ACTA PALAEONTOLOGICA ROMANIAE (2016) V. 12(2), P. 3-20

# MIDDLE MIOCENE (LATE BADENIAN) PHAEODARIA FROM ROMANIA

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Received: 1 November 2016 / Accepted: 27 November 2016 / Published online: 19 December 2016

**Abstract** This article represents a revision of the phaeodarian fauna from the middle Miocene (upper Badenian) of Romania published in 1964 and 1965 with illustrations in China ink. The present article has all illustrations with SEM photos except for the last figure that presents illustrations in optical microscopy. This fauna consists of representatives of 4 families: Challengeriidae, Medusettidae, Porospathididae and Geticellidae. Scanning electron microscopy has proved that the amphora shaped structure of the Miocene Challengeriidae is similar to that of the Recent and Late Cretaceous and that the oral appendages are parts of shell built after the building of the main shell with amphora-shaped wall structure. The oral apendages appear to be a result of secondary construction which is attached to the main shell. *Kozohashetta* n. gen. is erected for the former species *Challengeranium diodon* (Haeckel) and *Ch. torquatum* Dumitrică and considered to belong to the family Medusettidae on the basis of wall and oral arms structure. The family Geticellidae is formally described and the occurrence of the Porospathididae is for the first time reported in this fauna.

**Keywords**: Middle Miocene, upper Badenian, Subcarpathians, Phaeodaria, taxonomy, wall structure.

## INTRODUCTION

This article is not completely new. It is mainly a revision with re-description and illustration with scanning electron micrographs of the middle Miocene phaeodarian microfauna from Romania studied in optical microscopy and published about 50 years ago (Dumitrică, 1964, 1965) with drawings in China ink. However, it does not represent a simple repetition of the two articles because in the 50 years that passed I found other species and specimens, and our knowledge on different aspects of this group of protistans has considerably increased, so that the knowledge we have about them, about their place in the phylogenetic tree and especially about the microstructure of their shells and their geological history improved considerably.

Before these two articles in which I had described especially some new species of the family Challengeriidae, nothing was known about the fossil Phaeodaria. One had thought that, due to their incompletely silicified skeleton (Haeckel, 1887), they could not be preserved in fossil state, although Bailey (1856), Wallich (1869), Murray (1876, p. 536), and Riedel (1963) reported occurrences of some Challengeriidae and other phaeodarians in the recent deep-sea radiolarian oozes or in other surface or subsurface sediments. Campbell (1954), in his controversial contribution to the Treatise on Invertebrate Paleontology, for practically all families of Phaeodaria mentioned as range only Recent. There was a single exception for the family Cannosphaeridae Haeckel and the suborder Phaeodarina, respectively, for which he designated Cretaceous - Recent. As Deflandre (1960) remarked in a critic evaluation of Campbell's contribution, this designation was due to the misinterpretation of the dinoflagellate genus *Cannosphaeropsis* Wetzel from the Cretaceous flint as a fossil phaeodarian (O. Wetzel, 1933). As a consequence, the discovery of these first true fossil phaeodarians in the middle Miocene of Romania seems to have been, at that time, an event of a certain importance because it has been mentioned by Tappan and Loeblich, Jr. in the comprehensive look about the significant achievements in paleontology presented by R. C. Moore (1968, p. 1344).

During the 50 years that passed from these first reports of fossil phaeodarians, the inventory of fossil species of Phaeodaria enriched considerably and their occurrences have been reported not only in the Cenozoic (Dumitrică, 1972, 1973, 1978; Dumitrică & Eetvelde, 2009; Ling, 1975, 1991; Stadum & Ling, 1969; Runeva, 1974; Bjørklund, 1976, 1980, 1984); Petrushevskaya & Reschetnjak, 1980; Bjørklund & Ruiter, 1987), but also in the Late Cretaceous (Bragina, 2003; Takahashi, 2004; Dumitrică & Hollis, 2004) and even in the latest Triassic (Rhaetian) (Hori et al., 2009) (see also Nakamura & Suzuki, 2015).

## SAMPLES STUDIED

All species illustrated and discussed in this article come from a single geological formation, the so-called Radiolarian Shale Formation, well developed in the southern part of the Subcarpathians and in the Getic Depression. The samples in which phaeodarian species were found have been collected long time ago from 4 localities: one in the southern end of Eastern Subcarpathians and 3 in the Getic Depression, west of Olt river, in the district Râmnicu Vâlcea as follows (Fig. 1):

a) Sample 35, collected in 1960, along the Crângului valley from the Fințești village, Prahova district, southern end of Eastern Subcarpathians. The sample came from a level of indurated variegated grey marl from which radiolarians have been extracted by treatment with diluted HCl. Phaeodarian fauna found in this sample consisted

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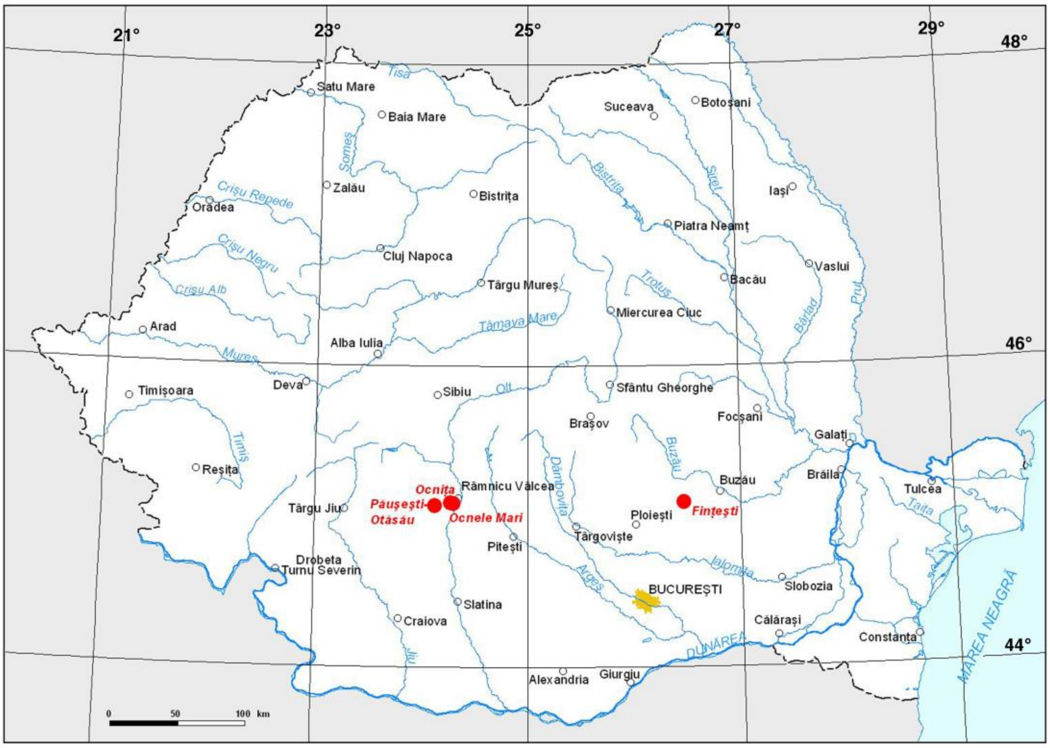

**Fig. 1** Map of phaeodarian occurrence localities in Romania.

only of specimens of the species *Protocystis deflandrei* Dumitrică published 4 years later (Dumitrică, 1964), which represented the first report of truly fossil phaeodarians. The main shell of the specimens was well preserved in this sample but, with some exceptions (Dumitrică, 1978, pl. 7, fig. 28), the peristome of most specimens was only partly preserved.

b) Samples 1006 and 1007, collected in 1963 along the Salina valley (valea Salinei) in the hamlet Ocnița of the village Ocnele Mari, SW of the town of Râmnicu Vâlcea. The samples come from the upper part of the Radiolarian Shale Formation.

c) Sample 1315, collected in 1963, from the Tilvici valley, Păușești-Otăsău village. The sample is the best of the 4 phaeodarian containing samples. It was situated towards the upper part of the Radiolarian Shale Formation and consisted of a bed of about 5 cm of yellow indurated marl full of large specimens of the radiolarian species *Centrocubus cladostylus* Haeckel, *Diplospongus dendrophorus* Mast (Dumitrica, 1983, p. 230) and *Lichnosphaera regina* Haeckel, all visible with the naked eye as white spherules. The bed was relatively well exposed when the sample was collected but one year later, when I revisited the section for additional sampling, it was covered by a landslide and became inaccessible. Phaeodarians from this sample have been published in Dumitrică (1965). The sample is the only sample with *Geticella compressa* Dumitrică and with the best preserved specimens of *Kozohasheta torquata* (Dumitrică).

d) Sample OM 54 was collected in 1989 from the right side of valea Sărată (Salted Valley), Ocnele Mari. Lithologically it was similar to the sample 1315 and consisted of a bed about 5 cm thick with large *Coscinodiscus* sp., *Diplospongus dendrophorus* Mast, *Centrocubus cladostylus* Mast, and *Lichnosphaera regina* Haeckel. The phaeodarian assemblage is rather similar to that of the sample 1315 except for *Geticella*, which is missing in it. The exposure was very good when the sample was collected but about 10 years ago, when I revisited it, it was completely covered by soil and unrecognizable. Given the lithological and faunistical resemblance between this sample and sample 1315, as well as its position at the upper part of the Radiolarian Shale succession and its yellow colour contrasting with the grey or dark grey colour of the radiolarian shales one can suppose that both samples represent one and the same bed.

Unfortunately the exact location with longitude and latitude of all these samples on the mentioned sections for a future re-collection is difficult at the present because the maps at 1:25.000 scale used in the field work were secret 55 years ago and are probably lost or difficult to find. And also, as I could remark and mentioned above, the outcrops change easily, especially in sections of soft rocks as those of the Radiolarian Shale Formation.

## GEOLOGIC SETTING

All phaeodarians studied for the present article come from the so-called Radiolarian Shale Formation or Radiolarian Shale Horizon separated by Gr. Popescu (1943/1951) and Fl. Olteanu (1943/1951) in the Romanian Subcarpathians, in a study of the stratigraphy and age of the salt breccia between Prahova valley and Buzău valley.

They considered this formation as being Tortonian in age and recognized in it, from bottom to top, the following

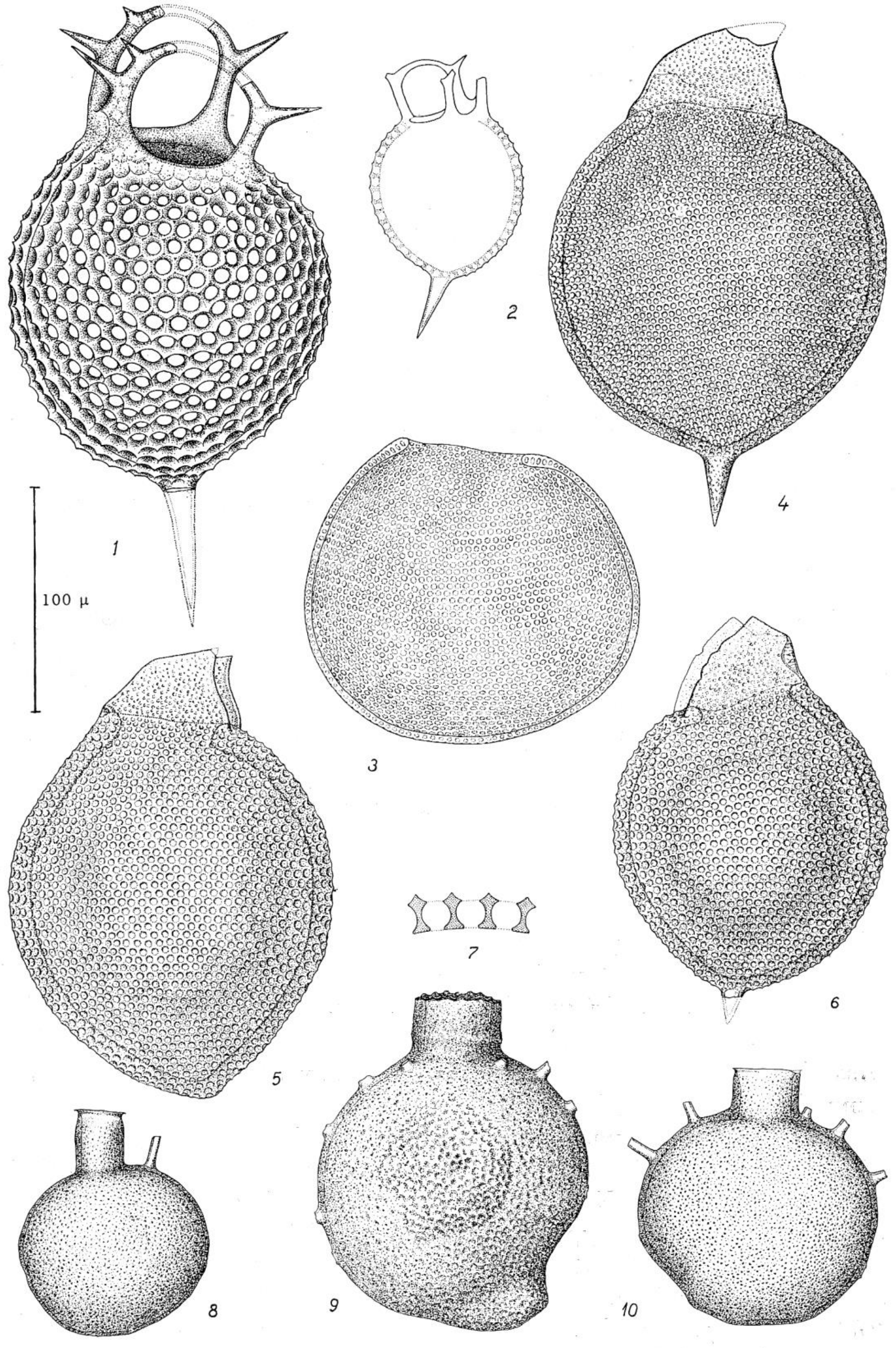

**Fig. 2** Phaeodarian species illustrated and described in Dumitrică (1965). **1**, **2**, **7** *Challengeranium torquatum* Dumitrică; **3** *Lithogromia reschetnjakae* Dumitrică; **4** *Protocystis fossilis* Dumitrică; **5** *Protocystis tortonica* Dumitrică; **6** *Protocystis deflandrei* Dumitrică; **8**-**10** *Geticella compressa* Dumitrică, **10** holotype. Generic and species names are those of originally given.

lithostratigraphic units or horizons, as they have originally been called:

- Tuff and Globigerina Marls,
- Salt Breccia with Salt Massifs,
- Radiolarian Shales,
- Spirialis Marls.

These units have been later recognized under the same or different local names all over Carpathian area in Romania (Subcarpathians, Getic and Transylvanian Depressions), Ucraina (Subcarpathians and Transcarpathians) and Poland (Silezian Basin).

The Tortonian age of these units, mentioned in my first two papers on the Miocene phaeodarians from Romania, was later changed into Badenian (Dumitrică et al., 1975; Dumitrică, 1978), a regional stage introduced in the Central Paratethys to replace the Tortonian and defined as a chronostratigraphic concept by Papp et al. (1968). The Badenian represents the basal stage of the middle Miocene in the Central Paratethys and was subdivided into 3 substages (Moravian, Wielician and Kossovian) (Papp et al., 1978). It encompases the time interval between 16.3 and 12.8 Ma (Hohenegger et al., 2014) and corresponds to the global stages Langhian and the lower part of Serravallian (Dumitrică et al., 1975).

The Moravian or Early Badenian is practically equivalent of the Langhian, a Mediterranian stage (Dumitrică et al, 1975) and corresponds to the Tuff and Globigerina Marl Formation or Slănic Formation as it is called in the Eastern Carpathians (Melinte & Stoica, 2014). It succeeded to a lacustrine environment, started with the *Praeorbulina glomerosa* Zone and marks the time when the Central Paratethys, although partly closed, had still connections with the Mediterranean Basin with which it can be still correlated. It corresponds to the time interval from 16.3 to 15 Ma (Hohenegger et al., 2014).

The Wielician corresponds to the Salt Breccia with Salt Massifs and Gypsum Deposits (Evaporitic Formation) interpreted as deposits of a giant and shallow salina basin developed in the Central Paratethys during the middle Badenian salinity crisis (Bąbel, 2004). It ranges from 15 Ma to 13.8 Ma (Hohenegger et al., 2014), the latter datum correlating with the base of the Serravallian, and characterized by a strong global cooling event.

The Kossovian or late Badenian comprises in Romania the other two units of the Badenian stage: the Radiolarian Shale Formation and the *Spirialis* Marl Formation. They prove that at the end of the evaporitic crisis a normal marine environment established in the Carpathian area of the Central Paratethys, in a first stage with a blooming of siliceous microfossils, corresponding to the Radiolarian Shale Formation, in the second stage, with calcareous micro- and macrofossils, corresponding to the *Spirialis* Marl Formation. This substage is delimited in time between 13.8 Ma, which corresponds practically to the Langhian-Serravallian boundary, and around 12.8 Ma at the top, which corresponds with the boundary between Kossovian and Sarmatian. In the Carpathian area at least the Radiolarian Shale Formation corresponds to the moment when the Central Paratethys had connections with the Indian Ocean as the radiolarians and silicoflagellates prove. Planktonic foraminifera of this substage display an advanced endemism and are inadequate for extra-Paratethydian correllations but radiolarians and silicoflagellates can be rather well correlated with the Indian Ocean and, through it, with the Pacific Ocean. The silicoflagellates belong to the *Corbisema triacantha* Zone (Martini, 1971, 1972), *Distephanopsis stauracanthus* Subzone (Bukry, 1981; Perch-Nielsen, 1985) and the calcareous nannoplankton indicates the NN6 Zone with *Discoaster exilis* (Martini, 1971) or with *Coccolithus miopelagicus* (Bukry, 1971), which define the same interval, and both correlate with the N11-N12 Zones of planktonic foraminifers (Dumitrică et al., 1975). Radiolarian Shale Formation consists of a series of finely stratified argillaceous or marly-argillaceous deposits of black, grey, brown colour, at some levels with intercalations of tuffs or sands. The latter are well developed in some areas forming an independent member. The thickness of this formation varies from several meters to about 150 m. The microfossil content is very rich and very diverse. It consists of radiolarians, silicoflagellates, diatoms, endoskeletal dinoflagellates, ebridians, calcareous nannoplankton and foraminifers, and very rarely phaeodarians. It is an assemblage that indicates a normal marine environment. The occurrence of phaeodarians is sporadic and it seems that it is only located at the upper part of the formation, whereas the other microfossils occur continuously on its whole thickness.

## SYSTEMATIC PALEONTOLOGY

Infrakingdom Rhizaria Cavalier-Smith, 2002 emend Cavalier-Smith, 2003
Phylum Cercozoa Cavalier-Smith, 1998, emend. Adl et al., 2005
Class Thecofilosea Cavalier-Smith, 2003, emend Howe et al., 2011
Subclass Phaeodaria Haeckel, 1879
Order Phaeogromida Haeckel, 1887

Family Challengeriidae Murray, 1876
Type genus: *Challengeria* Murray, 1876

*Discussions*. In the first two articles and especially in the second one (Dumitrică, 1965) I described under this family several new species among which one assigned to the genus *Lithogromia* (*L. reschetnjakae* Dumitrică) and three to the genus *Protocystis* (*P. deflandrei* Dumitrică, *P. tortonica* Dumitrică and *P. fossilis* Dumitrică). Another new species, assigned to the genus *Challengeranium* (*Ch. torquatum* Dumitrică), is now assigned to the new genus *Kozohashetta* n. gen. and attached to the family Medusettidae (see below).

The species *Lithogromia reschetnjakae* did not seem to raise taxonomic problems because it answered the diagnosis of this genus as defined by Haeckel: shell smooth without oral teeth and marginal spines. However, several

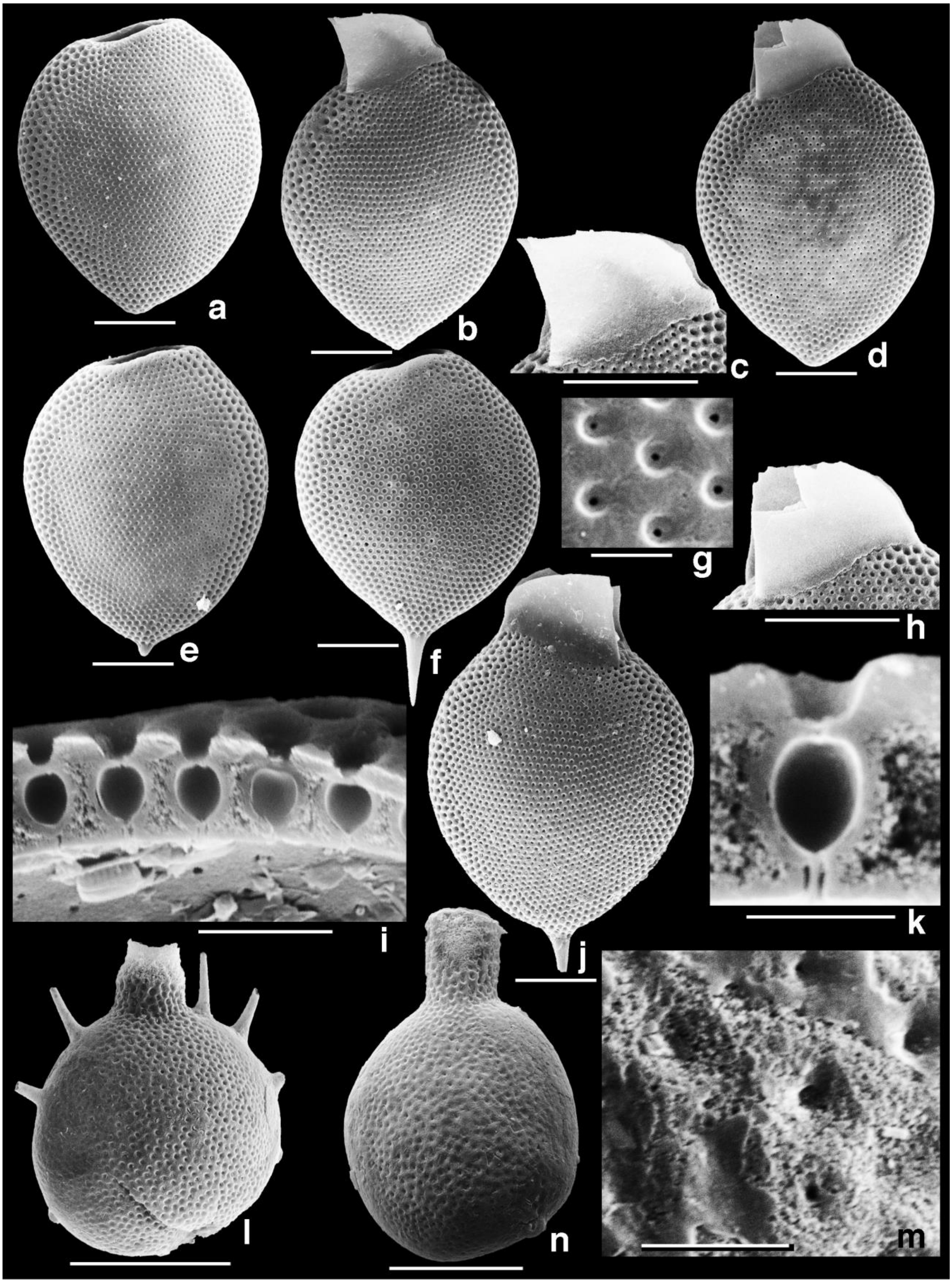

**Fig. 3.** **a-k** *Protocystis deflandrei* Dumitrică, sample 1315: **c** and **h** details of the connection between the oral appendage and shell of figs. **b** and **d**, respectively; **g**, detail of shell surface; **i** pores viewed in transverse section of shell; **k**, detail of pore and wall structure showing the granular structure of cement between amphora-shaped pores. **l-n** *Geticella compressa* Dumitrică, sample 1315: **m** detail of wall surface. Scale bar for figs. **a-f**, **j**, **l**, **n** = 50 µm. Scale bar for figs. **g**, **i**, **k**, **m** = 5 µm.

specimens of rather similar shape, without aboral spine, with round aboral end and with the dorsal and ventral sides of the mouth at practically similar height, (*Protocystis* ? cf. *deflandrei* Dumitrică, 1964, fig. 12), may have remains of peristomial appendages, and another specimen (*Protocystis* sp., Dumitrică, 1978, pl. 7, fig. 27) has a very short button shape aboral spine, round apical end and no oral appendages. These facts cast some doubts on the generic and specific taxonomy.

The taxonomic problems of these species concern the taxonomic value of the aboral spine and oral appendages. These two morphologic and structural characters have been taken into account in the discrimination of some genera and species of the family Challengeriidae. However, although most of the specimens recorded in the studied samples have the same cordate shape test they show a whole transitional series between the specimens with a well-developed aboral spine and specimens without such a spine (Figs. 3-6). In this case, since the challengeriids occurring in this formation can be considered as representing a single population, I think that, with a few exceptions, all specimens with cordate shape could be considered as representing a single species and those with rounded aboral end as another species. Before presenting the taxonomy, I shall discuss about the morphology and structure of their shell.

The Challengeriidae are a family of phaeogromid Phaeodaria with small, ovate, triangular, or lenticular and more or less compressed sack-like shell consisting usually of two parts: the sack-like shell with an oral aperture or mouth and, commonly, peristomial teeth or lamellar appendages. The shell has a bilateral symmetry relative to the sagittal plane that passes through the plane of compression and a dorsal and ventral side allowing distinction of a right and a left side. The border of shell has usually an aboral spine or two or more spines lying in the sagittal plane. All spines are hollow and undivided internally into chambers as in the family Medusettidae. Dorsal and ventral oral margins of shell are usually different and easy to recognize: the dorsal side is usually higher and partly closed by the peristomial appendages, whereas the ventral side is lower and always open.

The structure of the shell wall is very characteristic of this family and very different from all the other Phaeodaria. It has been remarked since the description of the family (Murray, 1876; Haeckel, 1887) and called diatomaceous structure because of its similarity to that of the frustules of diatoms. In modern times this structure was studied in scanning and transmitted electron microscopy by Ling & Takahashi (1977), Takahashi (1981, 1991), Takahashi et al. (1983) and Takahashi & Hurd (2007) who provided fundamental observations on micro- and ultrastructures of phaeodarian skeletons, including the Challengeriidae. They found a variety of microstructures apparently depending on taxa as well as different parts of the skeletons. Concerning the Challengeriidae, they found that the shell wall has an amphora-shaped structure with amphorae cemented with an amorphous and more easily dissolved silica (Fig. 3i, k). The wall of the amphora-shaped pores is massive so that in case of advanced dissolution of the amorphous cement these amphorae can be easily detached and the test looks like a colony of amphora-shaped microfossils (Takahashi, 1981 and 1991, pls. 47, 48, 51, 52; Takahashi et al., 1983; also Figs. 4h, 5k, 6k of the present article) or a plate with large pores (Figs. 4h, 6k). In the latter case the large pores are nothing else than remains of the hollows in which the amphora-shaped pores have been located.

Dumitrică & Hollis (2004) found the same structure in the Late Cretaceous species of the family, and a similar structure seems also to have the late Cenomanian species *Protocystis naibiensis* (Bragina, 2003), which in fact should be assigned to *Challengerebium* Haeckel 1887. The other species illustrated by Bragina from the same sample (*Challengeria* ? *sachalinica* Bragina) is somehow different from what we know about the wall structure of the Challengeriidae because, besides its shape that does not seem to be lenticular as the author mentioned but ellipsoidal with inflated middle part, it has two types of pores: circular at the oral end and elliptical at the aboral one and all irregularly disposed. Or such a structure has nothing to do with *Challengeria naresi* Murray with which it was compared, and is unknown with the Challengeriidae. It is a pity that the author, who mentioned that she had 4 complete specimens and several fragments, had no curiosity to investigate in detail its shell structure.

In the present article I illustrate and discuss this structure with the middle Miocene species.

As concerns the peristomial appendages or teeth, as they are commonly named, until the present very few studies discussed their structure and no one investigated the connection between the oral appendages and the main shell. Normally, they seem to be a continuation of the main shell, preserving partly its structure or changing it gradually, as for instance in *Challengeron willemoesii* Haeckel (Takahashi, 1981, 1991, pl. 47; Takahashi et al., 1983). Most species, however, show a rather clear change in structure and a clear-cut boundary between the main shell and the peristomal appendages. As an example, I illustrated here the living species *Protocystis harstoni* (Murray) (Fig. 8a). In transmitted light, this species shows a clear-cut boundary between the two parts of shell: the main part with amphora structure and the peristomial teeth with an irregular cellular-shaped microstructure. The peristomial end of the main body, in the vicinity of the peristomial teeth, shows an irregular zone with very slightly visible amphorae, as if they are screened by something. By comparison with what I found in the middle Miocene species, this corresponds to the portion of shell covered by the base of the peristomial skeleton so well seen in the Badenian specimens of *Protocystis* herein illustrated (Figs. 3b-d, h, j; 4a, b, e, k; 5h; 6e, f, h, i). The specimen of the late Badenian *Protocystis* illustrated in Fig. 8b shows also, on the dorsal side, that the peristomial appendages are not a continuation of the alveolar body but are superposed on its external face like a

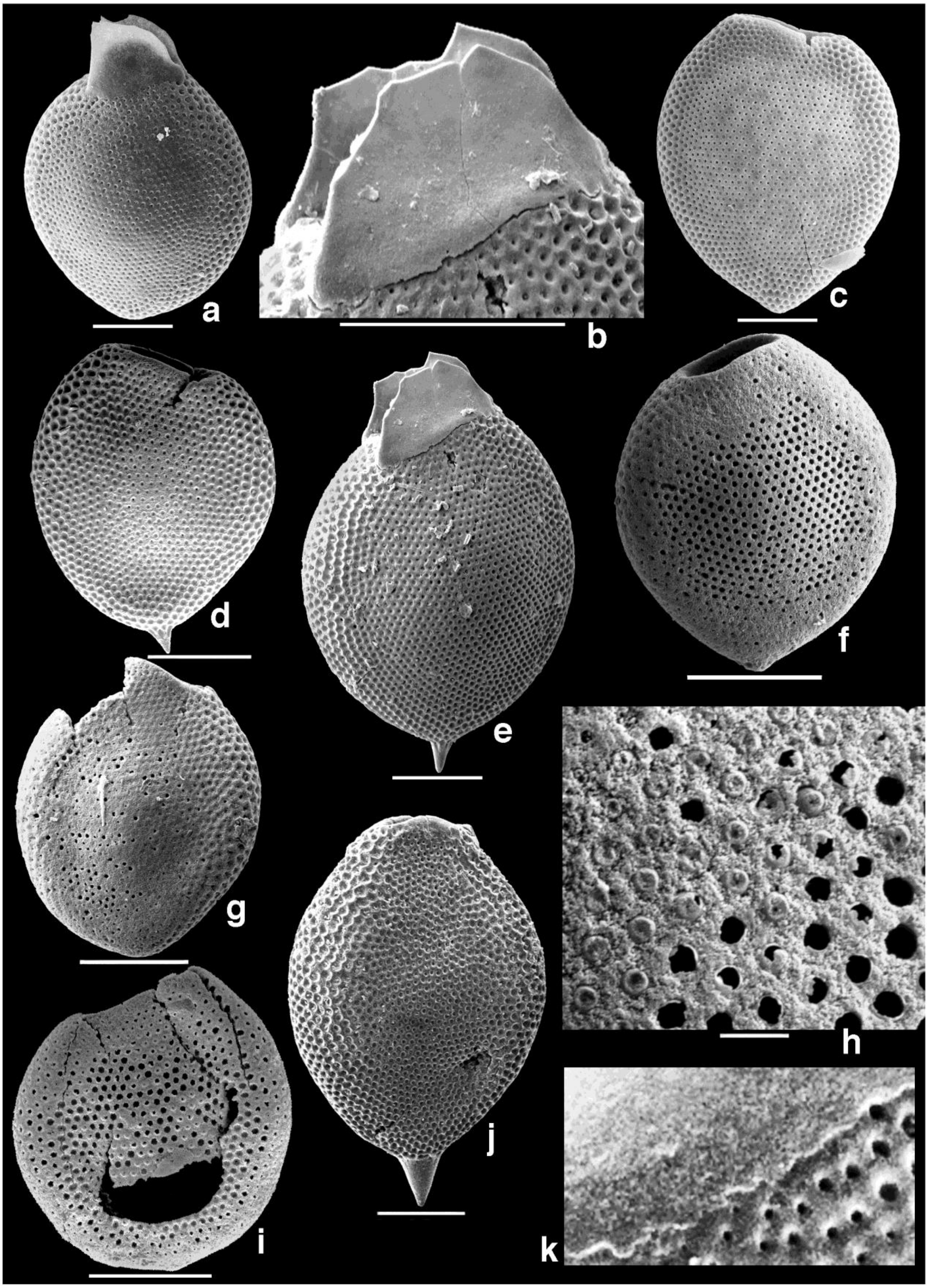

**Fig. 4. a-g**, **k** *Protocystis deflandrei* Dumitrică, specimens with aboral spine of different length, with or without oral appendages; **a-c**, sample 1315, **d-g** sample 1006; **b** detail of the contact between the oral appendage and the shell of fig. **e**; **k** detail of the contact between oral appendage and main shell of fig. b. **j** *Protocystis* sp. 2, sample 1006. **i**, **h** *Protocystis reschetnjakae* (Dumitrică), sample 1006, **h** detail of partly dissolved surface. Scale bar for figs. **a-i, j** = 50 µm, scale bar for fig. **h** = 10 µm

secondary constriction built in a second stage.

All these specimens provide essential information about this contact. Due probably to a slight superficial dissolution, they show that the peristomial appendages did not develop at the same time as the main shell. They are a kind of foreign bodies grown on the main shell around the oral aperture and start their building after the complete building of this amphorae-bearing shell, which they use it as a support. For this reason their outline at the contact with the main shell is very irregular in detail, since it follows all the irregularities of the surface of this shell. For the same reason these appendages can rather easily be detached from the main shell in fossil state, in which case the shell looks like that of *Lithogromia* Haeckel. This explains the presence of many specimens with only fragments of peristomial appendages or with none, as illustrated earlier (Dumitrică, 1964) and better in the present article. Based on these evidences one can consider that the fossil species of the genus *Lithogromia* are nothing else than young stages of *Protocystis*, or specimens with the peristomial appendages detached by fossilization process.

The peristomial appendages of the specimens occurring in the late Badenian consist of two subtrapezoidal and subparallel thin lateral lamellae, one on each side of shell, united with each other only at their base on the dorsal side. In optical view one can see that in this portion the lamella of the oral appendages is either very thin at its base, at the contact with the main shell body, and thick on the distal margin (Figs. 6j, l), or has the same thickness (Fig. 8b). These lamellae have no amphora structure but a microgranular or vacuolar one, as the structure of the test wall among amphorae, and their shape resembles the shape of the species *Challengeron radians* Borgert (Takahashi, 1981 and 1991, pl. 48 in both).

*Range*. Late Cretaceous (late Cenomanian) (Bragina, 2003) to Recent.

Genus ***Protocystis*** Wallich, 1869, emend. Takahashi, 1991

*Type species*: *Protocystis aurita* Wallich, 1869

*Remarks*. Since Wallich (1869), Borgert (1901, 1911) and Haecker (1906) defined this genus as having no marginal spine but one or several oral teeth, Takahashi (1991) emended it to include also species with peristome without oral teeth. As I demonstrated on the basis of the late Badenian specimens from Romania that the teeth or peristomial appendages are a part of the body grown later, after the building of the main shell, and superposed on it, the absence of the peristome could be considered either characteristic of young ontogenetic stages or, in the case of fossil specimens, a result of the loss by fossilization or by breaking during laboratory treatment. Moreover, almost all specimens from the upper Badenian so far known have practically similar peristomial appendages. For these reasons I include all Badenian challengeriids in a single genus – *Protocystis*.

The late Badenian phaeodarian fauna proves also that the presence or absence of an aboral spine cannot be a generic character. Even in the same species its length can vary from zero to several tens of microns. In this situation I took into account for species discrimination only the shape of the shell and of the peristomial appendages.

*Range*. Late Cretaceous to Recent.

*Protocystis deflandrei* Dumitrică

Figs. 3a-k; Figs. 4a-f; Figs. 5a-c, e, f; Figs. 6b-f, h, j, l

1964 *Protocystis* ? *deflandrei* n. sp. – Dumitrică, p. 219-222, figs. 2-11, 13-16.

1965 *Protocystis deflandrei* Dumitrică – Dumitrică, p. 3, fig. 6.

1965 *Protocystis fossilis* n. sp. – Dumitrică, p. 4., fig. 4.

1965 *Protocystis tortonica* n. sp. – Dumitrică, p. 4, fig. 5.

1969 *Protocystis deflandrei* Dumitrică – Reschtnjak, p. 138, pl. 3, fig. 19.

1969 *Protocystis fossilis* Dumitrică – Reschtnjak, p. 138, pl. 3, fig. 17.

1969 *Protocystis tortonica* Dumitrică – Reschetnjak, p. 138, pl. 3, fig. 18.

*Description*. Main shell cordate in lateral view, compressed, but with central part slightly raised so that between it and the peripheral part there is a slightly concave zone. Aboral end more or less acute, commonly with a spine of variable length, rarely without spine. Other spines never observed. Oral end with dorsal side higher than ventral one, but the difference in height between the dorsal and ventral parts is variable. Shell periphery with surface rougher than middle part of shell and with pores sensibly larger. Peristomial appendage consisting of two lateral trapezoidal plates united dorsally at their base. Ventrally there are no true teeth, but the trapezoidal plates show just acute corners whereas at the dorsal part they are usually rounded.

*Remarks*: For the reason discussed under the genus *Protocystis* I consider that the 2 new species (*Protocystis fossilis* and *P. tortonica*) I described in 1965 under this genus are in fact synonyms of *Protocystis deflandrei* Dumitrica 1964.

*Range and occurrence*. Late Badenian. The species occurs in all the 4 localities of the Radiolarian Shale Formation mentioned above.

*Protocystis reschetnjakae* (Dumitrică)

Figs. 4h, i; Figs. 5d, g-j; Figs. 6a?, d?, g, i, k; Fig. 8b

1964 *Protocystis*? cf. *deflandrei* n. sp. – Dumitrică, p. 219, pl. 2, fig. 12.

1965 *Lithogromia reschetnjakae* n. sp. – Dumitrică, p. 4, fig. 3.

1969 *Lithogromia reschetnjakae* Dumitrică – Reschetnjak, p. 138, pl. 3, fig. 16.

1978? *Protocystis* sp. – Dumitrică, pl. 7, fig. 27.

*Description*. Test lens-shaped with circular or subcircular outline and dorsal side slightly longer than ventral one.

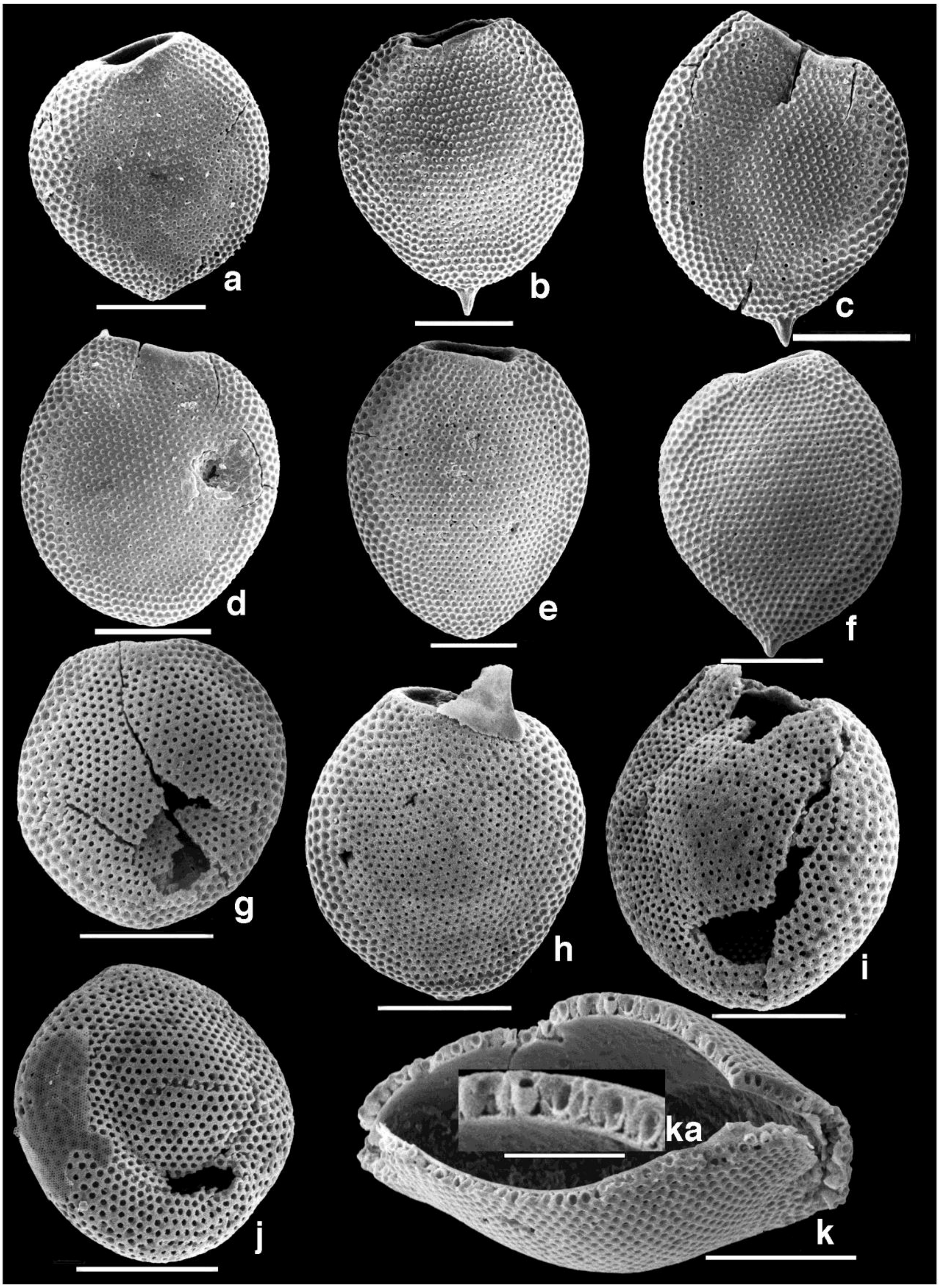

**Fig. 5. a-c**, **e**, **f**, **h**, **k, ka** *Protocystis deflandrei* Dumitrică, specimens with rather short aboral spines and practically without oral appendages; **k** broken specimen showing the wall structure and interporal wall partly dissolved; **ka** same, detail of a portion of shell. **d**, **g**, **i**, **j** *Protocystis reschetnjakae* (Dumitrică). Scale bar for all figs., except **ka**, = 50 µm, for fig. **ka** = 20 µm.

Peristome rarely present and incomplete. On the central part of the two faces wall seems to be thinner or easier dissolved so that the amphora-shaped pores are well exposed on the surface of shell or even detached. Without aboral spine.
*Remarks*. The specimens herein illustrated differ from the holotype by having, it seems, a slightly thicker shell. Since it seems that there is a continuum of the outline between this species and *P. deflandrei*, I considered as *Protocystis reschetnjakae* the specimens with rounded aboral end and without aboral spine. These specimens differ from the holotype by having a less flattened aboral end.
*Occurrence*. Sample 1315, Tilvici valley, Pauşeşti-Otăsău; 1006, 1008, Salina Valley, Ocnița and Valea Sării (Salt Valley), Ocnele Mari, sample OM54.

*Protocystis* sp. 1
1978 *Protocystis deflandrei* Dumitrică – Dumitrică, p. 244, pl. 7, fig. 28.
*Remarks*. The specimen I illustrated from the Fințești section as *Protocystis deflandrei* in Dumitrică (1978, pl. 7, fig. 28) differs from this species in having the dorsal wall of the peristome higher and of same thickness, and the two lamellar teeth with concave outline on both the distal and ventral parts, whereas the peristome of the species *P. deflandrei* illustrated in the present paper has the two lamellae broad and convex on the dorso-distal part, and its wall is thin at base and thick at margin in the dorsal part (Figs. 6j, l). Also, the shape of the main shell of *Protocystis* sp. 1 is not cordate but elliptical and has no aboral spine. All these differences suggest that that specimen might belong to a different species. Unfortunately, I found no other specimen with similar characters.
*Occurrence*. Sample 35, Finţeşti, Prahova district, Romania.

*Protocystis* sp. 2
Fig. 4j
*Remarks*. This specimen, the only one I found, differs from all the other specimens in having, as it seems, a bilateral symmetry in lateral view, an elliptical shape, a very thick aboral spine, no well defined dorsal side, and no peristome. It is possible that the specimen is slightly anomalous, as the irregularity of the boundary between the pores from the central side and periphery suggests.
*Occurrence*. Sample OM54, Salina Valley, Ocnele Mari.

Family Medusettidae Haeckel, 1887
*Type genus*: *Medusetta* Haeckel, 1887
*Remarks*. The members of this family differ from those of other phaeodarian families, Challengeridae especially, in having alveolate or articulate oral feet.
*Range*. Late Triassic (Rhaetian) – Recent. The Rhaetian occurrence is based on the species *Medusetta japonica* Hori, Yamakita & Dumitrica, 2009 and *Triassiphaeodina niyodoensis* Hori, Yamakita & Dumitrică, 2009 found in the Northern Chichibu Belt, Shikoku, Japan (Hori et al., 2009).

Genus ***Kozohashetta*** n. gen.
*Type species*: *Challengeron diodon* Haeckel, 1887, p. 1654.

*Diagnosis*. Shell ovate with distinct ventral and dorsal sides, with an aboral spine and two pairs of alveolate and hollow peristomial feet that interconnect forming two lateral peristomial arches, each one provided with one or several hollow spines of various length. Aboral spine may be surrounded by smaller additional spines. Shell wall with alveolate structure. Outer surface with honeycomb structure. Inner surface of wall with numerous dome -shaped elevations, each dome corresponding to an alveolus and having a sieve structure.
*Remarks*. Takahashi (1981, 1991), who studied in detail the structure of the wall of the species *Challengeranium diodon* (Haeckel), mentioned that its microstructure “appears to be very different from other Challengeriida in the presence of: 1) dimpled surface; 2) clusters of small pores associated with individual amphora (inner shell surface); and 3) thin and delicate amphorae which are different in shape from other species of the family”. He also mentioned that the texture of the outer shell surface resembles that of the medusettid *Euphysetta elegans* Borgert, that it is closer to that of the Medusettidae than to that of the Challengeriidae, and that, apparently, this species has an intermediate morphology between the two families. He even mentioned that a new assignment to a separate family is possible in future investigations. On the occasion of the description of the species *Challengeranium torquatum* (Dumitrică, 1965) I have also mentioned that, by bearing four alveolate peristomial feet armed with spines, this fossil species reminds certain Medusettidae (*Medusetta* Haeckel, *Euphysetta* Haeckel) and that, by this character, the genus *Challengeranium*, as interpreted by Haecker (1906, 1908), would occupy a special place among the other genera of the family Challengeriidae.
By having four feet, the new genus *Kozohashetta* resembles the genus *Euphysetta* Haeckel, from which it differs in not having a long odd foot and three smaller feet, but feet interconnected in pair forming two lateral arches with an opening between them and the shell. In fact, its place would be much closer to *Medusetta* Haeckel, *M. tetranema* Haeckel, for example, that has also 4 curved spiny feet arranged in two pairs and the peristome with the dorsal part longer than the ventral one. It is easy to imagine the connection of the two feet in each pair to form two arches provided with spines. This idea is supported by *Medusetta acifera* Jørgensen, 1900, and the fact that the middle Miocene species *Kozohashetta torquata* (Dumitrică), the oldest species of this genus so far known, has wider arches than the living species *Kozohashetta diodon* (Haeckel). In this idea, *K. diodon* appeared from *K. torquata* by reduction of the two arches and of the number of spines. Another medusettid that

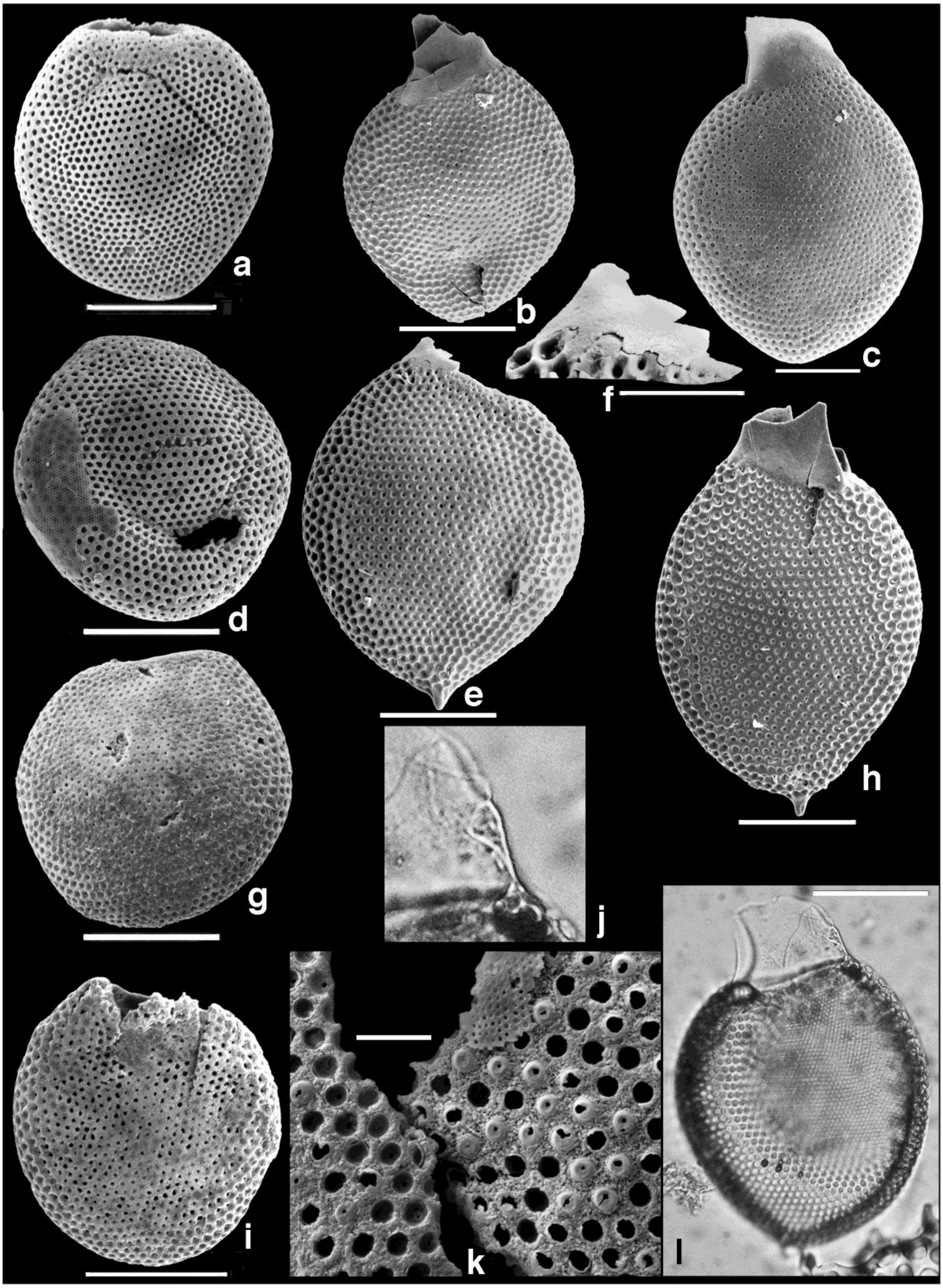

**Fig. 6**. **a-f**, **h**, **j**, **l** *Protocystis deflandrei* Dumitrică; **f** detail of fig. **e** showing the contact between the oral appendage and the main shell; **j** portion of the dorsal side of the oral appendage of fig. **l** magnified to see an inner thickness of this part. **g**, **i**, **k** *Protocystis reschetnjakae* (Dumitrică); **k** detail of a partly dissolved interporal wall.
Scale bar for figs. a-e, h, i, l = 50 µm, for fig. f = 20 µm, for fig. k = 10 µm.

shows the possible formation of arches is the late Cretaceous species *Pseudochallengeranium cretaceum* (Takahashi, 2004), from which *Kozohashetta* differs only in having well distinct hexagonally framed pores.

The use of the genus *Challengeranium* Haeckel by Haecker (1906) only for the species *Challengeron diodon* Haeckel was not an inspired decision. For Haeckel (1887, p. 1653) *Challengeranium* was a subgenus of the genus *Challengeron* Murray, (1879 in litteris) characterized by having the margin of the shell with a single spine on the aboral pole, opposite to the peristome. There was no mention of a fenestrate peristome, and *Ch. diodon* Haeckel was just a species among the six that have been originally included in this subgenus. By doing this, Haecker changed the diagnosis of this subgenus completely to include in it only *Ch. diodon* and species with similarly fenestrate peristome, and elevated it at the generic level. His diagnosis mentioned that *Challengeranium* includes species with ovoid test, peristome with two window-shaped openings, two peristomial spines and one aboral spine that may be accompanied by auxiliary spines. By mentioning the two window-shaped openings, Haecker had in mind that it is a challengeriid with two perforations in the peristome. He never thought that these openings could have resulted by the connection of the feet of a *Medusetta*-like ancestral species. Later, Campbell (1954) retained the original definition of this genus/subgenus and designated as type species *Challengeria swirei* Murray as the oldest described species among the ones included in *Challengeranium* by Haeckel. By doing this, we can easily exclude *C. diodon* from the genus *Challengeranium* because *Ch. swirei* is a challengeriid.

Interestingly for this discussion, the correlation between the classification based on skeleton and that based on molecular phylogeny proves the same distinction. Last year, while the manuscript was practically finished and the discussion above written, Nakamura et al. (2015) published a very interesting paper about the molecular phylogeny of most of the living groups of Phaeodaria. In that paper, on the basis of the analysis of the 18S rDNA sequences the authors recognized 11 subclades in the Phaeodaria clade that, with two exceptions, correspond to the families and orders of the current classification system. One of these exceptions was represented by the family Challengeriidae. Of the 13 species analysed 12 could be classified in 2 subclades (A and B), whereas one, *Challengeron diodon*, was included in the subclade F together with a species of the genus *Medusetta*, proving that *Ch. diodon* and *Medusetta* are closely related. This represents one of the best proves of the correlation between the two classifications: morpho-structural, and genetic.

*Etymology*. The genus is named for Dr. Kozo Takahashi, Graduate School of Sciences, Kyushu University, Fukuoka (1992-2012), and Hokusei Gakuen University, Sapporo (2012-present), Japan, for his great contribution to the knowledge of the microstructure of the shell of Phaeodaria. Feminine gender.

*Range*. Middle Miocene to Recent, so far as known.

*Kozohashetta torquata* (Dumitrică, 1965)
Figs. 7a-i, 8c-e

1965 *Challengeranium torquatum* Dumitrică n. sp., p. 4, figs. 1, 2, 7.

1969 *Challengeranium torquatum* Dumitrică – Reschetnjak, pl. 3, figs. 14, 15.

1978 *Challengeranium torquatum* Dumitrică – Dumitrică, p. 244, pl. 7, fig. 2.

*Redescription*. Shell ovate with an aboral spine and four articulated oral feet that are curved and fused two by two with their ends forming two lateral arches (figs. 1 and 2 in Dumitrică, 1965 and Fig. 8c of the present article), each one provided with two longer spines (one on the dorsal side, the other on the ventral side) and several shorter spines. Alveolated structure inside feet well visible in transmitted light and in broken feet. Shell with rather large hexagonally framed pore depressions giving the surface a honeycomb aspect. Crests of frames rather sharp with slightly raised vertices. Pore depressions usually closed, very few open usually in a circular opening of various diameter, and a single depression was seen with two pores (anomaly?). Some closed depressions show in their centre a circle marking the margins of the pores. It is as if the pores are closed by a circular operculum. Inner surface of shell with a dome structure, each dome corresponding to a pore. Sieve structure of these domes as illustrated with *Kozohashetta diodon* (Haeckel) by Takahashi (1991, pl. 52, fig. 11) and called by him ”many small pores”, is invisible, probably due to the quality of the image or to the degree of fossilisation, but supposed to exist. Aboral spine straight, about half as long as diameter of shell or shorter. Both aboral spine and oral feet have a superficial ornamentation consisting of slightly marked longitudinal crests.

*Dimensions*. Length of shell, without aboral spine and oral legs, between the base of aboral spine and depression between the dorsal oral legs 75-87 µm, same between the base of the aboral spine and the ventral oral margin of shell 69-93 µm, diameter of shell 63-66 µm, length of aboral spine 22-23 µm.

*Remarks*. To the above description I shall add that one pore of one specimen (Fig. 7f, h) is open on the inner side but closed on the surface by a lamella similar to the cover of the honeycomb cells (Fig. 7hi). *Kozohashetta torquata* (Dumitrică) differs from *Kozohashetta diodon* (Haeckel) in having two longer spines, one ventral and one dorsal, on each oral arch instead of one, and also in having larger oral windows. The species differs also from the late Cretaceous *Pseudochallengeranium cretaceum* (Takahashi) (Takahashi, 2004; Dumitrică & Eetvelde, 2009), that has also two peristomial arches, in having well marked and distinct hexagonally framed depressions.

*Range and occurrence*. Radiolarian Shale Formation, Middle Miocene (late Badenian) of the Getic Depression, Păuşeşti Otăsău and Ocnele Mari villages, west of the town of Râmnicu Vâlcea and of the river Olt, samples 1315 and OM 54, respectively.

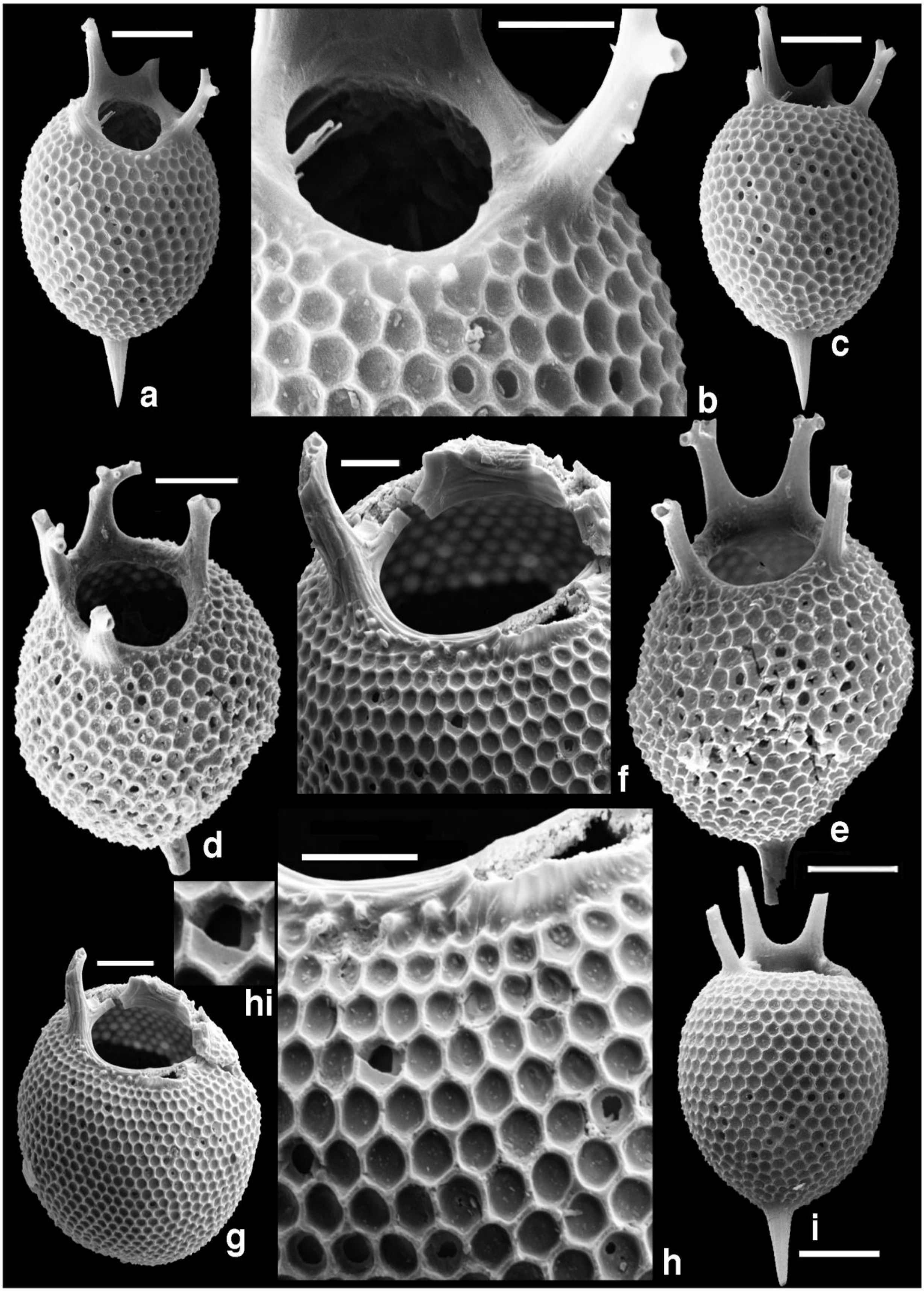

**Fig. 7. a-i** *Kozohashetta torquata* (Dumitrică) n. comb.: **a-c** specimen 1: **a** ventro-oral view; **b** same, detail of surface ornamentation; **c** same, ventral view; **d**, **e**, specimen 2 in latero-ventral and ventral views, respectively; **f-h** specimen 3 at different magnifications showing spine ornamentation and inner segmentation, **hi** detail of a cell pore of Fig. **h** with a superficial membrane, magnified x150 by comparison with Fig. 7h; **i** specimen 4 in ventral view; scale bars of figs. a, c, i = 50 µm; scale bars of figs. b, f, h = 10 µm, of figs. d, e, g = 20 µm.

Family Geticellidae Dumitrică, 1965
*Type genus*: *Geticella* Dumitrică, 1965
*Diagnosis*. Phaeodarians with lens shaped shell, a tubular peristome, hollow spines on the border of shell and the wall perforated by very small pores of unknown structure.
*Remarks*. The family was just suggested but not formally described in the short article in which the type species was described and illustrated. Since it is based on a single genus and species it is impossible to know its morphological and taxonomical diversity.
*Range*. Middle Miocene, late Badenian, so far as known.

Genus ***Geticella*** Dumitrică, 1965
*Type species*: *Geticella compressa* Dumitrică, 1965 (by monotypy).
*Diagnosis*. Siliceous lens-shaped shell with hollow spines on the periphery, a neck-shaped peristome and wall with tiny pores. Pore structure unknown. Wall structure microporous, amorphous or microgranular, with surface covered by a thin smooth plate
*Remarks*. The systematic status of this genus and of the family, respectively, is difficult to establish with certainty. It is certainly not a challengeriid, as originally remarked (Dumitrică, 1965), because its pores do not resemble those of the representatives of the family Challengeriidae and because no challengeriid so far known has a neck. It has the following three common characteristics with the Challengeriidae: the lens-shaped shell, the spines around the periphery, and the amorphous structure of shell wall. Anyway, it is undoubtly a phaeodarian as its siliceous skeleton and hollow spines prove. Of all the known groups of Phaeodaria so far known only the members of the family Porospathididae have a somehow similar neck, but their shell is spherical, has spines all around and a mammillated or tabulated surface, or a triangular meshwork. If we consider that this structure and the spherical or subspherical shape are just generic characters, and that the presence of an oral tube is the distinctive character of the family, *Geticella* could be considered as a member of the family Porospathididae.
*Etymology*. From the Getic Depression, SW Romania, from where the type species was reported.
*Range and occurrence*. The same as the type species.

*Geticella compressa* Dumitrică, 1965
Figs. 3l-n
1965 *Geticella compressa* Dumitrică, nov. sp., p. 250-252, figs. 8-10.
1969 *Geticella compressa* Dumitrică – Reschjetnjak, pl. 3, figs. 20-22.
1978 *Geticella compressa* Dumitrică – Dumitrică, p. 244, pl. 7, fig. 30.
*Redescription*. Shell very small, lenticular, circular or subcircular in face view with a cylindrical peristomial neck of various length but shorter than the radius of shell. Distal part of the neck thin-walled. Surface of shell smooth with small pores irregularly distributed and visible especially on the middle of faces. Towards the periphery the pores are very slightly visible and the shell surface is practically smooth. The neck has a rough surface on most part due to a sinuous or labyrinthic ornamentation resulted by the irregular ridges separating the pores. Periphery armed with up to 9 hollow spines developed especially on the oral half. Wall of shell has a microgranular structure, but its external and probably also internal surface are covered by a smooth lamella (Fig. 3m).
*Dimensions*. Diameter of lenticular shell 58-106 µm (average 85 µm), length of cylindrical peristome 15-30 µm (average 24 µm), diameter of peristome 20-37 µm (average 26 µm).
Remarks. The porous or granular wall microstructure of this species resembles that illustrated by Takahashi (1981, 1991) and Takahashi et al. (1983) on the species of the family Challengeriidae, which is an additional proof of the phaeodarian nature of this species and genus.
*Range and occurrence*. Radiolarian Shale Formation, Middle Miocene (late Badenian) of the Getic Depression, Tilvici valley, Păuşeşti Otăsău village, SW Romania, sample 1315. The species occurs only in this sample.

Family Porospathididae Borgert, 1901, emend. Campbell, 1954
*Type genus*: *Porospathis* Haeckel, 1879

Genus *Porospathis* Haeckel, 1879
*Type species*: *Porospathis tabulata* Haeckel, 1879

*Porospathis* cf. *holostoma* (Cleve, 1899)
Figs. 8f-i.
cf. 1899 *Polypetta holostoma* Cleve, p. 32, pl. 3, figs. 4a, 4b.
cf. 1901 *Porospathis holostoma* (Cleve) – Borgert, p. 48-49, figs. 56, 56a.
cf. 1908 *Porospathis holostoma* (Cleve) – Haecker, p. 240-242, pl. 48, figs. 371-376; pl. 49, figs. 392, 393.
cf. 1910 *Porospathis holostoma* (Cleve) – Borgert, p. 387, pl. 29, figs. 1-8; pl. 30, fig. 1.
cf. 1966 *Porospathis holostoma* (Cleve) – Reschetnjak, p. 166-167, fig. 52.

cf. 1969 *Porospathis holostoma* (Cleve) – Stadum & Ling, p. 485, pl. 1, figs. 16-18.
1972 *Porospathis* sp. aff. *P. holostoma* (Cleve) – Dumitrică, p. 842, pl. 15, fig. 14.
1973 *Porospathis holostoma* (Cleve) – Dumitrică, p. 754, pl. 5, figs. 1, 2, 6.

cf. 1981 *Porospathis holostoma* (Cleve) – Takahashi, p. 302-303, pl. 57, figs. 1-8.
cf. 1981 *Porospathis holostoma* (Cleve) – Takahashi & Honjo, p. 156, pl. 11, fig. 15.
cf. 1991 *Porospathis holostoma* (Cleve) – Takahashi, p. 150, pl. 57, figs. 1-8.
cf. 2012 *Porospathis holostoma* (Cleve) – Renaudie, p. 26, pl. 1, figs. 12A-B.

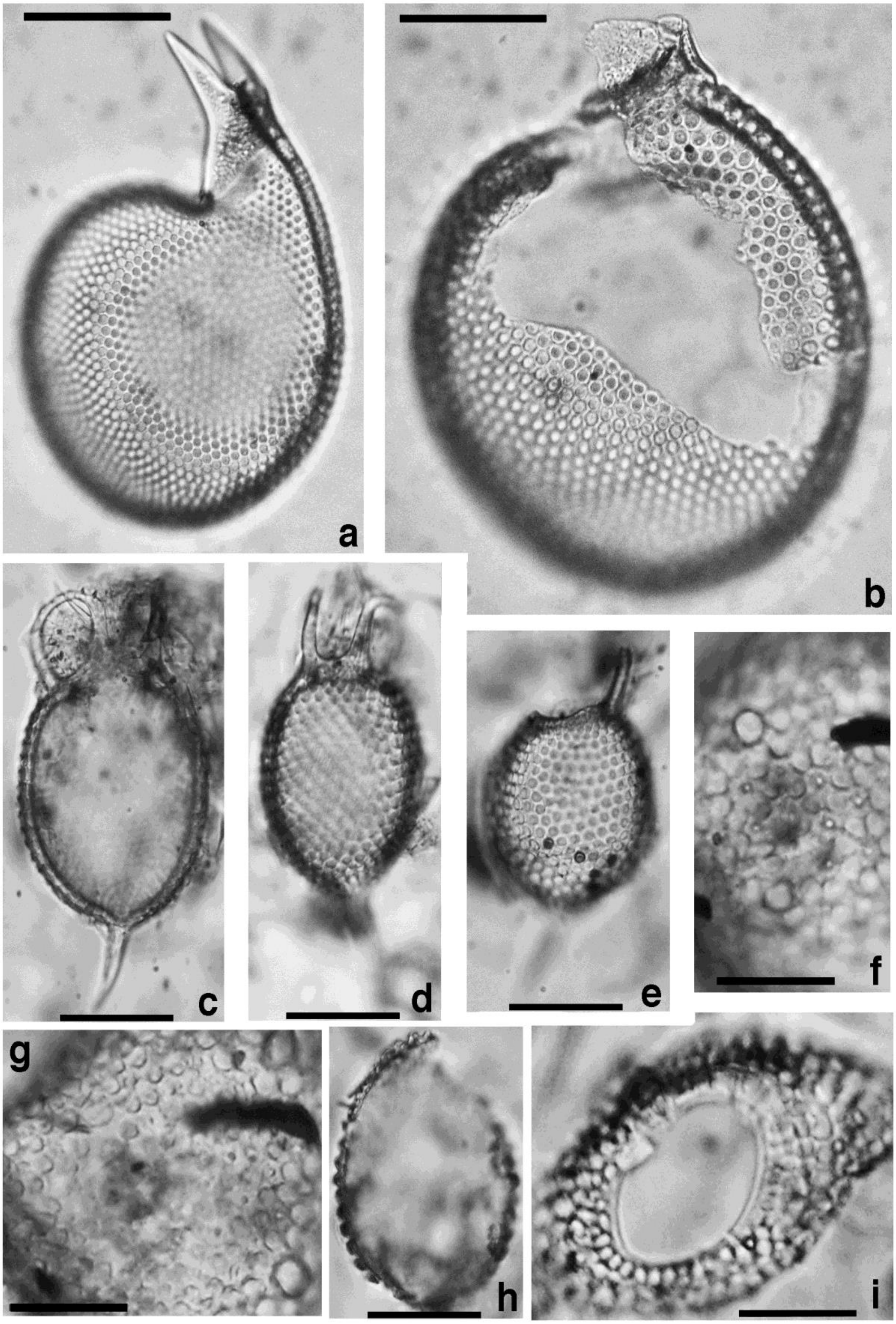

**Fig. 8. a** *Protocystis harstoni* (Murray), Quaternary, Norwegian See, showing the contact between shell and oral appendage. **b** *Protocystis reschetnjakae* Dumitrică, showing that the oral appendage is superposed on the central shell. **c-e** – *Kozohashetta torquata* (Dumitrică), sample 1007. **f-i** – *Porospathis* cf. *holostoma* (Cleve), sample 1007. Scale bar for figs. a-e, h = 50 µm; scale bar for figs. f, g, i = 20 µm

*Remarks*. This species, which is the most frequently cited in the literature from the Atlantic, Indian, Arctic and Antarctic oceans, and from surface or subsurface sediments up to Middle Miocene, is characterised by a spherical to ovoid test with a long tubular peristome, long hollow spines on all sides, and the wall covered with hollow papillae interconnected by straight lamellae forming a characteristic triangular ornamentation. In the samples of the Radiolarian Shale Formation the species is extremely sparse. In fact, I found several fragments, most of them herein illustrated, in the small fraction slides (smaller than 63 μm) from a single sample (1007) coming from the Salina valley, Ocniţa village, Ocnele Mari, Getic Depression (Dumitrică, 1973). They are well recognizable by the characteristic structure of the shell but because no one is entire a doubtless species determination is impossible. One can see in these fragments the papillae with a light centre, proving that they are hollow, and rare light circles corresponding to the base of the hollow spines. A fragment of shell (Fig. 8i) shows also the base of the peristome of this species surrounded by a circular row of pores.

*Range*. Middle Miocene (late Badenian) from Romania and Antarctic area to Recent.

## ACKNOWLEDGEMENT

The SEM photos have been taken with the scanning electronic microscope Zeiss EVO MA 10 (2014) from the Hochschule der Künste Bern (High School of Arts, Berne), responsible Dr. Nadim Scherrer to whom I am very much obliged. The photos at optical microscope have been taken by me with a camera Nikon Coolpix 5900 mounted on a monocular microscopic tube Zeiss. I thank very much the two reviewers: Prof. Kozo Takahashi, Graduate School of Sciences, Kyushu University, Fukuoka, and Hokusei Gakuen University, Sapporo, Japan, and Dr. Noritoshi Suzuki, Institute of Geology and Paleontology, Tohoku University, Japan, for their critical and fast review of this article.

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