmanni* differs from *S. diceratina* and *S. cylindrica* by its much better developed canals and through the lack of skeletal extensions (Milan 1969). Last but not least, Russo & Morsilli (2007) stated that in the so called “*Ellipsactinia* Limestone” from Upper Jurassic carbonates of Gargano promontory (Italy), *Sphaeractinia* is much more abundant than *Ellipsactinia*, as is also the present case in the Getic Carbonate Platform.

#### COMMENTS ON THE SYSTEMATIC POSITION

Generally, *Sphaeractinia* possesses (as most of the sponges described here) a stromatoporoid-type skeletal structure. Based on the main skeletal structure (canal system and radial elements), *Sphaeractinia* shares similarities with Actinostromina. For that reason Bachmayer & Flügel (1961) followed by Milan (1969) assigned *Sphaeractinia* (and also *Ellipsactinia*) to the order Sphaeractinoidea, superfamily Actinostromariidae, family Sphaeractinidae of the calcified demosponges.

#### STRATIGRAPHIC RANGE

Upper Jurassic (Kimmeridgian-Tithonian) (Milan 1969; Russo & Morsilli 2007; Schlagintweit & Gawlick 2007; Rusciadelli *et al.* 2011).

Genus *Calcistella* Reitner, 1991

*Calcistella jachenhausenensis* Reitner, 1992  
(Fig. 7D)

*Calcistella jachenhausenensis* Reitner, 1992: 157, pl. 24, figs 3–6. — Pleş *et al.* 2017: 104, fig. 8c.

#### GENERAL DESCRIPTION

Crustose sponge with densely packed aster-type microscleres and a canal system composed mostly of vertical tubules (Fig. 7D) with a light-orange color in normal transmitted light. Probably the most characteristic morpho-structural feature of *C. jachenhausenensis* is the concentrated agglomeration of tiny



FIG. 6. — Weathering surface of the Grădiștei Gorges carbonates: **A**, well preserved *Neuropora gigantea* Pleş & Schlagintweit, n. sp. specimen showing the external openings of the secondary tubules; **B**, transverse close-up view of the fibrous microstructure of the secondary elements in *Neuropora gigantea* Pleş & Schlagintweit, n. sp.; **C**, *Sphaeractinia steinmanni* Canavari, 1893 large specimen showing the inter-lamellar spaces pierced by numerous pillars and tubules. Scale bars: A, 1 cm; B, 1 mm; C, 0.5 cm.

spherical (aster-type) microscleres (Reitner 1992; West *et al.* 2013; Kaya & Altiner 2015; Pleş *et al.* 2017). The canal system is developed throughout the sponge skeleton and contains, beside the main vertical tubules, radially-arranged tubules (especially in the upper part) (Reitner 1992). This tubular organization can be regarded as the exhalant/inhalant system of *C. jachenhausenensis*. Tabulae are very rare. Reitner (1992) observed two types of secondary skeletal microstructures: a short-fibred calcite (first calcification phase) and micritic/granular microstructure. A stromatoporiid-type organization was regarded by Reitner (1992) and Kaya & Altiner (2015) for the secondary skeleton of *C. jachenhausenensis*.

#### REMARKS

Here, *Calcistella jachenhausenensis* was identified developing crustose fabrics around coral fragments and *Neuropora* specimens. Some *Calcistella* crusts can exceed 7–8 cm in thickness and possess well developed vertical tubules (Fig. 7D) best observed in cross-sections. This tubule system seems to be relatively dense and inter-tubular connections are very rare (Fig. 7D). The typically packed pattern of the spherical scleres (euasters) is visible in all *C. jachenhausenensis* crusts independently from the section plane. Regarding the mineralogy of the skeleton, Reitner (1992) stated that the original “organo/collagen matrix” of the primary skeleton was diagenetically replaced by a *synvivo* fibrous micrite.

#### COMMENTS ON THE SYSTEMATIC POSITION

According to Reitner (1992) *Calcistella jachenhausenensis* possesses a chaetetid-type basal skeleton, feature observed also in *C. tabulata* from the Albian of Greece (Reitner 1991). Compared to *C. tabulata* Reitner, *C. jachenhausenensis* has a rather crude system of tabulae (or completely absent). In the studied specimens this feature was not encountered. The sclere stacking is also much denser in *C. jachenhausenensis*. Moreover the tubular system from the holotype of *C. tabulata* (Reitner 1992: pl. 24, fig. 1) seems to be more closely-spaced and of larger size than in *C. jachenhausenensis*. Based on its general traits (especially the euaster-type microscleres) this taxon shares close affinities with the chondrillid-type demosponges. West *et al.* 2013 included *C. jachenhausenensis* in the Chondrosida order (Chondrillidae family) of the hypercalcified chaetetid-type demosponge group. Reitner (1992) mentioned the fact that *C. jachenhausenensis* is the first known taxon of this type from the Jurassic.

#### STRATIGRAPHIC RANGE

Reitner's (1992) *C. jachenhausenensis* holotype was found in upper Tithonian carbonates of the Solnhofen Plattenkalk quarry near Jachenhausen locality (Bavaria). Since that, numerous occurrences were noticed in Upper Jurassic (mostly Tithonian) carbonates from many countries of Europe (Austria – Schlagintweit & Gawlick 2008; Romania – Pleş *et al.* 2013; Turkey – Kaya & Altiner 2015; etc.). Beside the Upper Jurassic occurrences, Pleş *et al.*, 2017 identified *C. jachenhausenensis* in lower Aptian deposits from Eastern Carpathians. Summarizing all, the stratigraphic range of *Calcistella jachenhausenensis* is Tithonian-lower Aptian with an acme period in ?upper Kimmeridgian-Tithonian.

Genus *Perturbatacrusta*  
Schlagintweit & Gawlick, 2011

*Perturbatacrusta leini*  
Schlagintweit & Gawlick, 2011  
(Fig. 7F)

*Perturbatacrusta leini* Schlagintweit & Gawlick, 2011: 131, figs 5c, d, 7a-g, 8a-f. — Pleş & Schlagintweit 2014: 9–11, fig. 4.

#### GENERAL DESCRIPTION

Encrusting poriferan with low-domical medium sized skeleton attached mostly on other sponges and corals. The internal architecture of the skeleton is represented by a three-dimensional network of thick horizontal and vertical elements with smooth rounded walls penetrated by a labyrinthic system of interconnected tubules (canal meshwork) (Fig. 7F). According to Schlagintweit & Gawlick (2011) and Pleş & Schlagintweit (2014) an axial cavity, spicules and astrorhizae were so far not observed in *Perturbatacrusta leini*. For a detailed diagnosis see Schlagintweit & Gawlick (2011) and Pleş & Schlagintweit (2014).

#### REMARKS

*Perturbatacrusta leini* represents an abundant species within the Upper Jurassic shallow-water encrusting communities of the Tethyan rimmed carbonate platform systems (Schlagintweit & Gawlick 2008, 2011; Pleş *et al.* 2013; Kaya & Altiner 2015). Here, *Perturbatacrusta leini* was frequently identified as part of encrusting agglomerations associated mostly with *Cylindropsis verticalis*, *Sarsteinia babai*, *Calcistella jachenhausenensis*, *Crescentiella* morphotypes and with numerous syndepositional cement crusts (Fig. 4D). Cross- and longitudinally-sectioned individuals revealed that most of the internal tubules are filled with spar cements and, rarely, internal sediment (Fig. 7F). The skeleton has a smooth microcrystalline pattern with a light-grey colour as similar with other *P. leini* specimens from the Upper Jurassic carbonates of the Getic Carbonate Platform (Pleş *et al.* 2013, 2016; Pleş & Schlagintweit 2014) and Northern Calcareous Alps (Schlagintweit & Gawlick 2008, 2011).

#### COMMENTS ON THE SYSTEMATIC POSITION

Considering its main morphostructural attributes (encrusting fabric, lack of spongocoel, non-spicular skeleton, etc.) and some resemblances with another microencrusters (*Radiomura cautica*), *Perturbatacrusta leini* was either unjustifiably interpreted as *Radiomura cautica* (see the synonymy list in Schlagintweit & Gawlick 2011), or considered a microencruster of an unknown systematic position. In the original description of Schlagintweit & Gawlick (2011) the differences between both taxa (*P. leini* and *R. cautica*) are clearly explained and a possible poriferan nature of *P. leini* is discussed. The discovery of several well-preserved *P. leini* specimens in the Upper Jurassic carbonates of the central part of the GCP (Buila-Vânturarița Massif) by Pleş & Schlagintweit (2014: 11, fig. 4 a-f) allowed new insights into the structural architecture of this species. The labyrinthic system of interconnected tubules and the

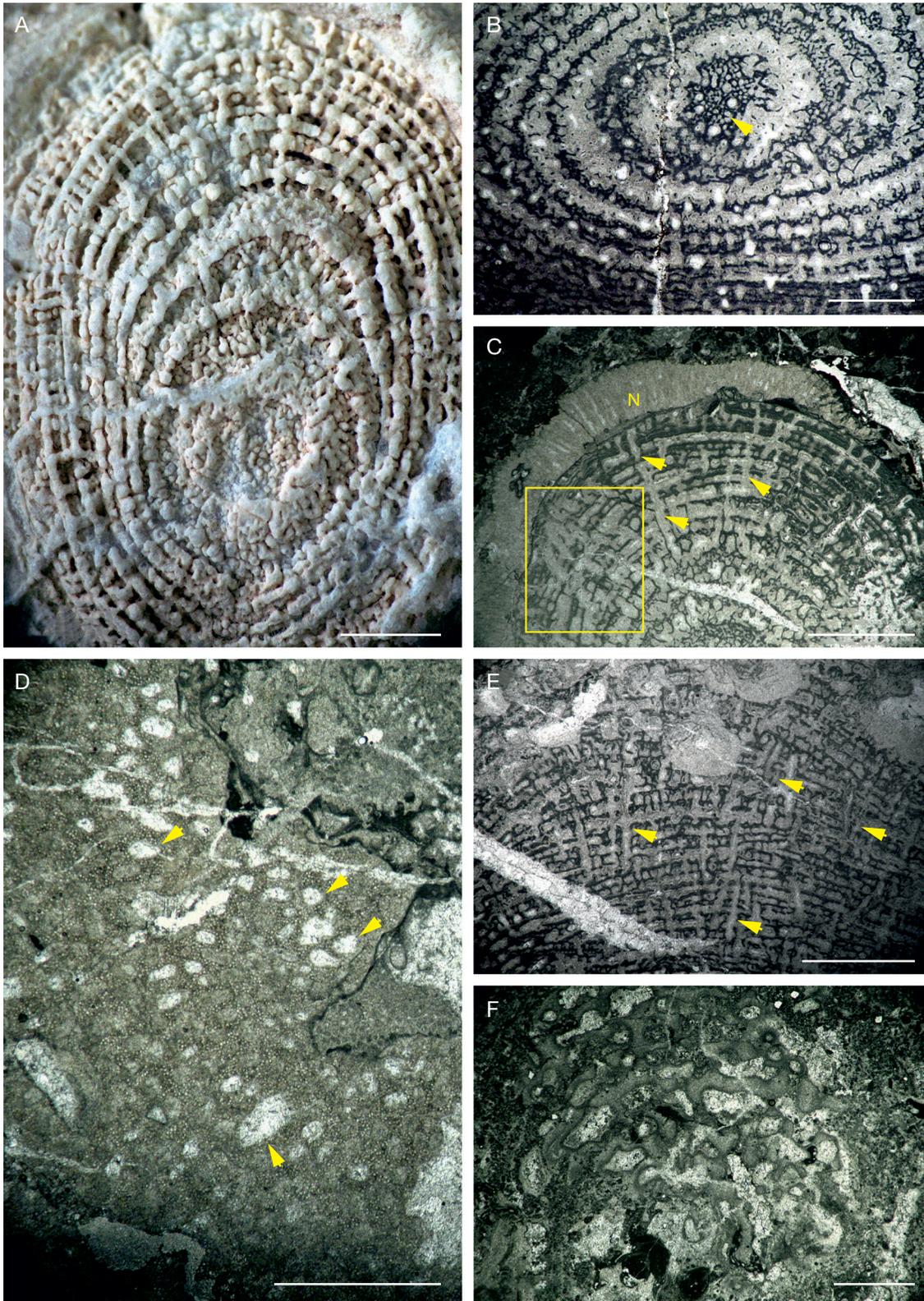


FIG. 7. — **A**, *Sphaeractinia steinmanni* Canavari, 1893 in weathering surface; **B**, cross-sectioned specimen of *S. steinmanni* showing the parent lamella (**yellow arrow**) and thick inter-lamellar spaces filled with spar calcite (sample 15092F); **C**, longitudinal/oblique *S. steinmanni* encrusted by *Neupora* Bronn, 1825 (**N**); numerous large radial tubules can be noticed connecting the inter-lamellar spaces (**yellow arrows**) or developing astrophorae-like structures (**yellow square**) (sample 15092J); **D**, *Calcistella jachenhausenensis* Reitner, 1992; notice the densely packed aster-type spherical microscleres and the spar filled vertical tubules (**yellow arrows**) (sample 15935); **E**, *Sphaeractinia steinmanni* with bundles of inter-lamellar tubules (**yellow arrows**) and its typical reticulated pattern (sample 15092I); **F**, low-domical encrusting skeleton of *Perturbatacrusta leini* Schlagintweit & Gawlick, 2011; notice the smooth microstructure of the skeletal walls and the inter-connected system of tubules filled with granular spar calcite (sample 15092S). Scale bars: A, 0.5 cm; B, C, E, 2 mm; D, 1 cm; F, 1 mm.

network of horizontally and vertically developed skeletal elements point to a stromatoporomorph-type development and, respectively, to a poriferan nature of *Perturbatacrusta* (Pleş & Schlagintweit 2014). Following these, *Perturbatacrusta leini* can be regarded as a calcified stromatoporomorph-type sponge rather than a typical microencruster.

STRATIGRAPHIC RANGE

Kimmeridgian-Berriasian (Schlagintweit & Gawlick 2011; Pleş & Schlagintweit 2014; Kaya & Altiner 2015).

Genus *Sarsteinia*

Schlagintweit & Gawlick, 2006 emend.

*Sarsteinia babai*

Schlagintweit & Gawlick, 2006 emend.

(Fig. 8A, B)

*Sarsteinia babai* Schlagintweit & Gawlick, 2006: 254-256, pl. 1, figs 1-8. — Kaya & Altiner 2015: 12, fig. 5l-m.

GENERAL DESCRIPTION

Large sized (4.2 cm in height; 2.8 cm in diameter) leuconid-type encrusting poriferan with a skeleton pierced by numerous anastomosing tubules forming a complex canal system. Thin section analysis revealed the fact that the canals are filled either by internal sediment or matrix (Fig. 8B) either by druzey- or mosaic-type spar cements (Fig. 8B). According to Schlagintweit & Gawlick (2006) the canals can possess smooth branches and could represent the exhalant canals of the sponge. The microstructure of the skeleton is characterized by the presence of interconnected dark micritic veins surrounded by a distinct layer of pale-yellow fibrous cement (Fig. 8B). It is possible that some of the micritic veins or fibres may represent septal projections. Spicules were not observed. Following the original description of Schlagintweit & Gawlick (2006) and Kaya & Altiner (2015), *Sarsteinia babai* does not possess a spongocoel and lacks segmentation. The outer surface of the skeleton is defined by the presence of tubercles or ridges.

REMARKS

Most specimens are found here developing encrusting fabrics together with *Calciostella jachenhausenensis*, *Cylicopsis verticalis* or *Perturbatacrusta leini*. Even so, two cylindrical or “barell”-like specimens (up to 9 cm) possess in the central part of the skeleton a large curve-edged cavity (Fig. 8B) that clearly represent the evidence for a spongocoel. Moreover, the outermost parts of the spongocoel are contoured by a micritic band associated with the thin dark fibres which are structuring the sponge skeleton (Fig. 8B yellow arrow). The possible connections of the canal system with the spongocoel are not visible or obturated prior to diagenesis but, considering them as exhalant channels (*sensu* Schlagintweit & Gawlick 2006), a relation between these elements should exist. Given the shape, position and the features mentioned above, the

observed central cavity in several *S. babai* specimens from Grădişteii Gorges Complex is clearly different than a biotic structure or an abrasional/fragmental feature. As it happens, the specimen illustrated in Fig. 8B displays a large bioerosive structure (perforation) with different observable traits than the existing spongocoel. The identification of a central cavity (spongocoel) in *Sarsteinia babai* specimens here represents a feature of great diagnostic value. It serve as an additional argument in the emendation of the description made by Schlagintweit & Gawlick (2006). Apart from this, some of the tubules which form the canal system (?main tubules) are interconnected through various points and appear to spread from the spongocoel to the exterior of the skeleton in oblique/longitudinal sectioned specimens (Fig. 8B). Frequently, *Lithocodium*-type superimposed microstructures are observed within the peripheral zones of the skeleton.

COMMENTS ON THE SYSTEMATIC POSITION

Regarding the systematic position of *S. babai*, following Schlagintweit & Gawlick (2006) this calcified sponge shares both inozoan (based on the tubular canal system) and stromatoporoid features (considering the skeletal microstructures). Depending on the identified central cavity (spongocoel), the *Peronidella*-type morphology of inozoans (Rigby & Senowbari-Daryan 1996) can be used for understanding the morphostructural features and water circulation patterns in *Sarsteinia babai*. It is highly possible that most of tubules which form the canal system represent inhalant canals, much of the exhalation process being made upward through the spongocoel. Regarding the stromatoporoid affinity of *S. babai*, Schlagintweit & Gawlick (2006) admit this possibility only in terms of skeletal microstructure. The lack of transverse elements, distinct aquiferous system and other stromatoporoid-type features makes this argument less probable. Considering all, *Sarsteinia babai* represents an example of calcified inozoanomorph sponge with a stromatoporoid-type skeletal microstructure.

STRATIGRAPHIC RANGE

Kimmeridgian-?Valanginian (Schlagintweit & Gawlick 2006; Kaya & Altiner 2015).

Genus *Calciagglutispongia* Reitner, 1992

*Calciagglutispongia yabei* Reitner, 1992  
(Fig. 8C, D)

*Calciagglutispongia yabei* Reitner, 1992: 288, pl. 52, figs 1-4. — Leinfelder *et al.* 2005: 295, fig. 7b.

GENERAL DESCRIPTION

Medium sized (2.3-2.8 cm in diameter) encrusting poriferan with a thick calcified skeleton characterized by a reticulate network of fibres made of agglutinated small particles (Fig. 8D). According to Reitner (1992) the original mineralogy of the skeleton was spongin. The agglutinated sediment which form

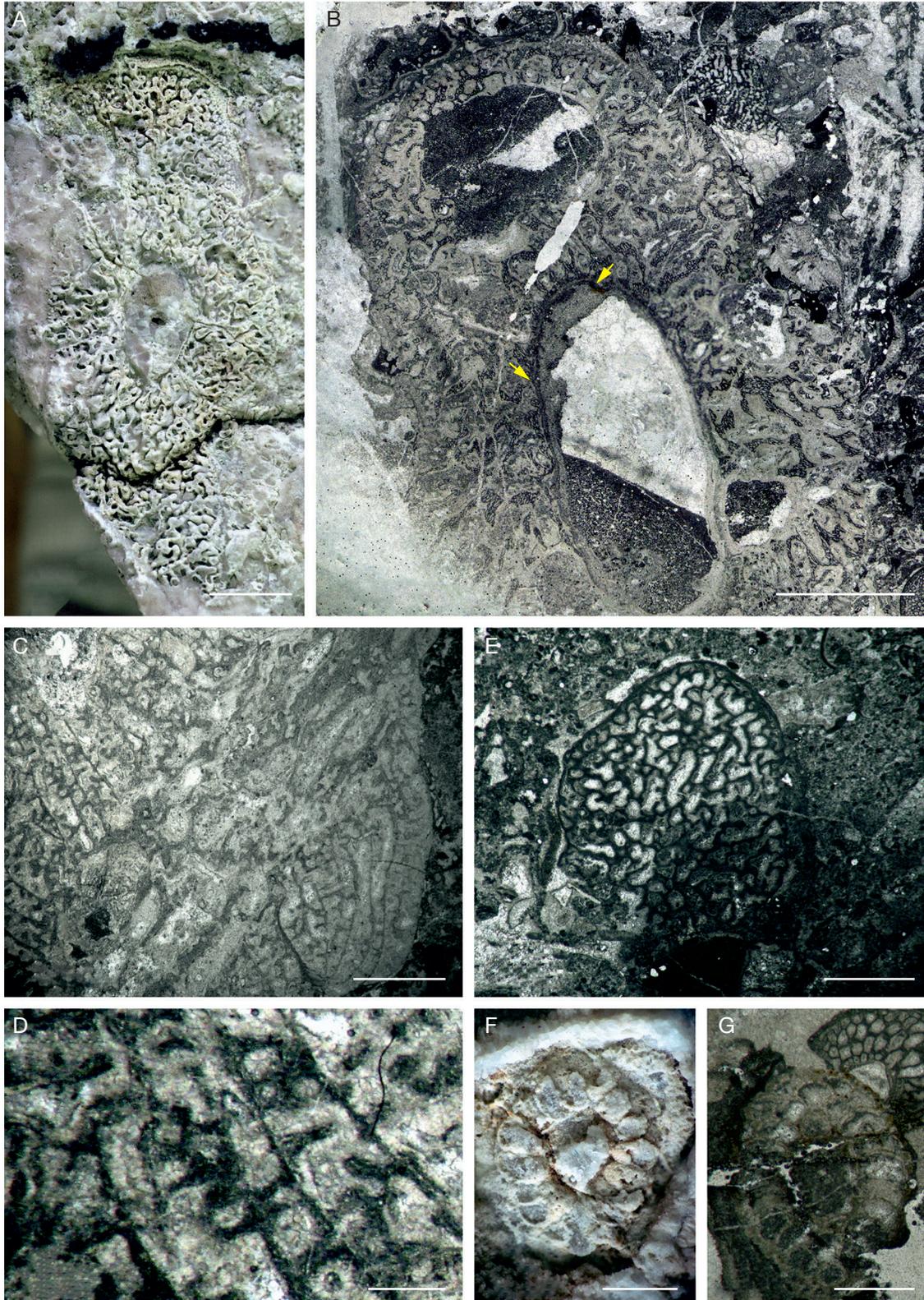


FIG. 8. — **A**, *Sarsteinia babai* Schlagintweit & Gawlick, 2006 emend. in weathering surface; **B**, longitudinally-oblique section of the *S. babai* presented in **A** (sample 15937); the dark micritic veins surrounded by a distinct layer of pale-yellow fibrous cement are noticed throughout the internal structure; in the central part of the skeleton the spongocoel cavity is preserved filled with geopetal sediment; the outermost parts of the spongocoel are contoured by a fine micritic rim (**yellow arrows**); a perforation cavity is also visible in the upper part of the skeleton; **C**, *Calciaagglutispongia yabei* Reitner, 1992 showing a system of large central tubules flanked by laterally developed tubes with a superimposed pattern (sample 15092R); **D**, *C. yabei* close-up view over the lateral tubes; it can be observed the agglutinated small particles which are forming a network of dark fibers (sample 15092R); **E**, *Cylicopsis verticalis* Tumšek, 1968 (sample 15092J); **F**, *Thalamopora lusitanica* Termier, Termier & Ramalho, 1985 in weathering surface; **G**, *T. lusitanica* longitudinally/obliquely sectioned specimen showing the fish-scales imbricated pattern of vesicles arrangement (sample 15092T). Scale bars: A, B, 1 cm; C, E, F, G, 2 mm; D, 0.5 mm.

the inner elements (fibres) is made of fine micritic sediment and grains (Fig. 8B). The canal system shows tube-diameter ranging from 400 to 750 µm. Spicules were not observed and astrorhizae-type structures are poorly developed.

REMARKS

*Calciagglutispongia yabei* specimens here are generally large (up to 5 cm high) and may develop crustose features. Some longitudinally-oblique sectioned skeletons (Fig. 8C) reveal new insights into the canal system development of this taxon. As illustrated in Figure 8C, a well organized system of large tubules are visible in the central part of the skeleton which is flanked by laterally developed tubules with a superimposed pattern. The skeletal walls of the central tubules are made also of agglutinated fine micritic sediment being much thicker than the fibre network of the lateral elements. Frequently, *Crescentiella morronensis* microbodies are found encrusted on *Calciagglutispongia yabei* skeletons (Fig. 8C).

COMMENTS ON THE SYSTEMATIC POSITION

Based on the micritic microstructure and its reticulate texture, *Calciagglutispongia yabei* shares some semblances with the actinostromariid sponges. Reitner (1992) stated that the agglutinated small grains which form the inner-skeletal elements (fibres) point to a keratose affinity of *C. yabei*. Moreover, the calcification model is recorded in numerous poriferans with an organic fiber skeleton. Considering all, *Calciagglutispongia yabei* can be regarded as a coralline sponge belonging to the Keratosa group (Reitner 1992).

STRATIGRAPHIC RANGE

Kimmeridgian-Tithonian (Reitner 1992; Leinfelder *et al.* 2005; Schlagintweit & Gawlick 2007).

Genus *Thalamopora* Römer, 1840

*Thalamopora lusitanica* Termier,  
Termier & Ramalho, 1985  
(Fig. 8F, G)

*Thalamopora lusitanica* Termier *et al.*, 1985: 214, pl. 9, figs 1-12. — Pleş *et al.* 2015: 53, fig. 5k.

GENERAL DESCRIPTION

Medium sized chambered calcified sponge (0.5-0.8 cm in height; 0.4-0.6 cm in diameter) with a cylindrical shape and a hollow central cavity (Fig. 8F, G). In early ontogenetic stages the shape of the skeleton is conical and enlarged upward. According to Termier *et al.* (1985), *Thalamopora lusitanica* has relatively thick multilayered walls composed of smooth elliptical elements (“elliptical sclérodermites”) in the internal part, a meshwork of tetractine spicules as a middle layer (observed mainly in tangential sectioned specimens) and a microcrystalline fibrous outer layer. The sponge chambers (vesicles) are developed regularly around the central cavity, in longitudinal sections appearing symmetrically arranged

around the spongocoel. In oblique and sub-axial sections the arrangement of the chambers shows an imbricated pattern (Fig. 8G) described by Termier *et al.* (1985) as “similar with fish scales” or “glomerate arrangement” *sensu* Senowbari-Daryan & Rigby (2011). The canal system is characterized by the presence of well organized small tubules. Short tubules are observed within the outer wall of the skeleton opening into the vesicles (Fig. 8G). Inter-chamber connections consist of thin pores best observed in longitudinal sections. Each chamber (vesicle) contains one larger pore (more or less elliptical in shape) which opens into the central cavity. Termier *et al.* (1985) stated that these elements stored the choanocytes of the sponge. In thin sections, *Thalamopora lusitanica* can be easily recognized by its chambered (segmented) structure and by its light-orange pored walls.

REMARKS

As most of the calcified sponges identified here, *T. lusitanica* occurs in association with microproblematic encrusting morphotypes (*Crescentiella* or *Lithocodium*) (Fig. 8G). The vesicles of *T. lusitanica* are normally filled with granular spar cement but, in some cases, few may be filled with internal fine sediment prior to abrasion of the skeleton walls (Fig. 8G). It is worth mentioning the fact that this species is not that abundant in comparison with the other poriferan species from the Grădişteii Gorges Complex carbonates. Schlagintweit *et al.* (2019) described from the Upper Jurassic carbonates from Iran several slightly different *Thalamopora* specimens (*Thalamopora* sp.) with lesser chambers in transverse sections in comparison with *T. lusitanica*.

COMMENTS ON THE SYSTEMATIC POSITION

The general structure of *Thalamopora lusitanica* practically follows the development plan of barroisid sponges (Termier *et al.* 1985; Senowbari-Daryan & Rigby 2011). The similarities between *Thalamopora* and *Barroisia* Munier-Chlamas are related to the skeletal wall design, while the discrepancies should be associated with the presence of elliptical pores and chamber development. As opposed to *Barroisia*, *Thalamopora* has a very regular chamber progression and “elliptical sclérodermites” *sensu* Termier *et al.* (1985) on the inner parts of the vesicle wall. The second feature is according to Termier *et al.* (1985) commonly observed in some Permian representatives of the genus *Permosphincta* Termier & Termier, 1974, therefore a convergence between *Permosphincta*-type sponges and sphinctozoans was regarded. In agreement with Senowbari-Daryan & Rigby (2011) the chambered poriferans are included in the Sphinctozoa group, thus *Thalamopora* was systematically placed here belonging to the Sphaerocoelellidae order of the Calcispongiae class.

STRATIGRAPHIC RANGE

*Thalamopora lusitanica* was found by Termier *et al.* (1985) in upper Oxfordian deposits from Portugal. Since that, several occurrences of this taxon were reported mainly in uppermost Jurassic (Kimmeridgian-Tithonian) intra-Tethyan carbonate platforms from Europe (Bucur & Săsăran 2005; Leinfelder

*et al.* 2005; Sásáran 2006; Schlagintweit & Gawlick 2008; Pleş *et al.* 2013; Mircescu *et al.* 2016). In conclusion the stratigraphic range of *T. lusitanica* is upper Oxfordian-Tithonian (possibly Berriasian).

## DISCUSSION

### TAPHONOMICAL FEATURES

The development of growth patterns of sponges can serve as important features in understanding some taphonomical processes here. As a rule, the crustose morphologies of most identified sponges (*Perturbatacrusta*, *Calciagglutispongia*, *Calcistella*, *Sarsteinia*) represent the result of the encrusting potential triggered by the instability of the reef flank sediments and episodic fragmented debris. Associated with numerous microencrusters (*Crescentiella*, *Radiomura*, *Lithocodium*-type microstructures) and early diagenetic cement crusts (mainly fibrous-radial), these sponges formed small bioherms (crustose patches, clusters, agglomerations) and well cemented reef-debris carbonates which have proven to be resistant to subsequent compactation and pressure dissolutions. Given these encrusting morphotypes, skeletal breakage of sponges occurred rarely in such forms, the most susceptible to deterioration being the columnar *Neuropora*. Even so, many *Neuropora* specimens are very well preserved (Figs 6A, C; 7A; 8A). Skeleton size can also represent a key factor for the fragmentation resistance as noticed in *Sphaeractinia steinmanni* large specimens and some *Neuropora* skeletons. Several diagenetic processes (recrystallization or neomorphic features) can modify the primary microstructure of the sponge skeleton resulting in some diagnostic uncertainties (Reitner 1992; West 2011). This scenario can be partly followed here, since most of the analysed sponges have probably an unaltered skeletal microstructure (as compared with the microstructural diagnostic traits of holotypes and other specimens). West (2011) stated that it is also possible that the main microstructure of some sponges could have been replaced by a diagenetically induced microstructure (prior to recrystallization or micritization processes) which may imitate the original microstructure. This might perhaps explain the smooth microstructure of *Perturbatacrusta* or the micritic/granular skeletal elements of *Calciagglutispongia*. As seen in the description chapter, some of the analysed poriferans do not possess spicules (or are very rarely preserved). One way to explain this is via biostratinomic processes. Considering the fact that the spicules of many hyper-calcified sponges are incorporated within the soft tissue of the skeleton (Reitner 1992; West 2011), possibly after death these spicules are either eroded/diagenetically altered or being found sporadically in some parts of the main skeleton. Taking into account that numerous hypercalcified demosponges are known to possess an aspicular skeleton (Reitner 1992; Leinfelder *et al.* 2005; West 2011; West *et al.* 2013), it can be deduced that such case can be traced here in some species.

Regardless of the fact that the general preservation of the sponge assemblage is very good, some taphonomical processes are observed to affect the morphostructural features of several

species. Bioerosional features (especially borings and perforations) are noticed in *Neuropora* or *Sarsteinia* specimens (Fig. 8A) mainly affecting skeletons in advanced ontogenetic stages. Micritization, cyanophycean activity (thin crusts) and replacement cementation can also affect the outermost (peripheral) zones of *Neuropora*, especially the thin skeletal elements such as the tabulae system (Fig. 5E). Abrasion might hold back the observation of the astrorhizae-type structures (aquiferous system) on the outer surface of the sponge skeletons but, in some cases, the presence of such structures can be followed within the inner-structure (e.g. *Sphaeractinia* specimens [Fig. 7C]). Skeletal breakage is present, but with less importance in species identification given the fact that most of the sponges are very well fossilized.

### PALAEOECOLOGY AND PALAEOGEOGRAPHIC SETTING

The palaeoecological significance of Upper Jurassic hypercalcified sponges assemblages represent a subject of great importance in understanding the evolution of reef environments within the intra-Tethyan realm. The available data on Paleozoic stromatoporoids (Kershaw 1990; Webby & Kershaw 2011; Da Silva *et al.* 2011; Kershaw 2012) and Upper Jurassic northern Tethyan shelves assemblages (Werner *et al.* 1994; Leinfelder *et al.* 2005) can be partly used for understanding some of the palaeoecological features exhibited by the present association.

Probably one of the most important response to the environmental settings of the present poriferan assemblage is represented by the morphostructural adaptations resulting in shape/size variations. In respect with the most abundant poriferans, two major trends can be noticed regarding the shape morphologies. First, considering the unstable hard substrate (intraclasts, skeletal debris) of the fore-reef environment, it is obvious that species like *Sarsteinia*, *Calcistella*, *Perturbatacrusta*, *Calciagglutispongia* (or several *Neuropora* specimens) should develop mostly crustose, low-domical encrusting growth patterns. Such features are commonly observed on Paleozoic stromatoporoids from high-energy reef settings (Webby & Kershaw 2011). Second, spherical, columnar/cylindrical or branching morphotypes are developed by *Sphaeractinia* and large specimens of *Neuropora gigantea* Pleş & Schlagintweit, n. sp. Even if the abundance of such forms can reflect in most cases low energy conditions (West 2011), a possible explanation for this feature here can be the competition for nutrient supply. Considering the fact that most of the nutrients are divided (or preferentially obtained) by corals and low-domical/encrusting poriferans, a higher elevation (cylindrical/erect form) over the substrate and a bigger size should facilitate additional nutrients (or prioritize the nutrient supply). Also such features can be triggered by fluctuations of the sedimentary input in this agitated environment since intraspecific morphostructural variations (switch from crustose patterns to cylindrical/columnar) were recorded in some Paleozoic and Mesozoic stromatoporoids (Leinfelder *et al.* 2005; Webby & Kershaw 2011). The same scenario can be applied for large individuals of *Sphaeractinia* and *Ellipsactinia*.

TABLE 2. — Comparison between Intra- and Northern Tethyan calcified sponge occurrences based on Pleş *et al.* (2013, 2016) for Getic Carbonate Platform (Romania); Schlagintweit (2011, 2012) and Schlagintweit & Gawlick (2007, 2008, 2009, 2011) for Northern Calcareous Alps (Austria); Milan (1969) and Turnšek *et al.* (1981) for Slovenia and Croatia; Hoffmann *et al.* (2017) for Štramberk carbonate platform (Czech Republic); Rusciadelli *et al.* 2011 and Ricci *et al.* (2018) for Apennines (Italy); Kaya & Altiner (2015) for Turkey; Termier *et al.* (1985) for Portugal; Leinfelder *et al.* (2005) and Reitner (1992) for Spain, Germany and France.

	Intra-Tethyan realm						Northern Tethyan realm			
	Romania	Austria	Slovenia & Croatia	Czech Republic	Italy	Turkey	Portugal	Spain	Germany	France
<i>Neuropora lusitanica</i> Termier, 1985	•	•	–	•	–	•	•	–	•	–
<i>Sphaeractinia steinmanni</i> Canavari, 1893	•	–	•	–	•	–	–	–	–	–
<i>Ellipsactinia</i> Steinmann, 1878	•	•	•	–	•	–	–	–	–	–
<i>Calcistella jachenhausenensis</i> Reitner, 1992	•	•	–	•	–	•	–	–	•	–
<i>Perturbatacrusta leini</i> Schlagintweit & Gawlick, 2011	•	•	–	•	–	•	–	–	–	–
<i>Sarsteinia babai</i> Schlagintweit & Gawlick, 2006 emend.	•	•	–	–	–	•	–	–	–	–
<i>Calciagglutispongia yabei</i> Reitner, 1992	•	•	–	–	–	–	–	•	–	–
<i>Thalamopora lusitanica</i> Termier, Termier & Ramalho, 1985	•	•	–	–	–	–	•	–	–	–
<i>Cylicopsis verticalis</i> Turnšek, 1968	•	•	•	–	–	–	–	–	–	•

Concerning the bathymetric implications of the present sponge assemblage, the identified species were reported mostly from shallow-water fore-reef environments from numerous sites in Europe (Schlagintweit *et al.* 2005; Schlagintweit & Gawlick 2008; Pleş *et al.* 2013; Kaya & Altiner 2015), as opposed to the northern Tethyan siliceous sponge bioherms which can bloom in much deeper settings. Both sedimentological (abraded skeletal debris, intraclasts, encrusting framework) and palaeontological features (sponges, corals, gastropods, worm tubes, benthic foraminifera, microencrusters) encountered in the Grădişteii Gorges carbonates are sustaining this statement. However, the abundance of *Sphaeractinia* and *Ellipsactinia* generally point to a steep angle of the fore-reef flank and, subsequently, to a slightly deeper sedimentary setting (Turnšek *et al.* 1981; Leinfelder *et al.* 2005). This is supported also by the fact that the analysed carbonates were developed in the easternmost parts of the Getic Carbonate Platform where a very steep slope existed facing the Sinaia Trough (Patrulius 1976). Furthermore, centimeter-sized *Neuropora* specimens were identified thriving in much deeper settings within the siliceous sponge facies of Portugal (Werner *et al.* 1994). Leinfelder *et al.* (2005) stated that beside *Neuropora*, no other Upper Jurassic stromatoporoid-type sponge can prosper in the same bathymetric range as the siliceous sponges. Concluding these, a slightly deeper fore-reef environment (several tens of meters) for the Grădişteii Gorges carbonates is assumed.

Given the fact that the present sponge assemblage and the associated palaeontologic content (corals, foraminifera, calcareous green algae) are known to thrive in elevated temperature seas (Leinfelder *et al.* 2005; Schlagintweit & Gawlick 2008; Flügel 2010), a warm tropical epicontinental palaeoenvironment

it is assumed for the formation of such carbonates. It is known that opposed to corals, stromatoporoids have a much bigger resistance to overheated waters (Kołodziej 2003; Leinfelder *et al.* 2005). Therefore it can be deduced that the dominance of coral-reefs over stromatoporoids in the northern Tethyan shelves (Spain, Portugal, Germany) can be related to a slightly cooler environment. According to Leinfelder *et al.* (2005), the observed differences in the stromatoporoid distribution throughout the Neotethys point to an increased species abundance in the intra-Tethyan region compared to the adjacent Tethyan zones (where corals or siliceous sponges dominate the reef biota). The authors (Leinfelder *et al.* 2005) suggested that such features can be related to the poriferan adaptations for much warmer waters, agitated environments and to oligotrophic conditions. This scenario can be followed here since a clearly dominance of calcified sponges abundance versus corals is recorded.

The similarities of the Getic Carbonate Platform (facies associations, biotic content, lithology) with synchronous deposits from Northern Calcareous Alps, Dinarides, Apennines (Morsilli & Bosellini 1997; Schlagintweit *et al.* 2005; Rusciadelli *et al.* 2011) point to an equivalent palaeogeographic domain where these isolated carbonate platforms evolved. Based on the existing tectonostratigraphical data and palaeogeographical models (Golonka 2002; Schmid *et al.* 2008; Gawlick *et al.* 2009; Missoni & Gawlick 2011) this large carbonate factory was located in the innermost parts of the Neotethyan ocean (between 20–35° northern palaeolatitude) bordered by the newly opened Penninic-Piemont ocean (Alpine ocean) to the north, Vardar ocean to the east and open oceanic environment of the Neotethys and African plate (Gondwana) to the southeast-east (Fig. 9).

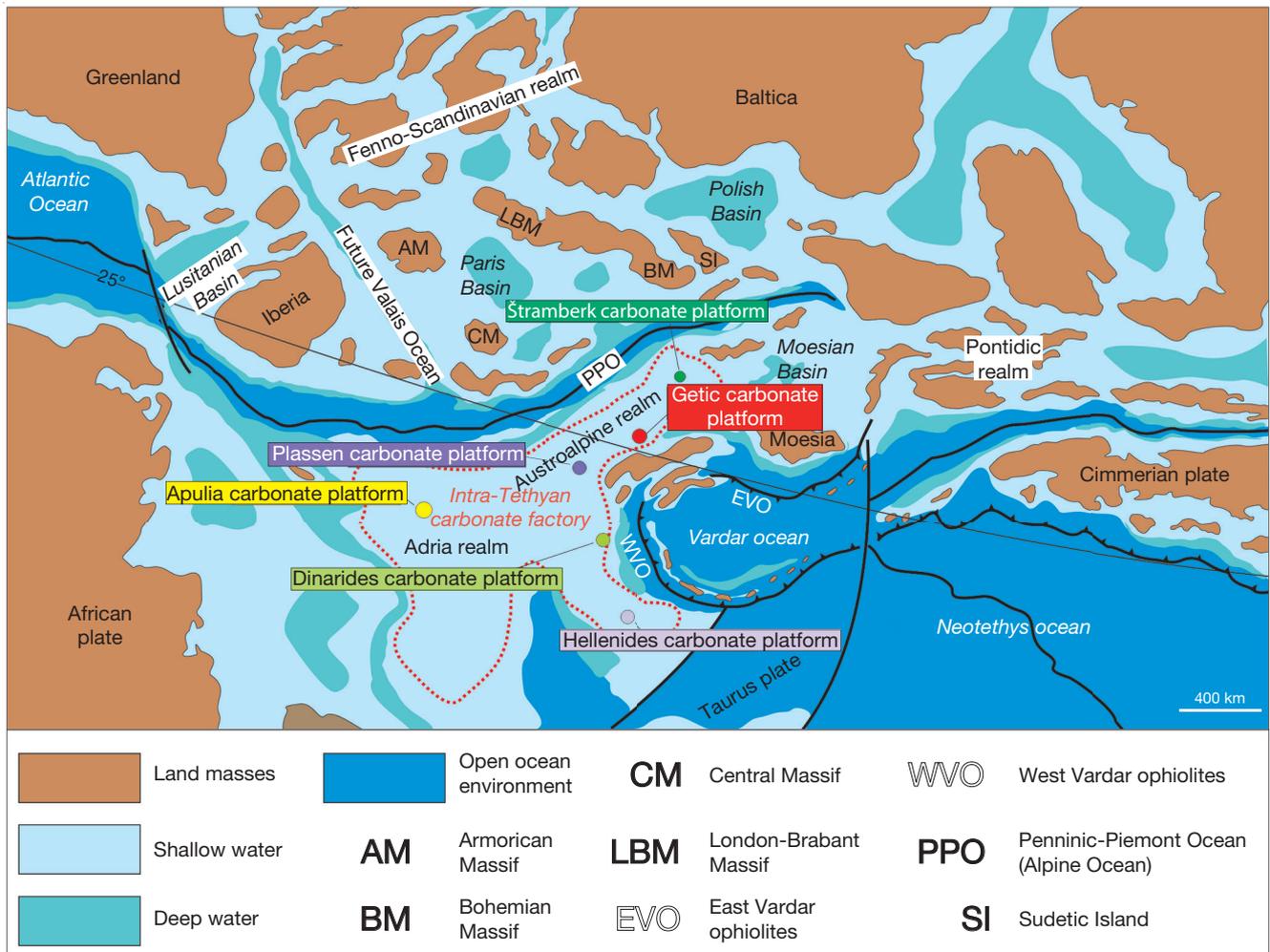


Fig. 9. — Simplified palaeogeographic map for the European Tethyan realm during the Late Jurassic-earliest Cretaceous and the presumed locations of the main intra-Tethyan carbonate platforms based on Paleogeography of Europe Series (Colorado Plateau Geosystems-[http://deeptime.com/wp-content/uploads/2016/05/150\\_Jur\\_EurMap](http://deeptime.com/wp-content/uploads/2016/05/150_Jur_EurMap)).

#### DISTRIBUTION PATTERNS AND THE INTRA-TETHYAN NATURE OF THE SPONGE ASSEMBLAGE

By comparison with the Paleozoic stromatoporoids (Kershaw 1990; Webby & Kershaw 2011; Da Silva *et al.* 2011; Kershaw 2012), the distribution patterns of Upper Jurassic calcified sponge assemblages are still poorly documented. Probably one of the most important studies which dealt with this subject was made by Leinfelder *et al.* (2005). The recorded occurrences have revealed that some Upper Jurassic calcified sponge species have a relative broad distribution throughout the Tethyan realm (Table 2). Statistical analysis made by Leinfelder *et al.* (2005) on numerous poriferan species from northern, southern and intra-Tethyan shelves highlighted the existence of typical sponge associations for these Tethyan domains with respect to the differences between the palaeoecological and palaeoenvironmental settings.

As implied by the microfacies traits, associated biota and the recorded occurrences (Table 2), the present sponge species represent a typical intra-Tethyan assemblage. The poriferan response to the palaeoecological conditions (climate, water temperature, bathymetry, nutrients) and palaeoenviron-

ments resulted in preferential adaptations to a specific region (Table 2). This might explain the occurrences of *Ellipsactinia* and *Sphaeractinia* only in the tropical shallow-waters carbonates of the intra-Tethyan shelves. Moreover, due to their specific morphostructural features (mostly encrusting skeletons), *Perturbatacrusta leini* and *Sarsteinia babai* thrived only in the intra-Tethyan small reefs of numerous isolated carbonate platforms (Table 2). As mentioned previously, some sponges have a higher adaptability rate to different ecological conditions, therefore *Neuropora lusitanica* might dwell also in slightly cooler, deeper environments of the northern Tethyan shelves (Table 2). Even if *N. lusitanica* represents a cosmopolitan species throughout the Tethys, most of its occurrences are from coral-sponge-microencruster buildups of the intra-Tethyan carbonate platforms (Schlagintweit & Gawlick 2008; Pleş *et al.* 2013, 2015). The same argument can be applied also for *Calcistella*, *Thalamopora* and *Cylicopsis* since very rare examples are recorded from Northern Tethys by comparison with intra-Tethyan abundance (Table 2). Other differences between Northern and intra-Tethyan calcified sponge assemblages can be found in Leinfelder *et al.* (2005).

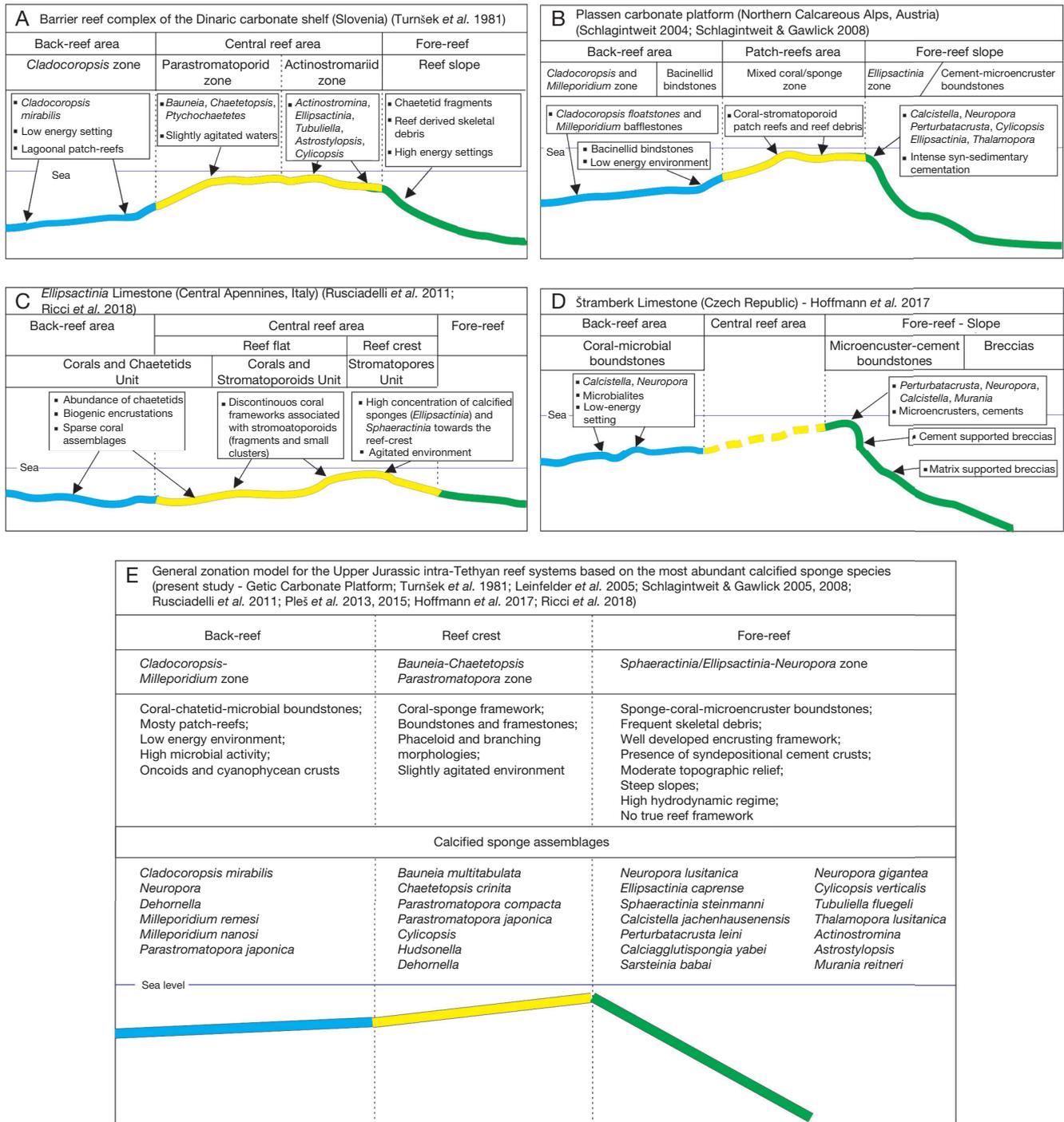


FIG. 10. — General reef zonation modes for the Upper Jurassic intra-Tethyan carbonate platforms based on calcified sponge assemblages.

INSIGHTS INTO REEF ZONATION

Studies regarding the reef environments of the intra-Tethyan isolated carbonate platforms (Turnšek *et al.* 1981; Schlagintweit & Gawlick 2008; Rusciadelli *et al.* 2011; Hoffmann *et al.* 2017) have proven that the biotic distribution towards the reef profile is strongly influenced by the environmental conditions generated by adjacent facies zones. Therefore, the calcified sponge species are not randomly distributed throughout the whole reef profile as recorded here or in Upper Jurassic carbonates from

Dinarides (Fig. 10A), central Apennines (Fig. 10C) and Northern Calcareous Alps (Fig. 10B). For example, poriferans like *Cladocoropsis* or *Milleporidium* are known to prefer less agitated environments from back-reef areas (Fig. 10A-C). *Bauneia*, *Parastromatopora* and *Chaetetopsis* are frequently reported from the reef flat while high concentrations of *Ellipsactinia* and *Sphaeractinia* are always indicators for an agitated environment towards the reef flank (fore-reef) (Fig. 10A-C). Based on these and other features discussed previously, the calcified sponge assemblage

from Grădiștei Gorges is characterizing by all traits a fore-reef environment. It is worth mentioning that *Thalamopora lusitanica* has a much wider distribution throughout the facies belts (e.g. back-reef and reef flat in the Plassen Carbonate Platform and Ernstbrunn Limestone) (Schlagintweit *et al.* 2019). The concentration of corals in the adjacent zones (reef flat and back-reef) and possibly the adaptation of *Sphaeractinia*, *Ellipsactinia* and *Neuropora* to oligotrophic conditions, may be one of the answers why these sponges bloom in the fore-reef environment. Even if most of the known reef systems of the intra-Tethyan realm share many similarities (palaeontological content, facies traits, etc.), some discrepancies exist mainly regarding the reef profile (lateral extension, topography, slope inclination) (Fig. 10A-D). Consequently, a general reef zonation model is in a continuous change since new data emerges from recent studies on this topic. Taking these into account a general zonation model for the intra-Tethyan reef systems is proposed here (Fig. 10E) based on the following features: 1) present calcified sponge assemblage, associated biota and facies traits; 2) newest data on other reef carbonates of the Getic Carbonate Platform (Pleș *et al.* 2013, 2016, 2019); 3) classical reef zonation models (Turnšek *et al.* 1981; Morsilli & Bosellini 1997; Rusciadelli *et al.* 2011); and 4) the available data on the most documented Upper Jurassic intra-Tethyan reefs in Europe (Fig. 10E).

## CONCLUSIONS

An exceptionally preserved calcified sponge association is described from the easternmost part of the Getic Carbonate Platform, Southern Carpathians of Romania. It allows new observations into the internal structure and growth patterns of the main poriferan species in order to decipher the biostratigraphical, taphonomical and palaeoecological conditions which influenced the genesis of mixed sponge-coral-microencruster build-ups. Thin section analysis permitted a three-dimensional perspective over the skeletal inner-architecture of all sponge species and, consequently the discovery of new diagnostic features in some species (*Sarsteinia babai*, *Sphaeractinia steinmanni*). Moreover, several species are described here for the first time from the Upper Jurassic carbonates of the Southern Carpathians (*Calciagglutispongia yabei*, *Sarsteinia babai*, *Sphaeractinia steinmanni*) including an interesting large *Neuropora* species (*Neuropora gigantea* Pleș & Schlagintweit, n. sp.).

Microfacies analysis provided valuable clues in understanding the depositional palaeoenvironment. By their traits (main components, morphostructural features, diagenetic record) the identified main facies associations (sponge-coral-microencruster boundstones and bio-intraclastic grainstones) point to an agitated reef-flank (fore-reef) depositional palaeoenvironment of a warm tropical epicontinental sea. The instability of the reef flank sediments and episodic fragmented debris led to the development of encrusting morphologies in most sponges (*Perturbatacrusta*, *Calciagglutispongia*, *Calcistella*, *Sarsteinia*). The abundance of *Sphaeractinia*, *Ellipsactinia* and *Neuropora* generally point to a steep angle of the reef slope and, subsequently, to a slightly deeper sedimentary setting (several tens of meters).

The observed growth patterns of the most abundant calcified sponges show both low-domical encrusting morphologies and spherical or cylindrical shapes. Considering the unstable hard substrate of the fore-reef environment, species like *Sarsteinia*, *Calcistella*, *Perturbatacrusta*, *Calciagglutispongia* (or several *Neuropora* specimens) should develop mostly crustose features. The cylindrical or spherical morphotypes (*Neuropora* and *Sphaeractinia*) are regarded as a result of the sedimentary input fluctuations in this agitated environment or as structural adaptations triggered by the competition for nutrients. The dominance of calcified sponges versus corals here can be explained by the poriferan adaptations for much warmer waters and agitated environments with lower nutrient input.

The existing palaeoecological and palaeoenvironmental conditions generated preferential adaptations of the sponge species to a specific Tethyan domain and also different distribution patterns towards the reef profile. Therefore, the described calcified sponge assemblage can be used as a supplementary proxy for understanding palaeoecological traits, and consequently, for establishing a general zonation model for the sponge-coral-microencruster dominated reefs. Corroborating the present material with the existing data on similar carbonates, three poriferan zones are proposed: *Cladocoropsis-Milleporidium* zone (back-reef area); *Bauneia-Chaetetopsis-Parastromatopora* zone (central reef area) and *Sphaeractinia-Ellipsactinia-Neuropora* zone for the fore-reef area. Despite the fact that this model cannot integrate each peculiarity of such Upper Jurassic reef carbonates, it presents the key features in recognizing facies zones based on biotic distribution and the intra-Tethyan character of the analyzed carbonates.

Even if the palaeogeographic picture of the intra-Tethyan realm during the Late Jurassic was characterized mainly by an extensional tectonic regime, this territory provided optimal conditions for the development of relatively small sponge-coral-microencruster build-ups on the marginal zones of the existing isolated carbonate platforms. The overall analysis of the calcified sponge assemblage provided valuable information in understanding why these peculiar reefs strongly influenced the carbonate production throughout this realm. In the absence of a true reef framework (e.g. northern Tethyan reefs) the calcified sponges developed typical morphologies, new palaeoenvironmental adaptations and associations with other biotic groups. These features also triggered competitive behavior among these organisms which has generated abundance events and, consequently, a substantial improvement of the bioconstructing potential. Concluding all, this might be one of the answers why a thick succession of uppermost Jurassic bioconstructed/reef debris limestones is recorded in numerous intra-Tethyan carbonates of Europe (Austria, Italy, Romania, etc.).

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#### Authors contribution statement

G.P. and F.S. conceived this study, made the systematic paleontology part, discussed the taphonomical features and established the new sponge species *Neuropora gigantea* Pleş & Schlagintweit, n. sp. I.L., I.B. and E.S. contributed to the age constraints, microfacies analyses and paleoenvironment interpretations. M.G. design the figures and performed together with G.P. field work campaigns. All authors discussed the results and contributed to the final version of the manuscript.

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