

Systematic updates of the agglutinated foraminiferal genus *Colominella* Popescu, 1998: insights from sectioned specimens

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Abstract: The occurrence of agglutinated foraminiferal specimens belonging to the Badenian (middle Miocene) genus *Colominella* Popescu, 1998 was recently documented for the first time in a lower Pliocene succession of the western Mediterranean area. Direct comparisons with topotype specimens of *Colominella paalzowi* (Cushman 1936), sampled in the Badenian type section of Lăpugiu de Sus (Transylvania), show that the Pliocene individuals from the western Mediterranean morphologically resemble the type species *C. paalzowi*, but they also differ in possessing a longer biserial chamber arrangement with a higher number of internal chamber partitions, in lacking a clear early triserial stage and in having a more complex microstructure of the agglutinated wall, thereby supporting the idea that the Pliocene Mediterranean specimens represent a new, more highly evolved species. The fact that the Pliocene individuals from the Mediterranean appear to be more evolved with respect to the Badenian specimens from Paratethys represents an interesting evolutionary development of the genus *Colominella* that also permits the known stratigraphical and geographical range of the genus, previously limited to the middle Miocene (Badenian) of the Paratethys, to be extended.

Keywords: Mediterranean Pliocene, Badenian Paratethys, agglutinated foraminifera, taxonomy, wall microstructure, SEM-EDS analysis.

Introduction

The genus *Colominella* Popescu, 1998 has been formally described from the Paratethyan Badenian (middle Miocene) Kostej succession, cropping out in Transylvania (Popescu et al. 1998; Kaminski 2004) and is based on a species (type species *Textulariella paalzowi*) first studied by Cushman (1936) from the same locality. The type species was subsequently recorded in the Badenian of the Rauchstallbrunngraben in the Vienna Basin (Popescu et al. 1998), in the lower Badenian Wagna succession (Styrian Basin) in the western portion of the Pannonian basin system within the Alpine-Carpathian arch (Spezzaferri et al. 2004), and more recently, in the lower Pliocene record of the Albenga Basin in the western Mediterranean region (Mancin et al. 2012).

According to Cushman's original description, *Colominella* (ex *Textulariella*) *paalzowi* is characterized by a very large (4 mm long and 1 mm in diameter), conical, mostly biserial test, triserial in the early stage, with typical internal vertical partitions, comparatively few in number, and a canaliculate test wall with a coarsely agglutinated surface.

Colominella likely evolved from the genus *Matanzia* (which is also canaliculate) during the Oligocene to middle Miocene (Kaminski & Cetean 2011). *Colominella* and *Matanzia* have been recently placed in the subfamily Colominellinae Popescu, 1998 together with two additional closely-related genera: *Colomita* Gonzales-Donoso, 1968 and *Cubanina* Palmer, 1936 (Kaminski & Cetean 2011 and references therein). In spite of this recent systematic review of the genus, not much is

known about the test wall microstructure of *Colominella* nor about its stratigraphical and geographical range, which is currently reported as limited to the Badenian of Paratethyan successions (Kaminski & Cetean 2011 and references therein).

In this work, we used high definition SEM-EDS images of entire and sectioned specimens, to investigate both the morphology and the test wall microstructure of some agglutinated foraminifera belonging to the genus *Colominella* coming from two sections exposed in the western Mediterranean area (Rio Torsero section) and in the Paratethyan Transylvanian Basin (Lăpugiu de Sus section) (Fig. 1A'). The main purpose of this study is to compare the Pliocene Mediterranean individuals with the Badenian topotypes in order to verify whether or not the Pliocene Mediterranean specimens described by Mancin et al. (2012) were correctly assigned to the species *Colominella paalzowi*, thereby extending the known stratigraphical and geographical range of the genus.

Materials and methods

The Lăpugiu de Sus section crops out in one of the most famous fossiliferous sites of the Transylvanian Basin (Hunedoara county, Rumania) along the Mureş River (Fig. 1A'). The very rich mollusc fauna, in particular bivalvia and gastropods, was mentioned in 1863 by Stur and then was exhaustively studied, as testified by the numerous palaeontological and stratigraphical data subsequently published (e.g., Petrescu et al. 1990; Chira 1994; Chira et al. 2000; Chira & Voia 2001;



Fig. 1. A–A': Simplified geographical map of the Mediterranean area and Eastern Europe with the location of the studied sections (1 — Lăpuşiu de Sus section in Romania; 2 — Rio Torsero section in Italy). B–C: Schematic palaeo-geographical maps of the Africa–Eurasia collision zone reconstructed for the Early Pliocene (partly modified and redrawn after Popov et al. 2006) and the Middle Miocene (partly modified and redrawn after Rögl 1999). Note that during the Badenian (Langhian) the Central Paratethys was connected with the Mediterranean Sea favouring the great similarity of their marine palaeontological record (de Leeuw et al. 2013). Since the late Badenian (early Serravallian) the connection failed causing the progressive faunal differentiation in the two basins (de Leeuw et al. 2013).

Harzhauser et al. 2003; Tămaş et al. 2013). The Badenian foraminiferal assemblages from the same locality were the subject of numerous studies since the pioneering work of Cushman (1936) (e.g., Nicorici et al. 1994; Popescu & Crihan 2005; Krézsek & Filipescu 2005; Báldi et al. 2002; Báldi 2006; Filipescu & Silve 2008; Boga 2013; de Leeuw et al. 2013). These studies provided a complete biostratigraphical and environmental framework for the central Paratethyan area.

In the western Mediterranean region, the Rio Torsero section crops out along the homonymous rivulet in the easternmost portion of the Albenga basin (western Liguria; Italy) (Fig. 1A'). This Pliocene outcrop has been well known since the 20th century thanks to its rich mollusc faunas (mainly gastropods) as

documented by several studies (e.g., Bernasconi & Robba 1984, 1994; Solsona 1999; Solsona & Martinell 1999; Andri et al. 2005; Harzhauser & Kronenberg 2008). Published micropalaeontological data (Violanti 1987; Mancin et al. 2012) pointed out the depositional environment of the Rio Torsero section, which probably recorded the sedimentation in the circalittoral zone, close to the shelf edge.

For the present study, we examined, under a Scanning Electron Microscope (SEM) equipped with an X-ray Energy Dispersive Spectrometer (EDS), four topotype specimens of *Colominella paalzowi*, that were isolated and picked from samples collected from the Badenian Lăpuşiu de Sus type section (Fig. 1A'). In order to directly compare the Paratethyan

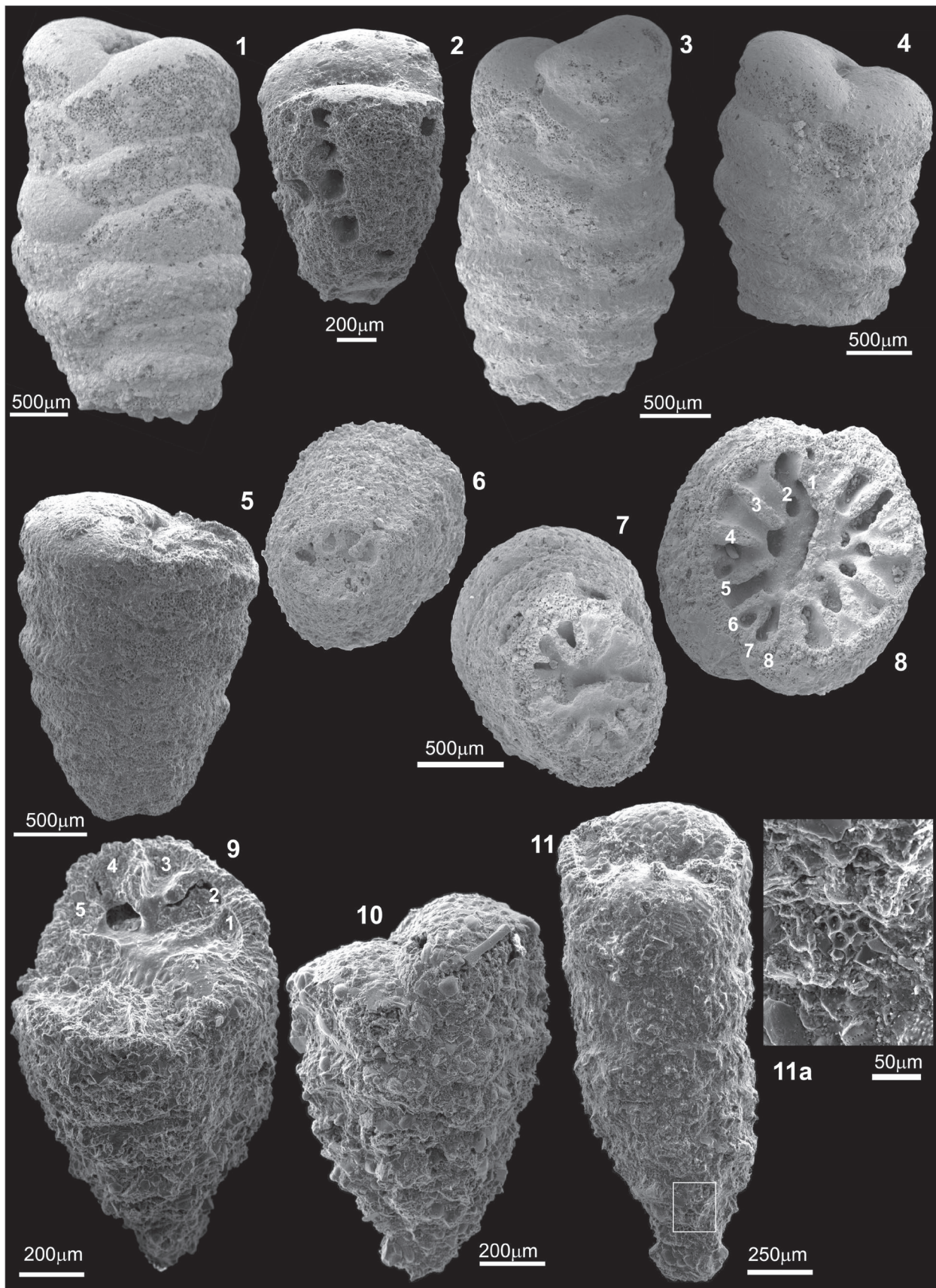


Fig. 2. Morphological variability of some *Colominella* specimens from the Pliocene Rio Torsero (images 1–8) and the Badenian Lăpușiu de Sus (images 9–11) sections. SEM images are in secondary electrons (SE).

and Mediterranean specimens of *Colominella*, we also analysed five new specimens of *Colominella* isolated and picked from the same samples previously studied by Mancin et al. (2012) collected from the lower Pliocene Rio Torsero section (Fig. 1A'). Moreover, to better compare new results with data reported in the previous paper of Mancin and co-authors, all the collected specimens were prepared and analysed following the same methodology described in Mancin et al. (2012) and recently standardized by Mancin et al. (2014). The studied specimens are stored in the micropalaeontological collection of the Department of Earth and Environment Sciences of the University of Pavia (Italy).

Results

Morphology of the *Colominella* test

The Pliocene Mediterranean specimens have a large test (from 2.5 to 3 mm long and 1.5 to 2 mm wide) with an elongate morphology typically with a well-developed biserial stage, but lacking a clear early triserial stage (Fig. 2, images 1–5). The internal radial partitions forming alcoves appear quite soon during the test growth, sharply increasing in number passing from the earlier to the later chambers (Fig. 2, images 6–8).

The Badenian topotypes are smaller (1 to 1.5 mm long and 0.5 to 1 mm wide), with a characteristic conical and more fusiform shape due to the chambers that sharply increase in size during ontogeny (Fig. 2, images 9–11; Fig. 3) and the occurrence of a well-developed early triserial stage (Fig. 3, image 1b). Chamber partitions appear later in the ontogenetic growth as they are missing from the earlier triserially arranged chambers (Fig. 3, image 1b arrow). The number of vertical partitions forming alcoves is also different in the Pliocene and Badenian individuals: alcoves are more numerous in Pliocene specimens (7 to 8 in the last chambers; Fig. 2, image 8) while they are less numerous (from 4 to 5) in the Badenian individuals (Fig. 2, image 9; see also Spezzaferri et al. 2004, Pl.6, fig. 9).

The Pliocene Mediterranean specimens, moreover, have an external, homogeneous smooth surface; a sort of external pavement that covers the open entrances of the canaliculi crossing the test wall. In some portions of the test, this pavement is missing because it was partly abraded by erosion (Fig. 2, images 1–4). Conversely, in the Badenian specimens the test surface is more coarsely agglutinated and made of heterogeneous grains consisting also of the remains of small calcareous foraminifera (Fig. 2, images 10–11a).

Microstructure of the agglutinated wall

In sectioned specimens, the microstructure of the agglutinated wall appears quite different in the Pliocene individuals with respect to the Badenian specimens. In the former, the test wall is thicker (over 100 μm) and abundantly crossed by canaliculi (Fig. 4, images 1a–c, 2a–b, 3a–b); they are straight and radial in the inner portion of the wall but become branching in the outer part (Fig. 4, images 1b, 1c, 2b). Moreover, canaliculi are present mostly in the upper portion of alcoves towards the external margin and are missing internally and on the secondary septa (Fig. 4, image 1d). The agglutinated granules are selected with respect to their size and disposition within the test wall: the largest grains are positioned toward the outside margin, while the smallest ones are internally arranged, simulating a sort of layered microstructure of the agglutinated wall (Fig. 4, images 1a, 1d, 2b, 3a–b). Where the agglutinated wall is crossed by canaliculi, the coarse-grained particles are embedded in an aggregate of very small detrital granules, 3 to 5 μm in size (Fig. 4, image 1b white arrow), probably to favour the development of the canaliculi themselves. The grain selectivity persists unchanged throughout the whole test (Fig. 4, images 1, 2, 3).

In the Badenian specimens of *C. paalzowi* the test wall is less thick (ca. 90 μm or less) and abundantly crossed by canaliculi that, as in the Pliocene individuals, are present mostly in the upper portion of alcoves towards the external margin and are missing on the secondary septa (Fig. 5, images 1a, 2a, 3b). However, the agglutinated granules are not always selected in size and disposition (Fig. 5, images 1a–b, 3a–b) resulting in a more disorganized wall microstructure without a distinctly layered grain arrangement.

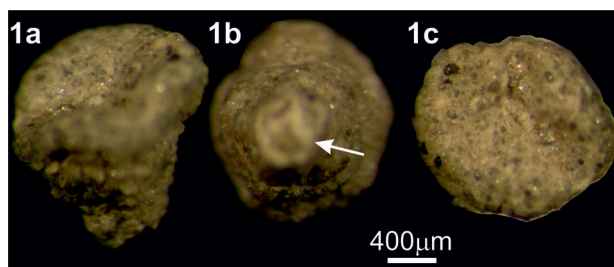
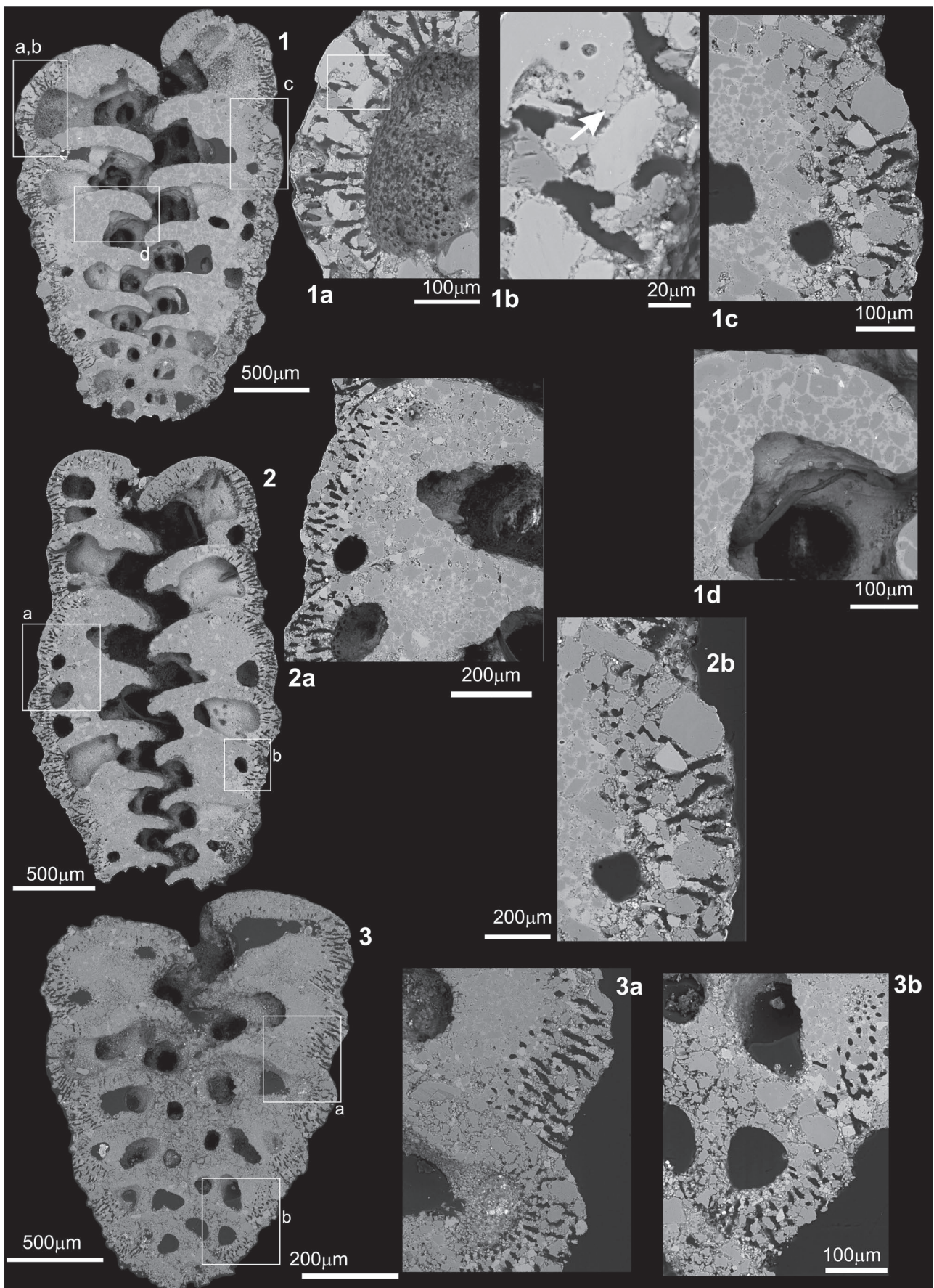


Fig. 3. Images at the stereomicroscope of a topotype specimen of *Colominella paalzowi* from the Badenian Lăpugiu de Sus section showing the typical conical shape (1a), a clearly evident early triserial stage without internal partitions (arrow in 1b) and a rounded profile in apertural view (1c).

Fig. 4. Sectioned specimens of *Colominella* from the Pliocene Rio Torsero section. SEM images are in back-scattered electrons (BSE). **1:** Specimen (the same of Fig. 2, image 1) longitudinally sectioned to show the internal partition of the chambers and the microstructure of the agglutinated wall; **1a** — detail of the agglutinated wall crossed by canaliculi, **1b** — enlargement of “a” showing how the coarse-grained particles are embedded by numerous small detrital granules (white arrow), **1c–d** — microstructural details of both the test wall and a septum showing the grains which are selected in terms of size and disposition, forming a layered microstructure (arrow). Note that only the test wall is crossed by canaliculi that are missing on the septa. **2:** Specimen (the same of Fig. 2, image 3) longitudinally sectioned; **2a–b** — details of the agglutinated wall. **3:** Specimen (the same of Fig. 2, image 5) longitudinally sectioned; **3a–b** — details of the agglutinated wall. Note that in all the sectioned specimens the microstructural characteristics of the agglutinated wall persist unchanged during the test growth.



Chemical-mineralogical composition of the agglutinated grains

Even from a compositional point of view the Pliocene and Badenian specimens are different. The former ones are characterized by agglutinated grains that are compositionally more homogeneous and mostly made of dolomite, quartz, with a minor amount of calcite and K-feldspar (Fig. 6, image 1a). Quartz grains mostly form the external pavement that covers the open entrance of canaliculi (Fig. 6, image 1d Si-map), on the other hand, the internal grains are mostly of dolomite. All the grains are cemented by calcite cement that appears as cloudy light grey areas among the detrital grains (Fig. 4, images 1c–d, 2a–b, 3a–b; Fig. 6, image 1c Ca-map).

Conversely, in the Badenian specimens, the agglutinated grains are compositionally more heterogeneous and formed by calcite (Fig. 7, images 1c, 2c Ca-maps), quartz (Fig. 7, images 1a, 2a Si-maps), with a minor amount of dolomite and albite (Fig. 7, images 1b, 2b Mg-maps and 2d Na-map). It is noteworthy that the quartz grains are heterogeneously distributed within the test wall even within the internal septa (Fig. 7, images 1a and 2a Si-maps) and they do not concentrate towards the external margin of the test wall to form a pavement covering the canaliculi. Moreover, some agglutinated grains are remains of planktonic foraminifera that, on the contrary, are never observed in the Pliocene specimens (Fig. 2 image 11a; Fig. 5, image 1a).

Do the Pliocene Mediterranean specimens belong to the type species *C. paalzowi*?

The direct comparison between the specimens of *Colominella* from the Pliocene Mediterranean record and the topotype individuals of *C. paalzowi* from the lower Badenian Paratethyan Lăpugiu de Sus section shows that the Pliocene Mediterranean specimens have a different, more complex test. The complexity of the agglutinated test, in terms of a major number of internal partitions, a test wall microstructure with a layered structure and a strong selection of the agglutinated grains, represents a higher grade of evolution probably driven by the adaptive response to different ecological conditions that persisted for a long time, most likely since the early Serravallian (ca. 13.5 Ma) when the marine connection between the Mediterranean and Paratethys failed (Rögl 1998, 1999) (Fig. 1A–C), promoting the progressive and inevitable faunal differentiation in the two basins

(de Leeuw et al. 2013). Mancin et al. (2012) interpreted the increased complexity of the *Colominella* test as an evolutionary adaptation to perform kleptoplastidy and/or to house photosymbionts probably at shallow bathymetries in warm-water environments.

The collected results support the idea that the Pliocene *Colominella* specimens from the Mediterranean Rio Torsero section are different from a taxonomic point of view, and therefore they cannot be assigned to the topotype species *C. paalzowi* (Cushman). The Pliocene Mediterranean specimens more probably represent a new, younger, more highly evolved *Colominella* species.

Our understanding of the occurrence of a new species of *Colominella* in the Mediterranean Pliocene record awaits the formal description of the type species and a formal update of the stratigraphical and geographical range of the genus *Colominella*.

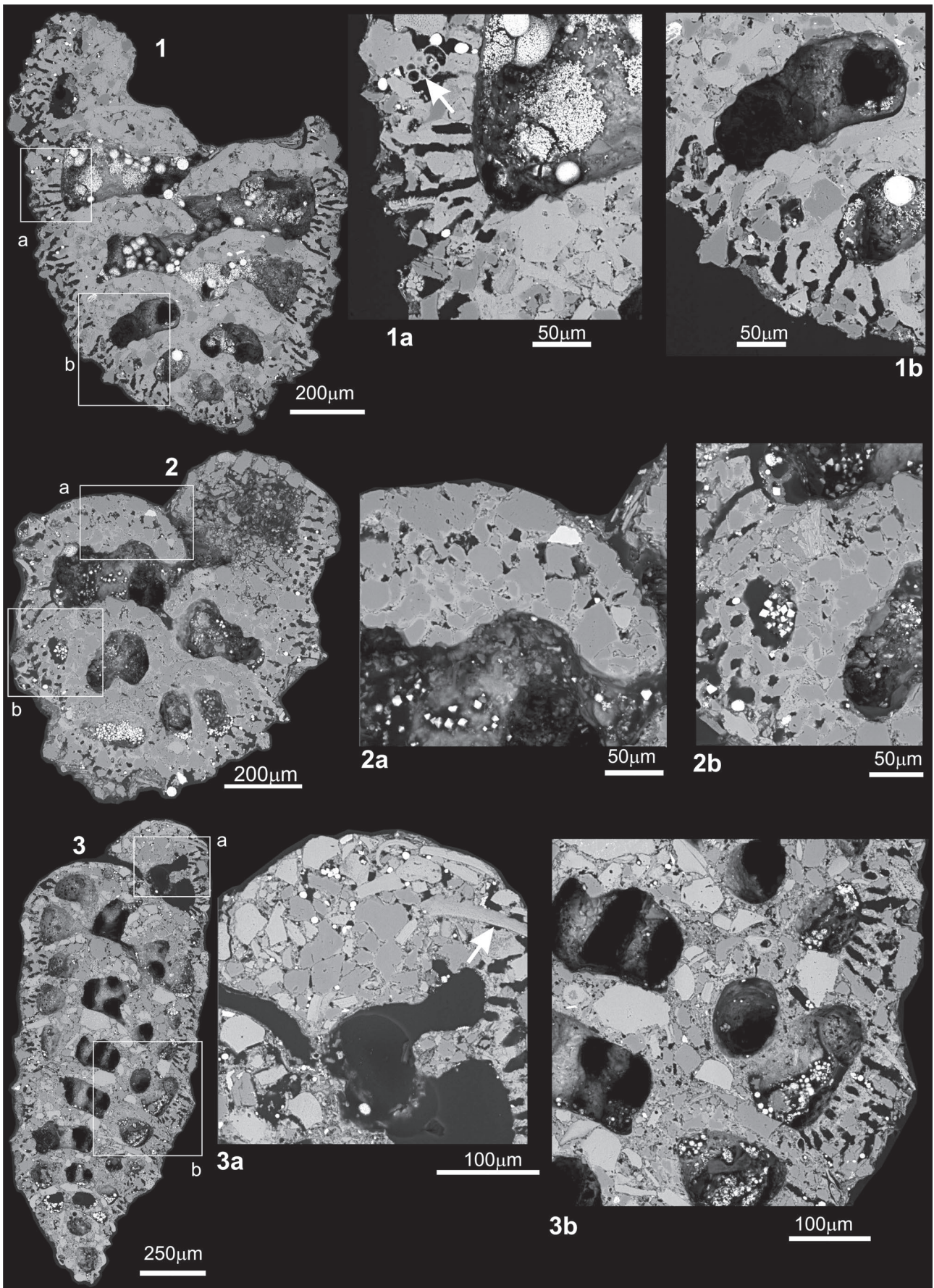
Final remarks

This study reports, through high definition SEM-EDS images of entire and sectioned agglutinated specimens, the direct comparison between specimens of *Colominella* sampled in a Pliocene succession from the western Mediterranean previously studied by Mancin et al. (2012) and topotypes of the species *Colominella paalzowi* recently sampled in the Badenian Lăpugiu de Sus type section.

The Pliocene Mediterranean specimens cannot be taxonomically attributed to the type species *C. paalzowii*, but more probably they represent a new, more highly evolved species. Further investigations on other middle Miocene–Pliocene shallow water records from the Mediterranean Sea are needed to provide a new understanding of how the genus *Colominella* had evolved in the Mediterranean Sea since the early Serravallian, and to formally describe the new Pliocene species.

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Fig. 5. Sectioned topotype specimens of *C. paalzowi* from the Badenian Lăpugiu de Sus type section. SEM images are in back-scattered electrons (BSE). **1:** Specimen (the same of Fig. 2, image 9) longitudinally sectioned to show the internal features of the test and the microstructure of the agglutinated wall. **1a–b** — Details of the agglutinated wall crossed by canaliculi. Note that granules are quite chaotically distributed and poorly selected in terms of size and disposition within the wall; note also that some of them are formed by fossil remains of planktonic foraminifera (arrow). **2:** Specimen (the same of Fig. 2, image 10) longitudinally sectioned; **2a–b** — details of the agglutinated wall. **3:** Specimen (the same of Fig. 2, image 11) longitudinally sectioned; **3a–b** — details of the agglutinated wall. The microstructural characteristics of the agglutinated wall appear to persist unchanged during test growth in all the sectioned Pliocene specimens.



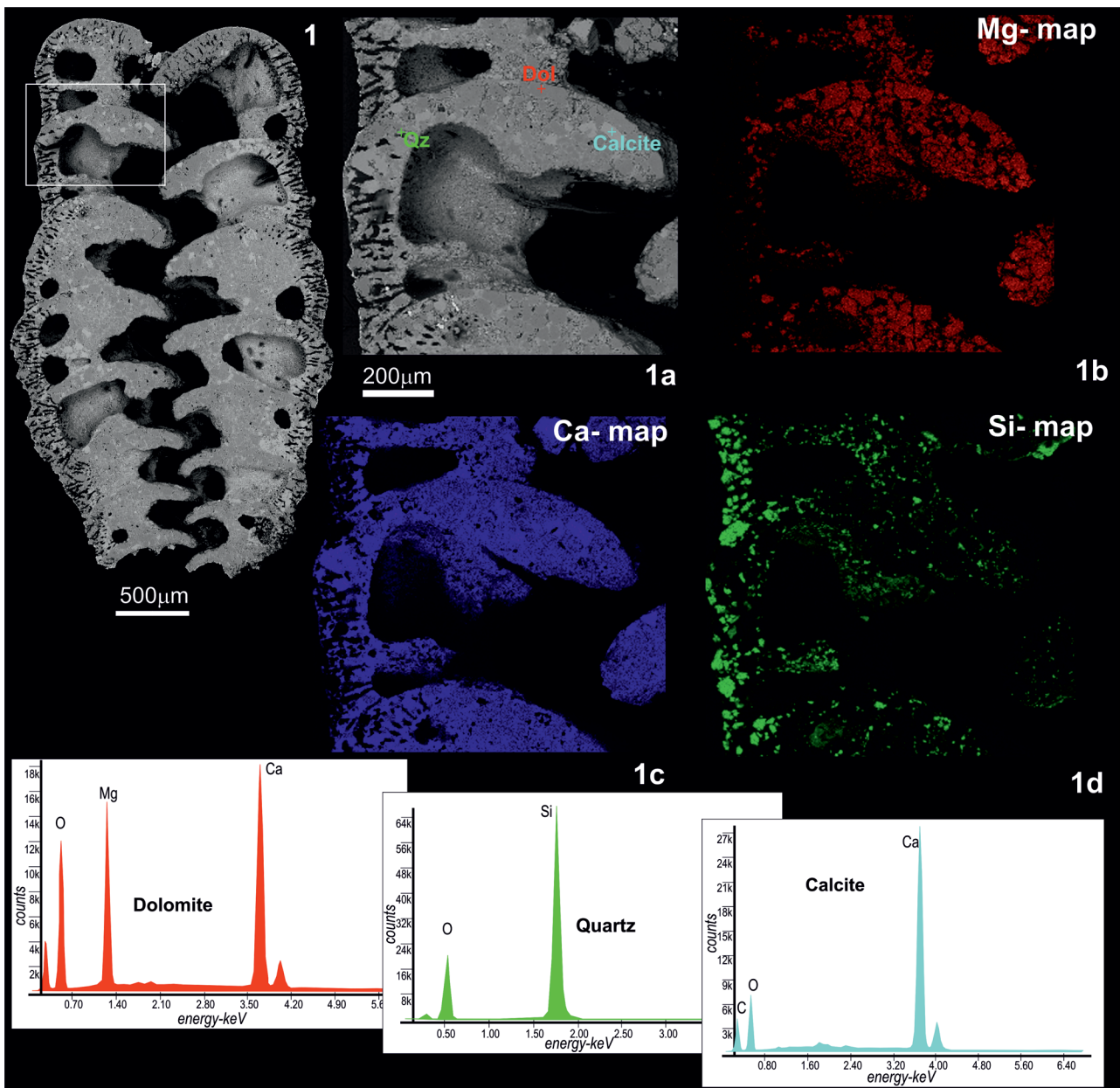
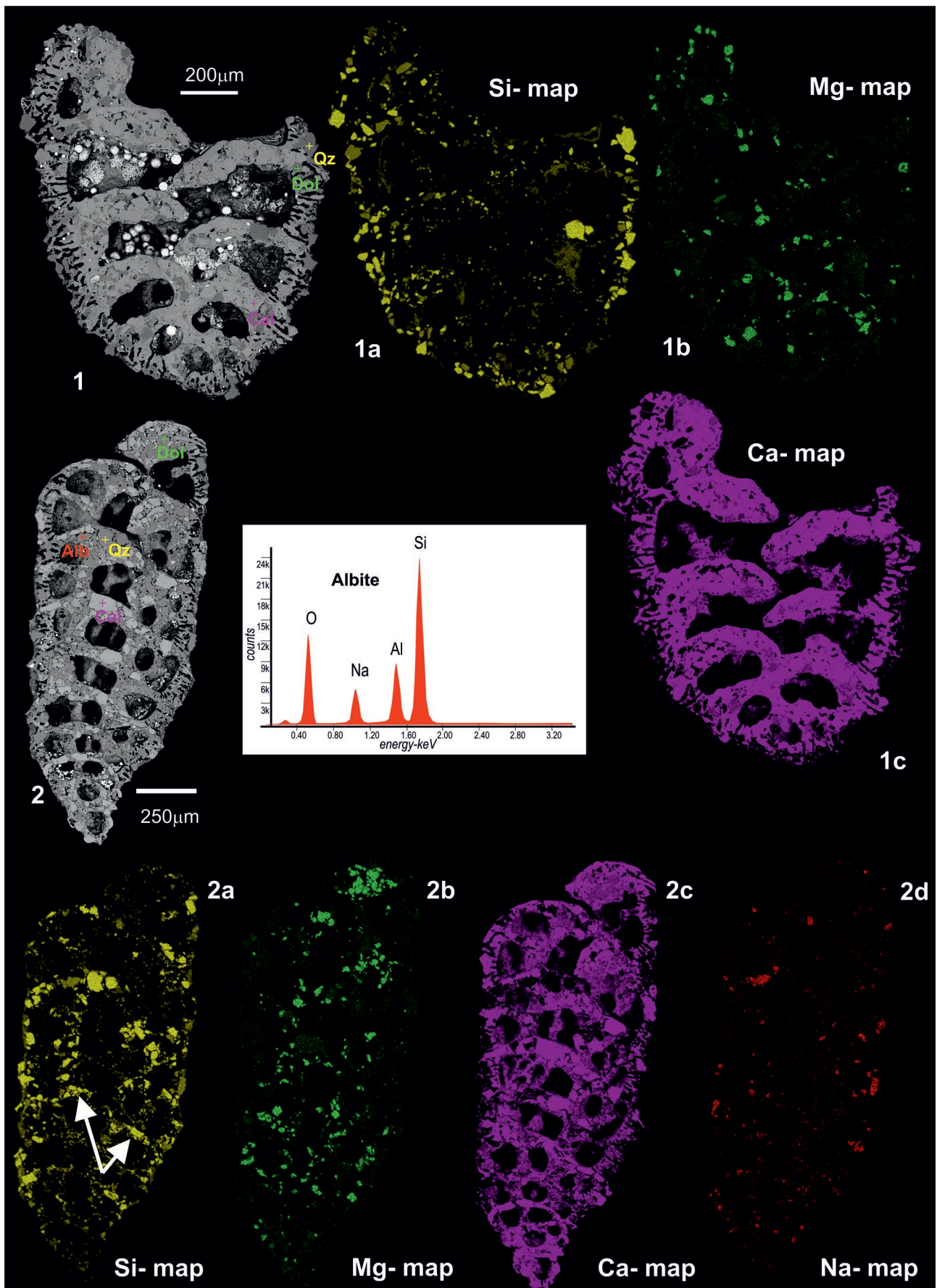


Fig. 6. Elemental characterization of the agglutinated grains in one specimen of *Colominella* from the Pliocene Rio Torsero section. Images are in back-scattered electrons (BSE). **1a** — Longitudinally sectioned specimen of *Colominella* showing a detail of the test wall microstructure (a) with indication of the spots for standardless microanalyses (coloured crosses) together with the corresponding EDX spectra used to compositionally characterize the agglutinated grains. **1b–d** — Elemental maps showing the distribution of Magnesium (b), Calcium (c) and Silicon (d) in the portion of test of *Colominella* recorded in image 1a. Mg and Si are here considered as discriminated elements of dolomite and quartz, respectively. Note that Si mostly concentrates in the external portion of the test forming the pavement that covers the canaliculi; on the other hand, Mg and Ca occur abundantly in the internal portion of the test wall.

Fig. 7. Elemental characterization of the agglutinated grains in two specimens of *C. paalzowi* from the Badenian Lăpugiu de Sus type section. Images are in back-scattered electrons (BSE). **1–2:** Longitudinally sectioned specimens of *C. paalzowi* showing the test wall microstructure with reported the spots for standardless microanalyses (coloured crosses) together with the corresponding EDX spectrum used to compositionally characterize the agglutinated grains (in this case a grain of albite). **a–d** — Elemental maps showing the distribution of Silicon (a), Magnesium (b), Calcium (c) and Sodium (d) in the whole sectioned tests recorded in images 1 and 2. Mg and Si are here considered as discriminated elements of dolomite and quartz, respectively, whereas Na is distinctive of albite. Note that most of the agglutinated grains are calcite while Si is quite rare and does not concentrate only in the external portion of the test but is also internally distributed sometimes in the upper margin of the septa (arrows). Mg and Na are quite rare and without any particular distribution within the test wall.



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