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UPPER JURASSIC TO LOWERMOST CRETACEOUS MICROFOSSILS FROM THE HĂGHIMAŞ MOUNTAINS (EASTERN CARPATHIANS, ROMANIA)

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Abstract The limestones of the Upper Jurassic to lowermost Cretaceous from the Hăghimaş Mountains were studied in two sections from the upper part of the Fagu Oltului valley, a tributary of the Olt River. The lower part of the succession is remarkable for the rich brachiopod fauna contained in a red limestone buildup, documented previously as a stromatactis mud-mound. The mound consists of bioclastic wackestones and packstones with numerous brachiopods, crinoids, and sponges. The mud-mound is covered with intraclastic grainstones and fine-grained limestones with pelagic bivalves. The following lithological units pass into shallow water limestone with nerineid gastropods, calcareous algae and foraminifera, in a regressive sequence.
The micropaleontological association identified in the Upper Jurassic to lowermost Cretaceous limestones from Fagul Oltului includes calcareous algae, foraminifera, saccocomid crinoid fragments, annelid worm tubes, sponge fragments, rare calpionellids and microorganisms with an uncertain systematic position. The identified microfossils have a wide stratigraphic distribution. The most important stratigraphic landmarks are *Trocholina conica* (which does not extend younger than Kimmeridgian) and *Calpionella alpina* (which does not appear before the upper Tithonian). Based on the whole micropaleontological assemblage, the lower part of the succession (the skeletal mud-mound) can be ascribed to the Kimmeridgian – lower-middle Tithonian, and the upper part to the upper Tithonian – Berriasian.

Keywords: microfossils, Upper Jurassic, lowermost Cretaceous, Eastern Carpathians, Romania

INTRODUCTION

The Mesozoic carbonate successions from the Hăghimaş Mountains (Eastern Carpathians) contain rich faunal assemblages that have been studied since the second half of the nineteenth century. The pioneering researches of Neumayr (1873) and Herbich (1878) were followed by numerous papers concerning the (macro)paleontology, stratigraphy and geotectonic evolution of the Hăghimaş Mountains (e.g., Jekelius, 1915; Atanasiu, 1928; Băncilă, 1941; Arkell, 1956; Săndulescu, 1967; 1968, 1969; Patrulius, 1965, Pelin, 1965; Preda 1969, 1973; Grasu, 1964, 1971; Grigore 2002). Micropaleontology and microfacies analyses of the Upper Jurassic-Lower Cretaceous carbonate successions from the Hăghimaş Mountains were performed by Dragastan (1975, 2011), Neagu and Neagu (1995), Bucur (2006, 2011), Neamţu et al., 2019. Lazăr et al. (2011) published a multidisciplinary study concerning a rare Kimmeridgian stromatactis mud-mound from the Hăghimaş Mountains, making it the first example of this type of deposit in geological record. This stromatactis mud-mound contains a superabundant brachiopod assemblage dominated by the rhynchonellid brachiopods *Lacunosella* and *Septaliphoria*, occurring within red crinoidal limestone of the *Saccocoma* facies. The aim of the present paper is to describe the micropaleontological assemblage and to clarify the stratigraphy of the studied mud-mound and of the overlying deposits from the Fagul Oltului Valley (Hăghimaş Mountains, Eastern Carpathians).

GEOLOGICAL SETTING

The Hăghimaş Mountains represent a huge syncline structure of the Eastern Carpathians and are built up of three superposed Alpine tectonic units: the Sub-Bucovinian Nappe, the Bucovinian Nappe and the Hăghimaş Nappe (Săndulescu (1975, 1984). The Hăghimaş Nappe is part of the Transylvanian Nappe System (Fig. 1a). The studied section belongs to the Hăghimaş Nappe, made up only of sedimentary formations of Upper Jurassic to Lower Cretaceous carbonate deposits associated with rare pre-Kimmeridgian ophiolites in the lower part of the sequence (Săndulescu 1975, 1984).
The studied section is located in the western flank of the Hăghimaş Mountains and crops out on the steep slopes of the Fagul Oltului Valley (N 46°42’47’’; E 25°47’50’’) at 1416 meters altitude (Fig. 1b).
The first part of the section (2,5 – 5,5 m thick) was studied by correlation of two profiles (FO1 and FO2) observed on the outcrops from the two slopes of Fagul Oltului Valley. This part of the section consists of reddish fine-grained limestone bearing stromatactis, crinoids, and densely packed rhynchonellid brachiopods and was documented by Lazăr et al. (2011) as a stromatactis skeletal mud-mound. The microfacies of the red stromatactis-bearing limestones rich in crinoids and rhynchonellid brachiopods is represented by bioclastic wackestones to packstones, with a micropeloidal matrix and a polymud fabric. Bioclasts are dominated by crinoids (mostly

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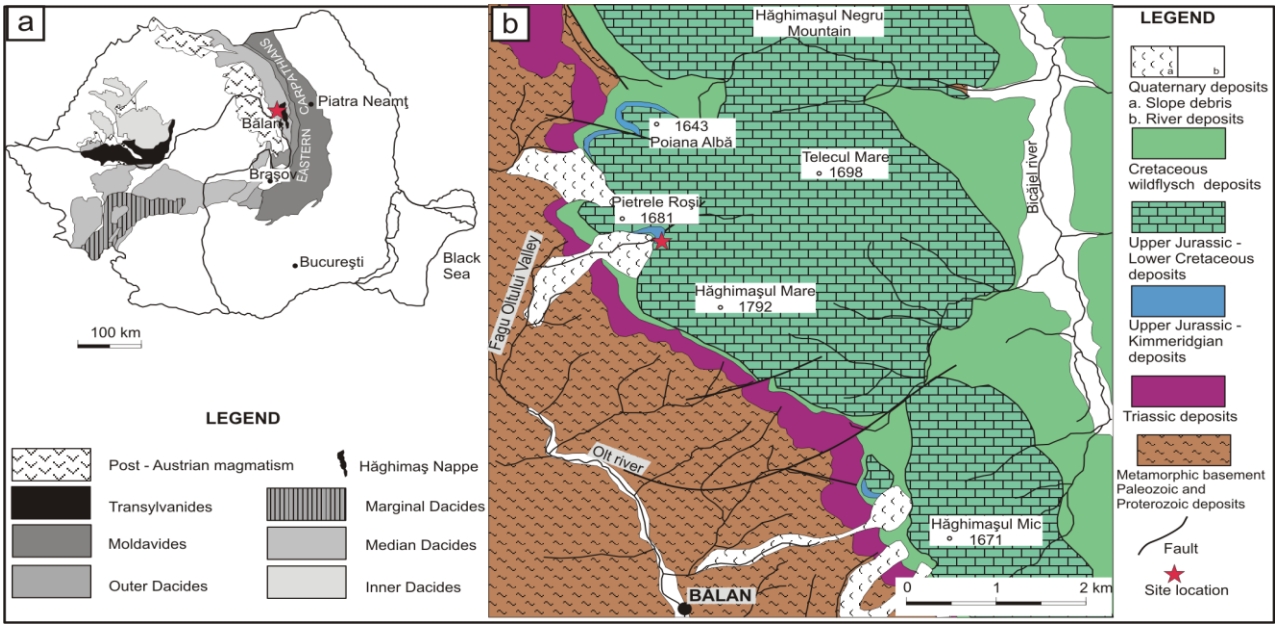

Fig. 1 Location of the studied section: **a** Location of the Hăghimaş Nappe within the Eastern Carpathians, based on the geotectonic map of Romania (Săndulescu, 1984). **b** Location of the Fagul Oltului Valley on the geological outline map of the Hăghimaş Mountains (based on Săndulescu, 1975).

Saccoccoma ossicles), echinoid ossicles and spines, lithistid sponge mummies, calcified spicules from hexactinellid sponges, brachiopods, and *Crescentiella morronensis* (Crescenti). Other skeletal grains such as foraminifera, juvenile ammonites, bryozoans, worm tubes are less abundant. Most of the bioclasts, especially brachiopod shell fragments and echinoderm ossicles are marginally micritized and some borings filled with ferruginous micrite have been observed perforating the brachiopod shells and other skeletal grains. The predominant mud-mound biotas are represented by tens-of-thousands of rhynchonellid brachiopods with taphonomic features indicating successive generations/ biocoenoses (Lazăr et al., 2011). The next beds (3,5 m thick) are represented by yellowish to pink intraclastic granular limestone (bioclastic packstones to floatstone) containing 0,05 – 0,20 m thick beds, with scarce macrofauna. The upper part of the succession (about 7 m thick) represented by yellowish to pink intraclastic granular limestone pass gradually into shallow water limestone with nerineid gastropods, calcareous algae, and benthic foraminifera, in a regressive sequence.

MATERIALS AND METHODS

More than 70 rock samples were collected from the Fagul Oltului Valley. Detailed sample locations are indicated in figures 2 and 3. About 60 thin-sections were studied petrographically by polarized light microscopy. The rock samples and thin sections are housed in the Collection of the Laboratory of Palaeontology, Department of Geology, University of Bucharest.

MICROPALEONTOLOGICAL ASSEMBLAGE

The micropaleontological association identified in the Upper Jurassic to lowermost Cretaceous limestones from Fagul Oltului includes calcareous algae, foraminifera, saccocomid crinoid ossicles, annelid worm tubes, sponge fragments, rare calpionellids, and microorganisms with an uncertain systematic position.

Calcareous algae: The calcareous algae are mainly represented by dasycladalean remains. Fragments attributable to *Actinoporella* sp. or *Clypeina* sp. (Fig. 4a-e) and *Salpingoporella pygmaea* (Gümbel, 1891) (Fig. 4f-h) are relatively common. *Terquemella* sp. (Fig. 4j-k) and rare fragments of *Rajkaella bartheli* (Bernier, 1971) (Fig. 4l) are also present. It is worth mentioning the presence in thin section FO6 of some charophyte remains in a limestone containing terrigenous material. Rare cyanobacteria of the *Rivularia*/*Cayeuxia* type have also been identified (Fig. 9f).

Foraminifera: The association of benthic foraminifera consists of *Bramkampella arabica* (Redmond, 1964) (Fig. 5a-i), *Textularia* sp. (Fig. 5j), *Mayncina* sp. (Fig. 5k-m), *Protopeneroplis* cf. *ultragranulata* (Gorbatchik, 1971) (Fig. 5n-o), *Nautiloculina* sp. (Fig. 5p), *Reophax* spp. (Fig. 5q, r), *Ammobaculites* sp., *Trocholina conica* (Schlumberger, 1898) (Fig. 6a-c, e, f), ?*Seracenaria* sp. (Fig. 6d), *Mohlerina basiliensis* (Mohler, 1938) (Fig. 6g), *Coscinoconus alpinus* Leupold in Leupold & Bigler 1936 (Fig.6h, i), Epistominidae indet. (Fig. 6j, l-o), Nodosariidae indet. (Fig. 6k), *Spirillina* sp. (Fig. 6p-q), *Lenticulina* sp. (Fig. 6s, v) and encrusting foraminifera (Fig. 6t, u). Numerous specimens of *Bramkampella arabica* have been identified. In sub-axial logitudinal sections (Fig. 5a, b) the initial planspiral part is visible, followed by the

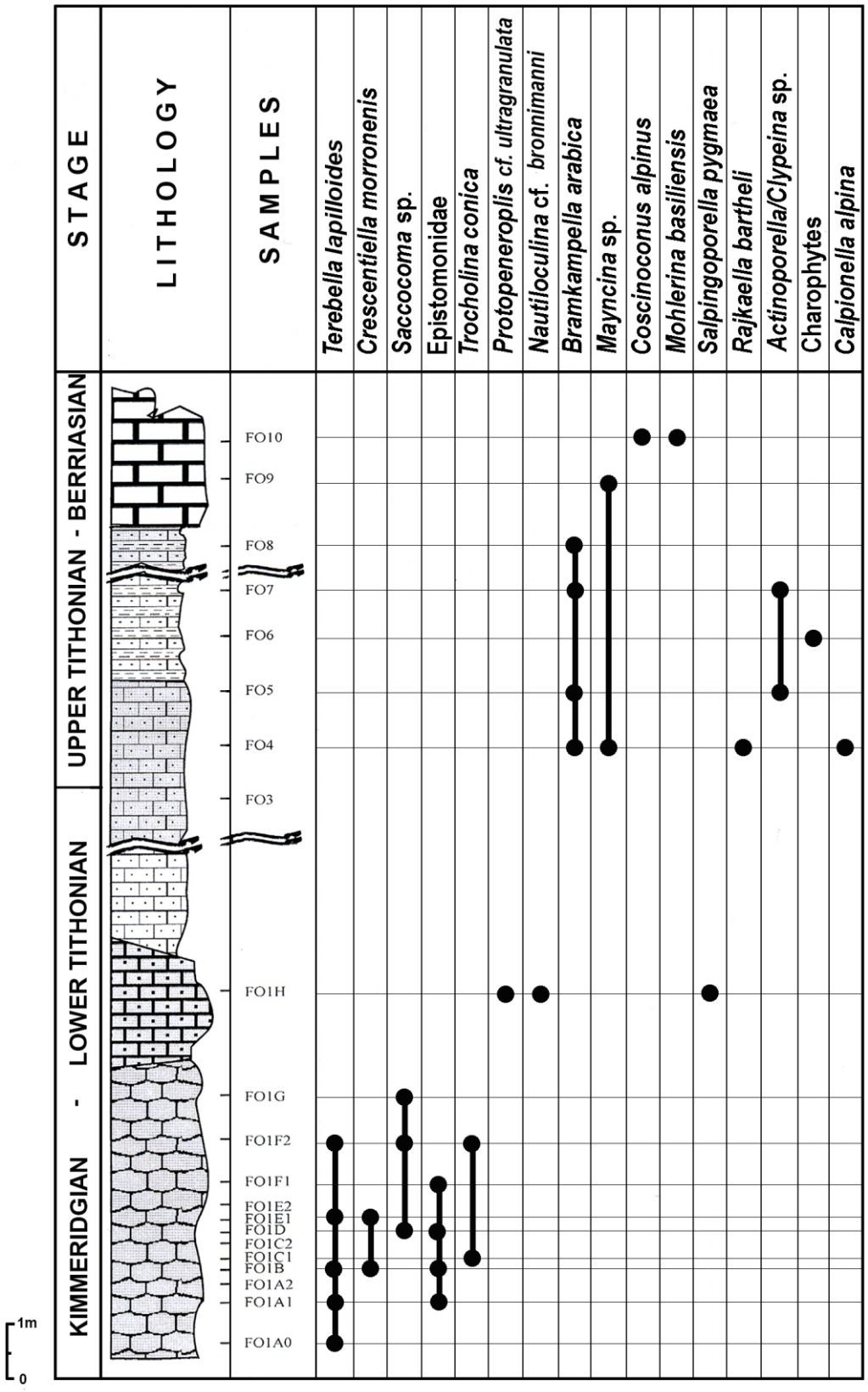

Fig. 2 Succession of the Upper Jurassic-lowermost Cretaceous limestones in the FO1 profile with stratigraphic range of the identified microfossils.

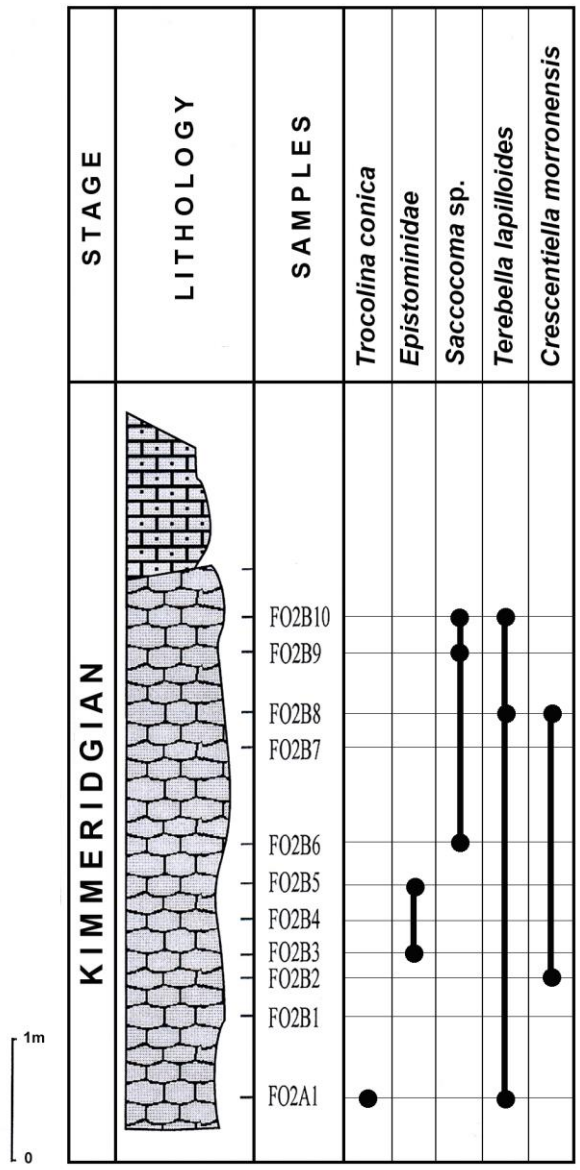

Fig. 3 Succession of the Upper Jurassic limestones in the FO2 profile with the stratigraphic range of the identified microfossils.

uniserial stage consisting of 5-6 chambers with a thick alveolar wall and cribrate aperture. The tangential and oblique sections (Fig. 5c-e, h) show the alveolar structure of the hypodermis consisting of alveoli that divide once outwards (Banner & Whittaker, 1991). In cross sections (Fig. 5f, g, i) the transverse partitions extending from the periphery to the middle of the test are visible (Redmond, 1964; Banner & Whittaker, 1991).

Protopeneroplis cf. *ultragranulata* (Fi. 5n, o). We have identified rare specimens of a trochospiral *Protopeneroplis*, with an equatorial diameter of 0.40–0.45 mm. Such specimens could represent transitional forms between the small trochospiral *Protopeneroplis* identified in Oxfordian deposits (Bucur et al., 2004) and *Protopeneroplis ultragranulata* from Middle-Upper Tithonian to Barremian (Bucur, 1993, 1997).

Numerous specimens of *Trocholina conica* (Schlumberger) have been identified at the lower part of the succession. Originally attributed by Schlumberger (1989) to the genus *Involutina*, the species was later transferred to the genus *Trocholina* (e.g., Henson, 1947; Reichel, 1955) a genus recently emended by Rigaud et al. (2013) based on the presence of reduced lamellae on the spiral side and papillose lamellae on the umbilical side of the test. The papillae on the umbilical side, delimited by a marginal groove, are also visible on our material (Fig. 6a, b, e, f).

Saccocomid crinoid ossicles: The lower part of the succession is rich in fragments of *Saccocoma* sp. These are represented almost exclusively by sections of secondary brachial parts (secundibrachials). A detailed description and illustration of *Saccocoma* remains was made by Benzaggagh et al. (2015) based on numerous specimens collected from France, Tunisia and Morocco.

Agglutinated Annelid tubes: We identified *Terebella lapilloides* Münster in Goldfuss, 1833 in longitudinal (Fig. 8l), longitudinal-oblique (Fig. 8k, n) and transverse (fig. 8j, m) sections. Assigned to annelid worms that build agglutinated tubes, *Terebella lapilloides* has been described in detail by Kaya & Altiner (2014). Hughes (2018) reported the species from the Kimmeridgian-Tithonian of Saudi Arabia. The maximum length observed in the specimens from Hăghimaş is 3.6 mm; the external diameter ranges between 0.63-0.73 mm and the internal one between 0.2-0.46 mm; the thickness of the wall is 0.15-0.16 mm.

Organisms with an uncertain systematic position:

Crescentiella morronensis (Crescenti, 1962) (Fig.8a-i) is frequently associated with *Saccocoma* and *Terebella* in the lower part of the succession. Originally (Crescenti, 1962) assigned to the genus *Tubiphytes*, this microorganism was reassigned to the new genus *Crescentiella* by Senowbari-Daryan et al. (2008) and considered a symbiosis between a nodophthalmiid foraminifer and cyanobacteria. The cyanobacterial "cortex" has variable thickness (around 0.5 mm in Hăghimaş specimens) and a laminar structure within which tubular formations are sometimes distinguished (Fig. 8c), an additional argument of the cyanobacterial nature of the "cortex".

Muranella parvissima (Dragastan, 1966) (Fig. 9i): Initially assigned to the genus *Clypeina* (Dragastan, 1966), these remains were reassigned to the genus *Didemoides* (Misik & Borza, 1978), the genus *Enigma* (Eliašová, 1981) and later to the genus *Muranella* (Eliašová, 1985). They are small spherical or ovoid corpuscles, often grouped in clusters, made up of calcite prisms developed around a micritic center with an irregular outline. Their nature remains uncertain.

Microbial crusts: the studied limestones are rich in microbial structures (Lazăr et al., 2011). They sometimes develop in the form of laminated stromatolite crusts (Fig. 9a) or microbial-ferruginous crusts (9h).

Planktonic microorganisms: in thin section FO4 we identified rare calpionellids, some of which certainly belong to the species *Calpionella alpina* Lorenz (Fig. 9g), representing small globular forms characteristic of the Upper Tithonian.

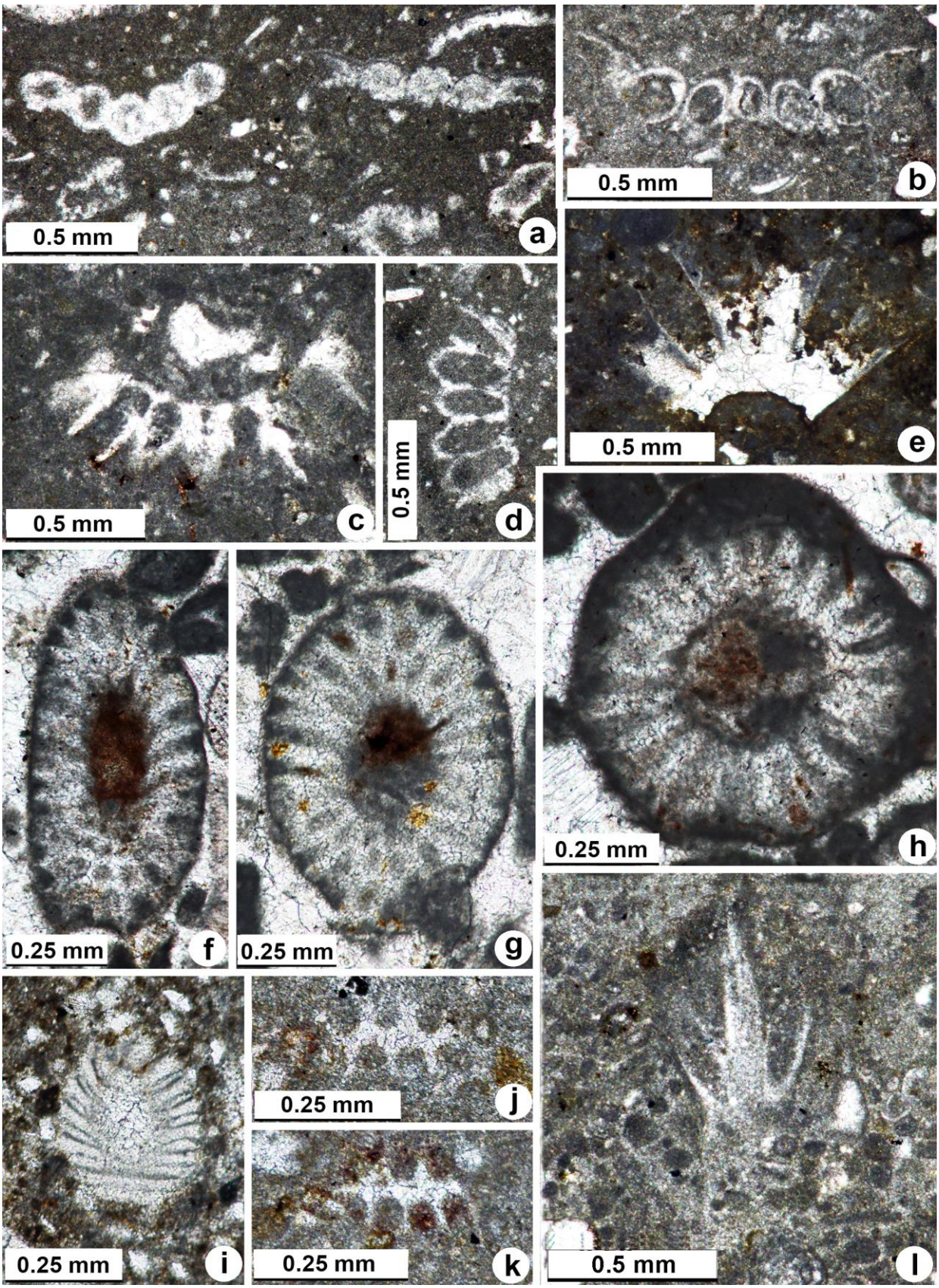

Fig. 4 Calcareous algae. **a-e** *Actinoporella/Clypeina* sp. Different sections through laterals; a, d – thin section FO7-A; b, c – thin section FO7-C; e – thin section FO1-H. **f-h** *Salpingoporella pygmaea* (Gümbel). Oblique (f, g) and transverse (H) sections; f, g – thin section FO1-H(2); g – thin section FO1-H. **i** Charophyte gyrogonite; **j, k** *Terquemella* sp.; thin section FO8. **l** *Rajkaella bartheli* Bernier. Section of the distal part of the primary lateral and the secondary laterals; thin section FO4.

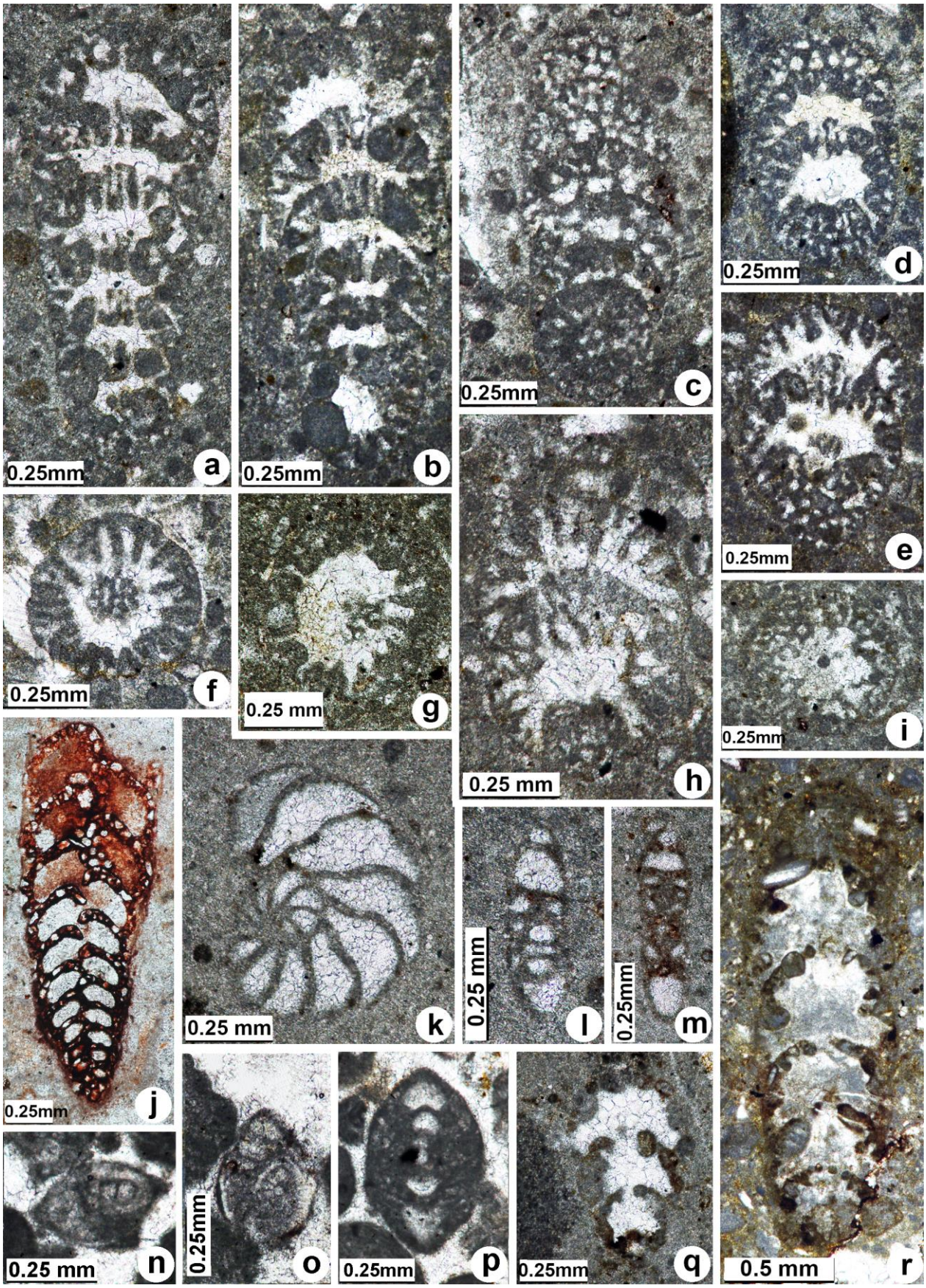

Fig. 5 Foraminifera. **a-i** *Bramkampella arabica* Redmond. Longitudinal (subaxial) (a, b), longitudinal-tangential (c), oblique (d, e, h), and transverse (f, g, i) sections; thin section FO4. **j** *Textularia* sp., thin section FO1-G(2). **k-m** *Mayncina* sp. k – thin section FO9B; l, m – thin section FO9A. **n, o** *Protopeneroplis* cf. *ultragranulata* (Gorbatchik). Subaxial (n) and subequatorial (o) sections; thin section FO1-H(2). **p** *Nautiloculina* cf. *bronnimanni* Arnaud-Vanneau & Peybernès, subaxial section; thin section FO1-H(2). **q, r** *Reophax* spp. q – thin section FO9-A; r – thin section FO5.

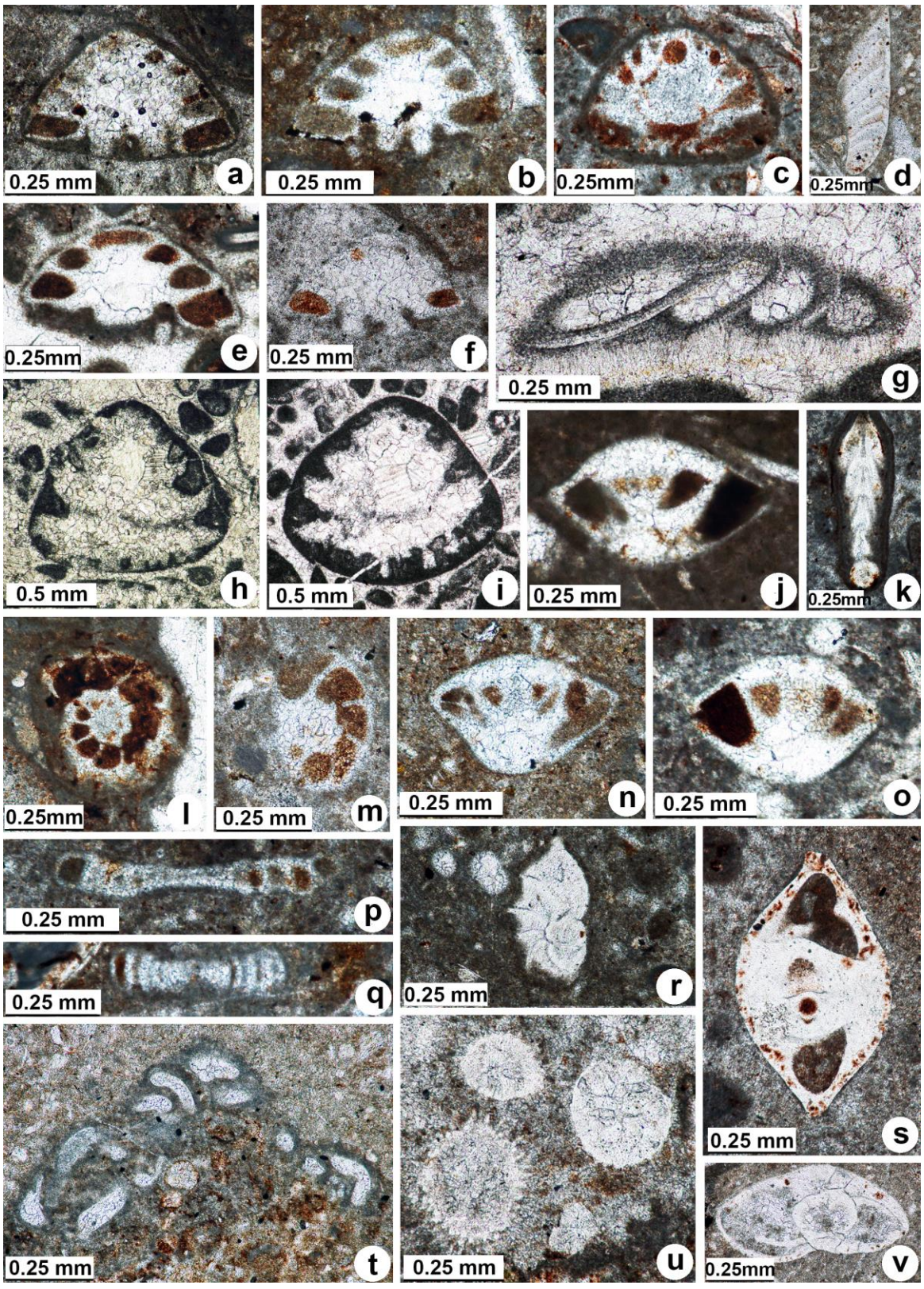

Fig. 6 Foraminifera. **a-c, e, f** *Trocholina conica* (Schlumberger). Subaxial (a-c), and oblique (e, f) sections; a – thin section FO2-A1(3); b – thin section FO1-C(1); c – thin section FO2-A1(2); e – thin section FO1-F2; f – thin section FO2-A1. **d** ?*Saracenaria* sp., thin section FO2-B8. **g** *Mohlerina basiliensis* (Mohler), oblique-tangential section; thin section FO-10A. **h, i** *Coscinoconus alpinus* Leupold in Leupold & Bigler, subaxial sections; thin section FO-10A. **j, l-o** Epistominidae. j – thin section FO2-B5; l – thin section FO1-A1; m – thin section FO1-F(1); n – thin section FO1-D; o – thin section FO2-B3. **k** Longitudinal section through a nodosariid foraminifera; thin section FO3. **p, q** *Spirillina* spp. Axial sections. p – thin section FO1-A0(1); q – thin section FO2-B4. **r, s, v** *Lenticulina* spp. Subequatorial (r, v) and subaxial (s) sections; r – thin section FO2-B10; s – thin sections FO2-A1; v – thin section FO1-C1. **t, u** Encrusting foraminifera. t – encrusting agglutinated foraminifera, thin section FO1-E; u – *Bullopora* sp., thin section FO1-F92).

DISCUSSION - STRATIGRAPHIC RANGE OF THE IDENTIFIED MICROFOSSILS

Most of the identified species have a wide stratigraphic distribution. Among dasycladalean algae, *Salpingopoella pygmaea* is known from Bathonian to Aptian (Granier & Deloffre, 1993; Bucur, 1999; Caras et al., 2005). *Rajkaella bartheli* is a common species in the Berriasian, but its presence in older, Tithonian deposits has been reported by Schlagintweit (2011). In the Fagul Oltului sections (Fig. 2, 3), *Rajkaella bartheli* appears in the sample FO4, associated with *Calpionella alpina*, in limestones attributable to the upper Tithonian.

In terms of foraminifera, *Bramkampella arabica* was originally described from deposits attributed to the basal Cretaceous (Berriasian; Redmond, 1964), and was later identified in limestones ranging from Kimmeridgian to lower Valanginian (Noujaim-Clark & Boudaher-Fadel, 2001; Bucur & Săsăran, 2005; Masse et al., 2015; Pleș et al., 2015; Hughes, 2018; Mircescu et al., 2020). In the studied section. *Bramkampella* appears in the upper part of the succession, assigned to the upper Tithonian–Berriasian.

Protopeneroplis ultragranulata is a species known from the Middle Tithonian (Septfontaine et al., 1991) to the Barremian (Bucur, 1993). The specimens identified in Fagul Oltului section as *Protopeneroplis* cf. *ultragranulata* are located in the middle part of the succession in deposits attributed to the lower–middle Tithonian, associated with *Nautiloculina* cf. *bronnimanni* and *Salpingoporella pygmaea*.

Trocholina conica is known from the Bathonian to Kimmeridgian (Reichel, 1955; Bucur et al., 1997; Rigaud et al., 2013; Schlagintweit & Moshammer, 2015). In the studied section this species is associated with *Terebella lapilloides*, *Crescentiella morronensis*, *Saccocoma* sp. and epistominid foraminifera in the lower part of the succession, assigned to the Kimmeridgian (Lazăr et al., 2011). The upper part of the succession also contains *Coscinoconus alpinus* and *Mohlerina basiliensis*, common foraminifera in the Tithonian-Berriasian.

The remains of crinoids belonging to the genus *Saccocoma* are common in the Oxfordian-Tithonian deposits of the Tethyian area (Bezaggagh et al., 2015). In the Carpathians, as in other regions of the Neotethys, they are common in the Lower Kimmeridgian–Tithonian interval, often constituting a discrete facies (*Saccocoma* facies or *Saccocoma* limestone; e.g. Kuhry et al., 1976; Michalik et al., 2009; Flügel, 2010).

According to Kaya et al. (2014) *Terebella lapilloides* is known from Triassic to Berriasian, but specimens of this annelid have been identified by us (I.I.B., unpublished data) in the Barremian in the Dâmboviciara area. In the studied section it frequently appears in the lower part of the succession (Kimmeridgian).

Crescentiella morronensis is associated with *Terebella lapilloides* and *Saccocoma* in the lower part of the Fagul Oltului succession. In the Tethyian area, this *incertae sedis* microorganism is known from the Oxfordian to Aptian (Senowbari-Daryan et al., 2008; Schlagintweit et al., 2005; Pleș et al., 2017).

In conclusion, the microfossil species identified in the Fagul Oltului sections have a wide stratigraphic distribution. The most important stratigraphic landmarks are *Trocholina conica* (which does not extend younger than Kimmeridgian) and *Calpionella alpina* (which does not appear before the late Tithonian). It is also important mentioning that Lazăr et al., (2011) recovered from the red limestones in the lower part of the succession one specimen of *Sowerbyceras* cf. *loryi* (Munier-Chalmas), which is characteristic for the Kimmeridgian.

CONCLUSIONS

The study of the Upper Jurassic to lowermost Cretaceous limestones in the western part of the Hăghimaș Mountains (Fagul Oltului Valley) allowed the identification of a micropaleontological association composed of calcareous algae, foraminifera, saccocomid crinoid ossicles, annelid worm tubes, sponge fragments, rare calpionellids, and microorganisms with an uncertain systematic position. *Saccocoma* sp. and *Terebella lapilloides*, associated with *Crescentiella morronensis* are abundant in the lower part of the succession, representing a skeletal mud-mound containing numerous brachiopods (Lazăr et al., 2011). From these red limestones in the lower part of the succession Lazăr et al. (2011) mentioned one specimen of *Sowerbyceras* cf. *loryi* (Munier-Chalmas), which is characteristic for the Kimmeridgian. Among the microfossils, the most important stratigraphic landmarks are *Trocholina conica* (which does not exceed the Kimmeridgian) and *Calpionella alpina* (which does not appear before the upper Tithonian). Based on the whole micropaleontological assemblage, the lower part of the succession can be ascribed to the Kimmeridgian to lower – middle Tithonian, and the upper part to the upper Tithonian – Berriasian.

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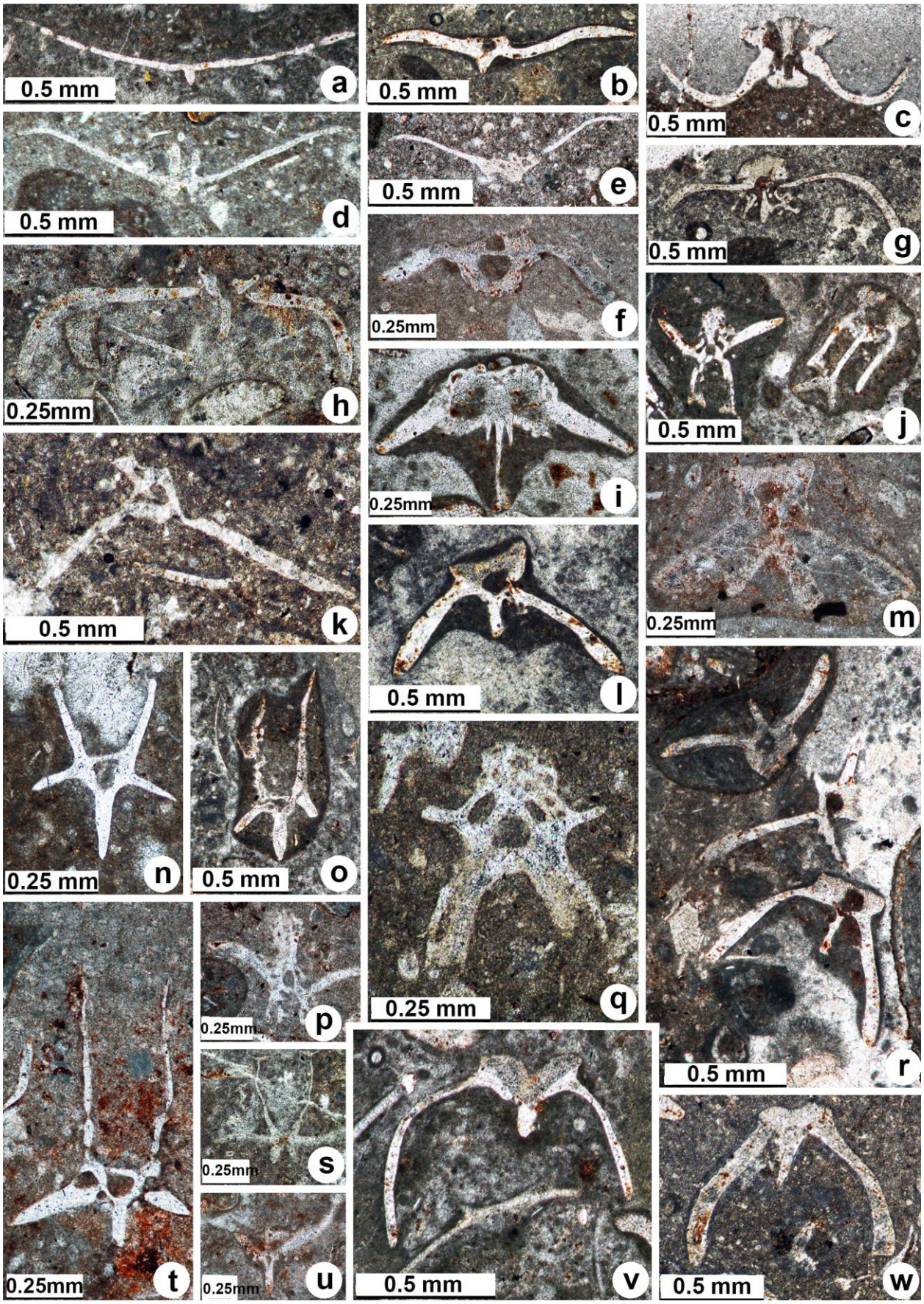

Fig. 7 Planktonic crinoids. **a-w** *Saccocoma* sp. Different sections of secondibrachials. a, v – thin section FO2-B1C(2); b, u – thin section FO2-A1(2); c – thin section FO2-B10; d, i – thin section FO2-B9; e, k – thin section FO1-D; f, l, m, p, q, t, w – thin section FO1-F2(2); g, r – thin section FO1-F2; h, s – thin section FO2-B6(2); j – thin section FO1-G2.

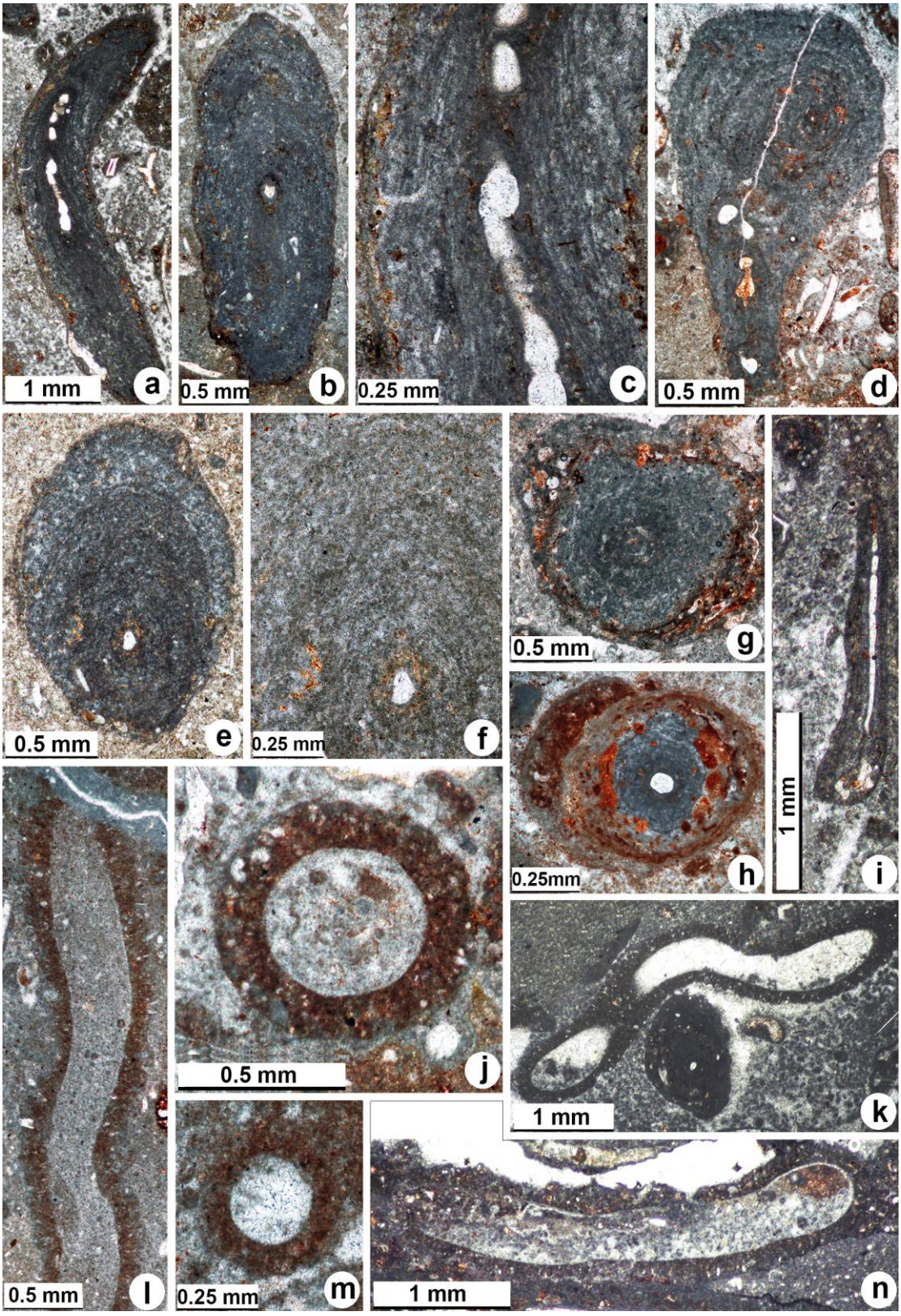

Fig. 8 *Incertae sedis* microorganisms and agglutinated worm tubes. **a-i** *Crescentiella morronensis* (Crescenti) in longitudinal-oblique (a, c, i), oblique (b, d, e, f), and transverse (e, h) sections; a, c – thin section FO1-B (c = close-up view of the middle part in a); b – thin section FO2-B8; d – thin section FO2-A1(3); e, f – thin section FO1-E (f = close-up view of the middle part in e). g – thin section FO1-A1; h – thin section FO2-A1; i – thin section FO1-F2(2). **j-n** *Terebella lapilloides* (Münster). Longitudinal (l), longitudinal-oblique (k, n), and transverse (j, m) sections; j – thin section FO2-B10; k – thin section FO1-B; l, m – thin sections FO1-A0; n – thin section FO2-A1.

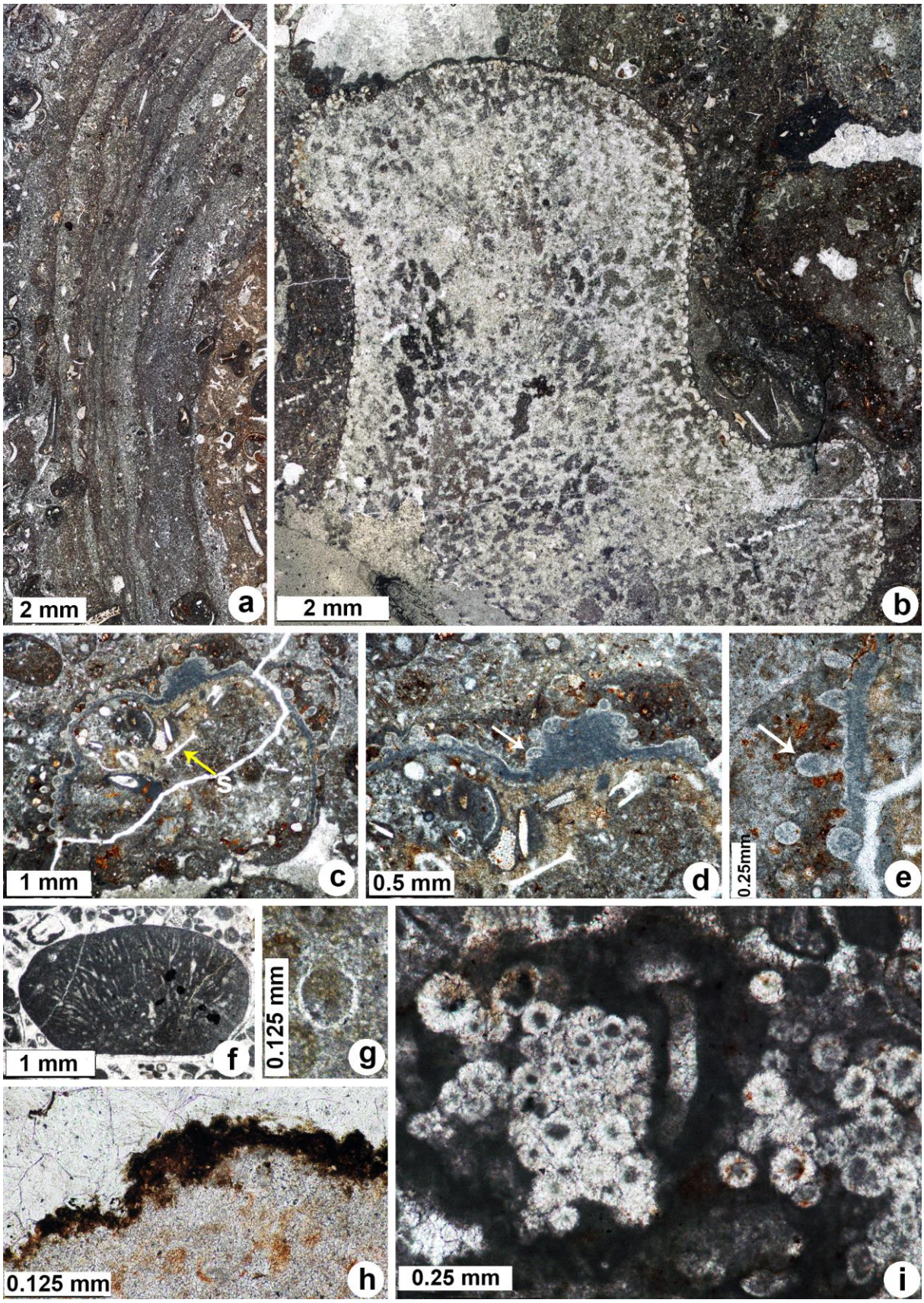

Fig. 9 Microbial crusts and sponges. **a** Laminated, fine-peloidal stromatolitic structure; thin section FO1-F2(2). **b** Lithistid(?) sponge; thin section FO2-B6(2). **c-e** Microbial crust around a sediment fragment containing different bioclasts showing encrusting *Koskinobulina socialis* Cherchi & Schroeder (white arrows in d and e = close-up views of c). The arrow in c points to a saccdocomid ossicle); thin section F1-G. **f** *Rivularia/Cayeuxia* type cyanobacteria; thin section FO1-10B. **g** *Calpionella alpina* Lorenz; thin section FO4. **h** Microbial-ferruginous crust; thin section FO2-A1. **i** *Muranella parvissima* (Dragastan); thin section FO1-H(2).

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