Goni spheres: probable agglutinated Silurian foraminifera linings and radiolaria capsular membranes (South-eastern Sardinia, Italy)

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ABSTRACT – Spherical and hemispherical organic microfossils recovered from residues of hydrofluoric acid digestion of chitinozoans from the black "Lower Graptolitic Shales" (middle Silurian) of Central-Eastern Sardinia, are discussed from a morphologic point of view. Comparisons with microfossils of similar shape and different biologic affinity are made. These microfauna are presumed to represent a polyphyletic group with representatives of agglutinated foraminifera and capsular membranes of radiolaria. From the paleoecological standpoint the assemblages of likely agglutinated foraminifera testify to the existence of a benthonic, epiphytic life on floating algae or even rooted in the muddy anoxic bottom sea before and after the occurrence of the great biological crisis (*lundgreni* Event) that severely affected primarily epiplanktonic organisms.

RIASSUNTO - [*Nuovi microfossili a parete organica del Siluriano della Sardegna centro-orientale*] - Vengono descritti e discussi, da un punto di vista morfologico, microfossili organici di forma sferica ed emisferica ritrovati copiosamente nei residui per chitinozoi dell'intervallo biozonale *Cyrtograptus rigidus* – (?)*Colonograptus vulgaris* (?)*Colonograptus gerhardi* (Sheinwoodian-Homerian) dei Lower Graptolitic Shales della Sardegna centro orientale. Essi vengono confrontati con microfossili di forma simile e differente origine biologica. Si ritiene che la microfauna rappresenti un gruppo polifiletico con rappresentanti di foraminiferi agglutinanti (*Saccamina* ed *Hemisphaerammina*) di radiolari forse Spumellari, di cui si sarebbero fossilizzate le membrane capsulari. Da un punto di vista paleoecologico una parte dei microfossili testimonierebbero l'esistenza di una vita bentonica, forse epifitica su alghe galleggianti o radicate nel fondo marino anossico e fangoso del Wenlock prima e dopo la grande crisi biologica (*lundgreni* Event) che ha colpito severamente gli organismi epiplanctonici (graptoliti, chitinozoi, conodonti).

INTRODUCTION

In the course of a detailed palynological study of the Wenlock beds of the Goni section in Central-Eastern Sardinia (Jaeger, 1976; Barca & Jaeger, 1990) we recovered thousands of specimens of organic microfossils of uncertain taxonomic origin. These share morphological features with the lining of foraminiferal tests and to some extent with capsular membranes of radiolaria, However, except for some forms closely resembling agglutinated foraminifera, the vast majority of the assemblages have no certain taxonomic position. In the literature similar forms are treated either as inner linings of agglutinated foraminifera (Winchester-Seeto & Bell, 1994; Bell & Winchester-Seeto, 1999), as dubious radiolaria (Lloydell *et al.*, 1988), or else as central capsular membranes of radiolaria (Dumitrica, 1999). Spherical and hemispherical organic linings of agglutinated foraminifera are documented in shallow marine limestones, marls and shales from Ordovician to Devonian of many Palaeozoic continents (Winchester-Seeto & Bell, 1994; Bell & Winchester-Seeto, 1999). In SW Sardinia (Gnoli & Serpagli, 1985) similar forms have been recorded in Upper Silurian and Lower Devonian limestones. The existence in fossil state of radiolarian soft bodies (Dumitrica, 1999), some of which share common features with the microfossils examined here, broadens their probable affinity to several biologic groups.

Due to the difficulty of actually comparing these diverse microfossils with other similar assemblages, here we illustrate and present an outline of their common morphotypes and discuss their relationships with some fossil forms belonging to different biological groups.

Materials and methods

The studied material comes from the Goni area in Central-Eastern Sardinia (Fig. 1). It was chemically extracted from six samples: S40, S41, S42, S44, S43, S45 of carbon-rich black shales, with minute pyrite crystals and phosphorite nodules, of the section studied by Jaeger (Jaeger, 1977; Barca & Jaeger, 1990) cropping out at Peinconi, near the Goni village.

The samples belong to the "Lower Graptolitic Shales" lithostratigraphic unit and encompass the *Cyrtograptus rigidus - Cyrtograptus lundgreni* interval to ?*Colonograptus vulgaris* - ?*Colonograptus gerhardi* Biozones.

The graptolitic black shales, characteristic of the Silurian eastern basin of Sardinia, deposited in an anoxic deep marine bottom, where probably few kinds of organisms tolerated living conditions in the muddy, euxinic, salty environment. Up to now the known documented paleontological content is represented by graptolites (epiplanktonic organisms), chitinozoans (epiplanktonic and probably benthonic part of organisms) and these "organic microfossils" (Pittau & Del Rio, 2000a, b; Cotza, 2000).

These were recorded the first time from samples processed in the search for chitinozoans; thus a second method of treatment was adopted to avoid dissolution of any mineralised shells present. 50g of crushed rock per sample was treated. Acid digestion in 5% HF for 4 hours was followed by rinsing with distilled water and sieving at 250µm mesh. Acid digestion and sieving was repeated several times until the sample was completely dissolved. The organic tests were mounted on gold-coated stubs and viewed under the scanning electron microscope. All material is housed at the Dipartimento di Scienze della Terra, Cagliari University, Palynological Collection.

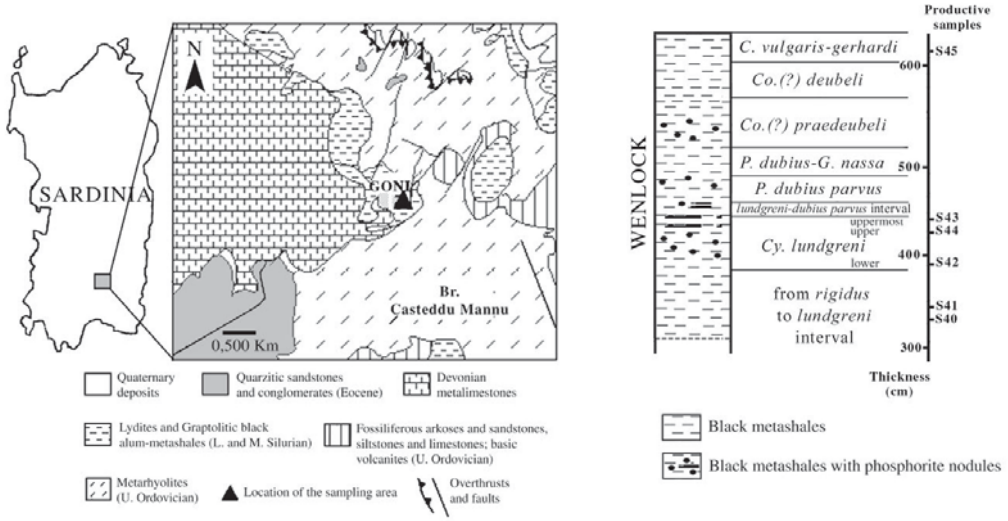

Fig. 1 - Geological map of the studied area and stratigraphic section of the Wenlock sedimentary succession. The zero, reference level for the metric location of the processed samples, is the old oak tree rooted in the section and direction sampling is southward.

CHRONO STRATI GRAPHY		productive samples	BIOSTRATIGRAPHY		PALEONTOLOGIC CONTENT		
Serie	Stage		Graptolite Biozones (1)		Organic microfossils	Graptolites	Chitinozoan communities (2)
Wenlock	Homerian	2745	*Co.(?) vulgaris-Co.(?) gerhardi*		morphospecies B, C	small graptolites	unnamed
			Co.(?) deubeli				
			Co.(?) praedeubeli				
			P. dubius-G. nassa				
			P. dubius parvus				
			from *lundgreni to dubius parvus* interval			no graptolite interval (?)	
		2743	*Cy. lundgreni*	uppermost	morphospecies A, B, C	giant graptolites	*goniensis* "relict"
		2744		upper	morphospecies B, C		*serpaglii-ichnussae*
		2742		lower	morphospecies A, B, C, D		*goniensis*
	Sheinw.	2741	from *rigidus* to *lundgreni* interval		morphospecies B, C	no graptolite interval (?)	*Conochitininae*
		2740			morphospecies B, C		

Fig. 2 - Biostratigraphic scheme showing the paleontological content in the Goni section during the Homerian stage; (1) Barca & Jaeger, 1990; (2) Pittau & Del Rio, 2000a.

General results

In the section under study these microfossils appear for the first time in the *Cy. rigidus-Cy. lundgreni* Biozones and their distribution is shown in Fig. 2. They occur in very large numbers in the lower part of the *Cy. lundgreni* Biozone, decreasing in the upper *Cy. lundgreni* (*M. testis* Subzone?) to become very abundant again in the uppermost *Cy. lundgreni* Biozone*;* they are missing in the *Pristiograptus dubius parvus* Biozone up to the *Co.(?) vulgaris-Co.(?) gerhardi* Biozone where small numbers are present. Absolute abundance has not been determined. In the lower and uppermost *Cy. lundgreni* Biozone where they occur in great abundance, several tens of thousands of specimens are contained in 50 grams rock*;* decreasing to hundreds of specimens in the *Cy. rigidus - Cy. lundgreni* interval and in the upper *Cy. lundgreni* Biozone*,* to less than a hundred specimens in the *Co.(?) vulgaris-Co.(?) gerhardi* Biozone.

Most of the specimens are thermally mature; they are black, but for the most part entirely preserved in full volume. They range in size from 60 μm to 160 μm and no colonies or clusters of individuals have ever been observed.

The assemblages comprise an assortment of morphologies ranging from hemispherical, to spherical ovate to subspherical with an invaginated area, the latter being the most common shape.

The wall likely consists of amorphous organic material; the surface may be smooth or of diverse texture: wrinkled, reticulated, dome-shaped protuberances, spirally rolled raised ridges, undulating basal membranes. Those retrieved using the acid digestion technique for radiolaria have smooth surface and siliceous coating made up of tightly packed, radially arranged crystals (Pl. 2, Figs. 6, 7). These crystals composed of 98% silica may be the result of post-diagenesis infilling (crystallization) once the original shell had dissolved; the orderly arrangement of the crystals around the organic test suggests microbially mediated growth.

Many specimens have holes of different kinds on the surface; for the most part these are pores, around 1 – 1,5 μm in diameter (Pl. 1, Fig. 4) and are frequently rimmed (traces left by thin minerals boring the tests?); others are probably main apertures, of the order of 10 μm, always flush with the test surface (Pl. 1, Fig. 4). One type of surface reticulation (Pl. 1, Figs. 1, 2) may be related to the outlines of the agglutinated mineral used in an outer wall by organisms such as arenaceous foraminifera, whilst the "blocky" reticulation observed in the specimen of Fig. 3 Pl. 2 is very likely due to a (post?) diagenetic mineralisation (pyritization). Dome-shaped protuberances are very frequent in these microfossils, particularly in the spherical ones and in those with a small invaginated region in the test. At first sight these appear to be artefacts, again the result of preservational processes, but in the literature we have observed similar protuberances in microfossils recorded in the Triassic of Romania and in the Silurian of England (Loydell *et al.*, 1988).

Discussion and comparisons

The general shape of the globular "reticulate" form (morphotype A) is comparable with organic linings of the agglutinated foraminifer *Saccamina*, in particular with species of this genus recorded in the Devonian limestones by Bell & Winchester-Seeto (1999).

Specimens with a surface broken by a continuous pattern of dome-shaped protuberances, similar to that of the Goni spheres and hemispheres of morphotype B, C and D, have been recorded in the Llandovery "deep sediments" of Wales (Lloydell *et al.*, 1988) tentatively referred to internal moulds of radiolaria. In this regard the living radiolarian *Rizoplegma radicatum* (Fig. 3) and some other Spumellaria possess a capsular membrane that during ontogenesis increases in volume forcing club-shaped protuberances through the pores of the shell, which is extracapsular, of similar shape to our spheres with dome-shaped protuberances.

Radiolarian soft bodies can be fossilized and this may happen irrespective of the siliceous skeletons. This has been discussed and demonstrated by Dumitrica (1999) based on findings of central capsular membranes in Mesozoic limestones of Romania and the reinterpretation of Triassic microfossils previously described as foraminifera.

As Dumitrica (1999) remarks, the difference between capsular membranes and agglutinated foraminifera is not always evident; in fossil central capsular membranes the pores are simple and protuberances, when existing, have no pores. As regards the chemical composition of the Goni spheres, they consist of organic matter (electron microscopy only revealed the presence of silica in the post-diagenetic envelopes) and the outer membrane is also thin and compact, as in the living forms of radiolaria (Hollande *et al.*, 1970 *in* Dumitrica, 1999, p. 160). In *Cenosphaerocapsula gibbulosa* the presence of «small inflations» or «tubercles» in the spherical shell is a diagnostic feature (Dumitrica, 1999). This feature together with the similar size range of this species, bears resemblance to the spherical specimens examined here (morphotype C).

The hemispherical forms (morphotype B) on the other hand are comparable with two different fossil types: firstly, test linings of agglutinated foraminifera like *Hemisphaerammina*; secondly, central capsules of radiolaria lying eccentrically with

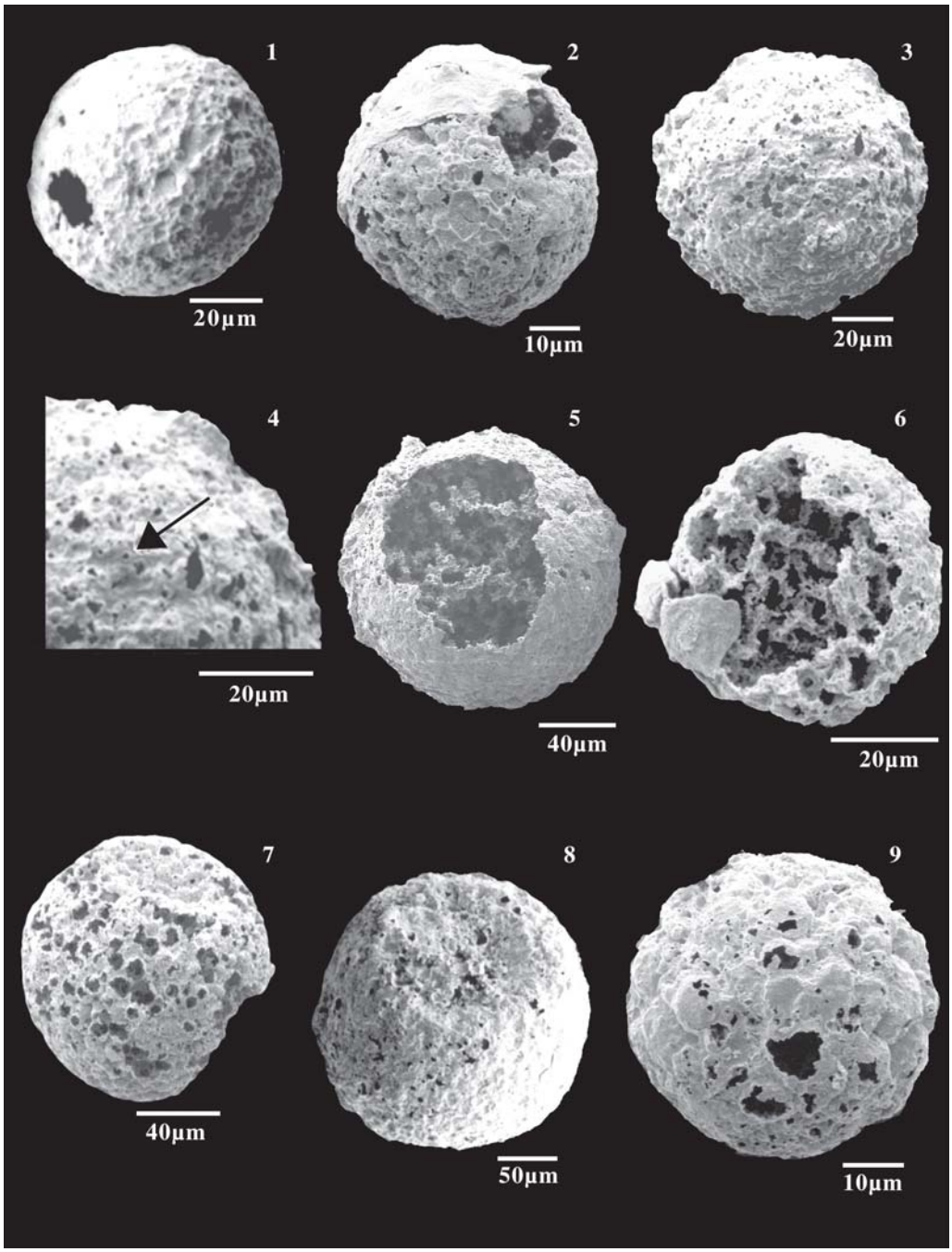

Plate 1

Figs 1, 2 - Morphotype A. The specimens are similar to *Saccamina mea* Bell & Winchester-Seeto 1999.

Figs 3-6 - Morphotype B. All the illustrated specimens display the basal flange and numerous holes in the surface; 4: particular of fig. 3 showing the equatorial rim and holes in the surface.

Figs 7-9 - Morphotype C. Microfossils showing a depression area and the pattern surface broken by dome-shaped protuberances.

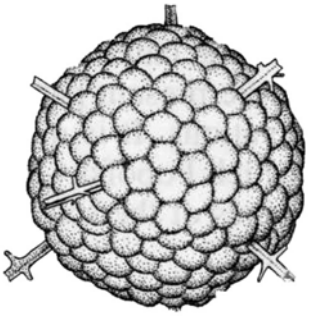

Fig. 3 - Capsule of *Rizoplegma radicatum*, living radiolarian with numerous club-shaped protrusions showing a dome-shaped outer morphology (after Dumitrica, 1999, fig. 2).

respect to the cortical shell (Dumitrica, 1999). The presence in most of the specimens of a basal flange supports the first hypothesis. No agglutinant was found in the test linings of our specimens but, as suggested by Bell & Winchester-Seeto (1999), its absence may be either an environmental response or a preservational artefact.

Spherical organic walled microorganisms have been described from the Upper Cretaceous of northern Germany (Gocht & Wille, 1971). These are clusters of individuals, each with a three-partite opercular aperture and measuring 100 μm overall. These have been referred to coenobia of chlorophycean algae (*Palambages morulosae* Wetzel) but, aside from the globular morphology, all other features such as size, kind of aperture and aggregation differ from the Goni spheres.

The Goni spheres have similar size range to the Santana spheres (Smith, 1999) thought to be ostracod eggs, but are dissimilar in shape and surface ornamentation. Lastly, it is highly improbable that the spheres are metazoan eggs or embryos, which are usually much larger in size (700-1000 μm) (Bengtson & Zhao, 1997; Xiao & Knoll, 2002).

Description

In the fossil assemblages we distinguished three morphotypes: one apparently with the main aperture and with a perfectly smooth surface; another subspherical, apparently with main aperture missing and an invaginated area; the last morphotype with spirally rolled ridges. For these three morphotypes any postulated biological affinity is unwarranted.

Morphotype A
(Pl. 1, figs 1-2)

Description. Ovate to spherical organic test, with circular main aperture just beneath or flush with surface; wall surface "reticulate", with raised ridges outlining smaller or larger smooth areas. These ridges likely represent the outlines of the agglutinated minerals used in an outer wall, but lost through diagenesis. Test diameter ranging from 50 to 80 mm; aperture diameter 9-10 μm.

Discussion. Morphotype A recalls the agglutinated foraminifer *Saccamina* that, as defined by Loeblich & Tappan (1988) has a single aperture on a raised neck, and according to Holbourn & Kaminski (1995) may also be provided with a single round aperture flush with the surface.

The Goni specimens are very similar in shape and size to *Saccamina mea*, a species recorded in the Australian and in Siberian Lower Devonian shelf limestones (Bell & Winchester-Seeto, 1999).

Occurrence. In the Goni assemblages this morphotype is not very common.

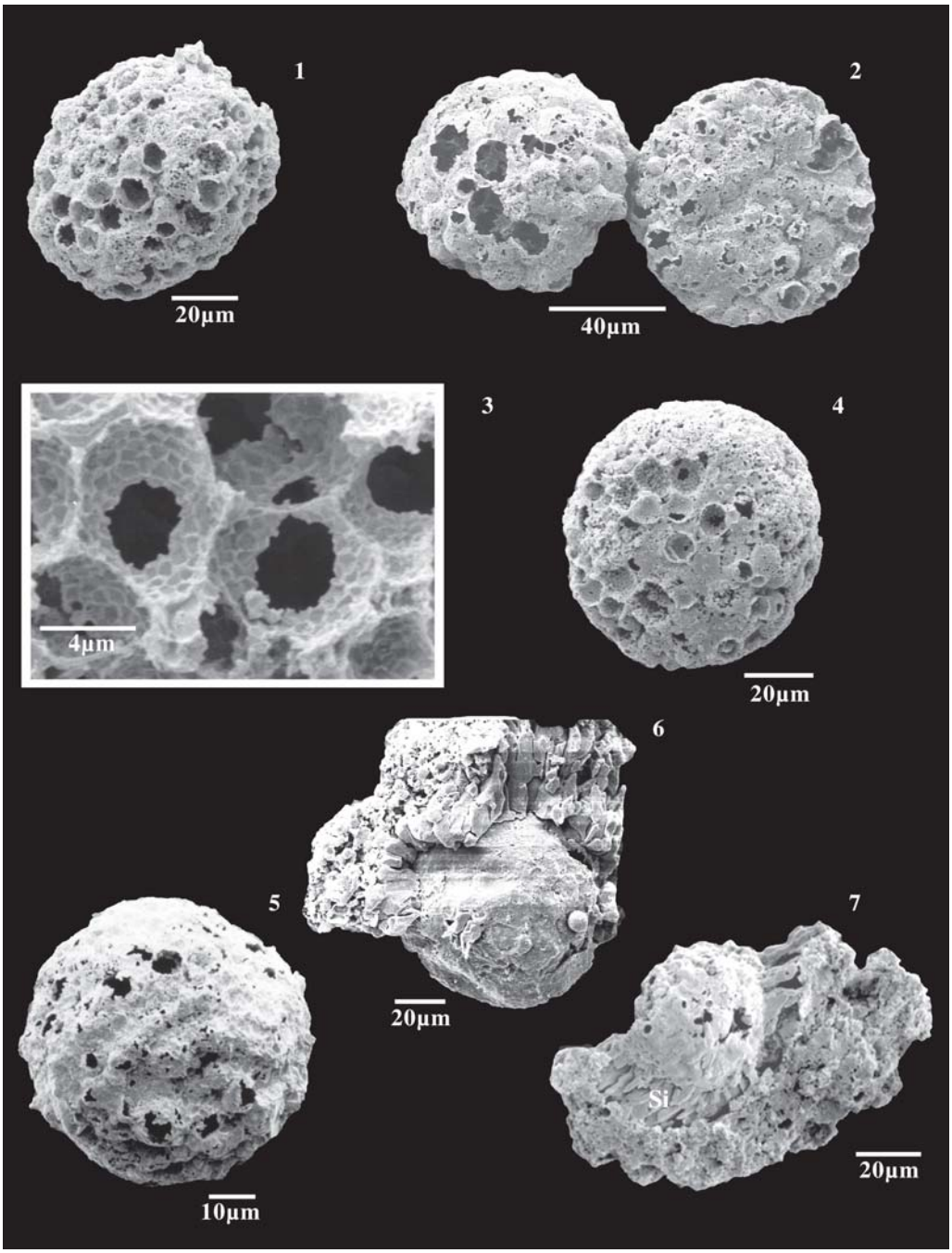

Plate 2

Figs 1-4 - Morphotype C. SEM magnification of the moulds left after dissolving minerals grown during diagenetic or postdiagenetic processes in the dome-shaped protuberances. Minerals smaller than 1 µm.
Fig. 5 - Morphotype D.
Figs 6, 7 - Spheres encrusted with silica crystals radially grown.

Morphotype B
(Pl. 1, figs 3-6)

Description. Hemispherical organic tests with more or less pronounced dome-shaped protuberances, 10 – 12 μm in diameter. The surface is dotted with small holes, often with thickened rim. The test with hemispherical chamber may or may not have basal flange or basal lip around the test. The presumed basal attachment surface is flat, apparently originally smooth. Test diameter from 60 to 150 μm.

Remarks. The inner surface of protuberances show honeycombed imprints of small (0.5 mm) hexagonal polygons probably produced by diagenetic mineralisation and subsequent acid digestion during extraction. Dissection of chamber reveals the majority to contain amorphous organic matter with three-dimensional alveolar-spongy architecture bearing traces of tiny but highly mineralized structures (Pl. 2, Fig. 3) with minerals in honeycombed pattern, similar to the protuberances.

Discussion. Leaving aside the alterations produced after death, the shape of these organic tests, particularly those with basal flange, resembles the agglutinated foraminifer *Hemisphaerammina*. The hemispherical chambers devoid of flange or lips have been associated by us to the same morphotype since Loeblich & Tappan (1988) reclassified as *Hemisphaerammina* those species belonging to *Metamorphina* characterized by the absence of basal flange around the test. Hemispherical central capsules have also been recognized in some radiolaria which differ from this morphotype for the proximal, concave side, bearing an invagination in the centre coinciding with the imprint of the medullary shell.

Occurrence. This morphotype is particularly frequent. Thousands of specimens with hemispherical chamber have been recovered from samples n° S42, S43 .

Morphotype C
(Pl. 1, figs 7-9; Pl. 2, figs 1-4)

Description. Globular, subspherical, ovate test with more or less pronounced dome-shaped protuberances, 10 – 12 μm in diameter. The surface is dotted with small holes. The depression in the subspherical test probably corresponds to an attachment surface or to the impression of an eccentric part of a skeleton. The interior of some dissected tests was filled with poorly preserved organic matter, with numerous cavities and mineral imprints.

Discussion. This group is the most common morphotype in the assemblages. The specimens resemble the *Cenosphaerocapsula* sp.2 specimen illustrated by Dumitrica (1999, Pl. 1, fig. 5). The hemispherical invagination suggests a medullary shell and the eccentric position of the capsule within the spherical cortical shell. The biological affinity of this morphotype remains highly uncertain since *Cenosphaerocapsula* is questionably assigned to Radiolaria (Dumitrica, 1999).

Morphotype D
(Pl. 2, fig. 5)

Description. Globular or ovate organic test with spirally arranged raised ridges; circular aperture seemingly present. Roughly 100 μm in diameter.

Occurrence. This morphotype is the least common of the spherical forms.

Conclusions

In conclusion, it is difficult to find decisive arguments that fully support the affinity to Radiolaria or agglutinated foraminifera for the Goni spherical and hemispherical forms. They probably represent remnants of the two biological groups and the possibility of them being algae can be ruled. The finding of these microfossils provides new data that contribute to furthering knowledge about the Silurian marine environment of the eastern Sardinia basin during a time of recognised biological crisis.

Morphologic groups A and B are indeed very similar to the linings of agglutinated foraminifera, whilst morphologic groups C and D resemble in some aspects capsular membranes of fossil Radiolaria and, as remarked by Dumitrica (1999), the difference between capsular membranes and agglutinated foraminifera is not always evident and, moreover, these membranes are usually associated with agglutinated foraminifera. At present we cannot differentiate further and until comparable works are undertaken in other parts of the world, no other conclusions can be drawn.

From the palaeoecological standpoint, these microfossils are related to anoxic sediments and the high concentration in the rocks may be related, to some extent, to the condensation of the investigated sediments. The assemblages are dominated by a profusion of two morphotypes (B and C). Similar significant abundance in some horizons may be attributed to "flood" events, like those observed for agglutinated foraminifera in the Silurian of England at the Llandovery/Wenlock boundary (Mabillard & Aldridge, 1982) and in the Silurian of Oklahoma as well (Amsden *et al.*, 1981 *in* Mabillard & Aldridge, 1982, p. 129).

These microfossils likely lived in a deep marine environment, probably in the outer shelf, and paleontologically are associated with planktonic and perhaps benthonic fossils (some types of chitinozoans). The spherical and ovate forms suggest an epipelagic or hemipelagic lifestyle whilst a benthic, probably epiphytic lifestyle may be hypothesized for the flattened forms that probably lived on the water surface attached to floating algae or even to algae rooted to the muddy sea bottom.

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