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# The Silurian of Sardinia

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# Chitinozoan assemblages and biostratigraphy of the Silurian of Sardinia

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ABSTRACT - Silurian chitinozoan assemblages and biozones of southeastern Sardinia are well calibrated against graptolite biozones, whereas those deriving from isolated blocks of the Fluminimaggiore Formation of southwestern Sardinia have less precise biochronologic constraints. An attempt to arrange, into a regional frame, the up to now known chitinozoan assemblages according to the stratigraphic significance of index species, is presented in this short paper. One biozone, *Conochitina emmastensis*, is recognized in the Aeronian - Telychian of the Rio Ollastu section. Three chitinozoan biozones: *C. goniensis-C. subcyatha, Sphaerochitina jaegeri, S. serpaglii* are correlated from the *belophorous-rigidus* to the *lundgreni-testis* graptolite biozones. One chitinozoan biozone, *C. pachycephalana*, calibrated against *vulgaris-gerhardi* graptolite biozone and fitting ecostratigraphically within the *Cardiola docens-C. donigala* bivalves community. *Angochitina* cf. *elongata* Biozone ecostratigraphycally encompassing the *Cardiola docens* community; *Urnochitina urna* and *Eisenackitina bohemica* ecostratigraphically correlating respectively with *Cheiopteria-Patrocardia-Cardiolinka, Patrocardia evolvens evolvens-Panenka* bivalves communities and *Pterinopecten-Cybele nesiotes* and *Patrocardia evolvens evolvens-Panenka* communities that encompass Pridoli and Lochkovian.

KEY WORDS - Silurian, Sardinia, Chitinozoans, Biostratigraphy.

## INTRODUCTION

The Silurian stratigraphy of Sardinia is relatively well known due to the intensive studies carried out by experts in graptolites (for references see Storch & Piras, 2009, this volume) and in conodonts (for references see Corriga et al., 2009, this volume). Besides these two fossil groups, researches have been also focused on Wenlock, Ludlow and Pridoli molluscs, cephalopods, bivalves, gasteropods and on other minor components of the faunal associations that have been of primary significance in defining paleoecology and paleonvironments of the depositional settings; but, have of minor importance in defining the stratigraphic column. Studies on chitinozoan microfaunas, in turn, are relatively recent and commenced in the 1990s.

Chitinozoan assemblages have been studied in the allochtonous Silurian succession of southeastern Sardinia (External Nappe Zone), and in western autochtonous External Zone of the island, as well. Pittau & Del Rio (2000), Pittau et al. (2002a, 2002b, 2003, 2006) studied chitinozoans in several tectonic units, in the Gerrei area, and Sarrabus area; Dufka and Gnoli (1996) described chitinozoans from the autochtonous Silurian of the Fluminese area, in southwestern Sardinia.

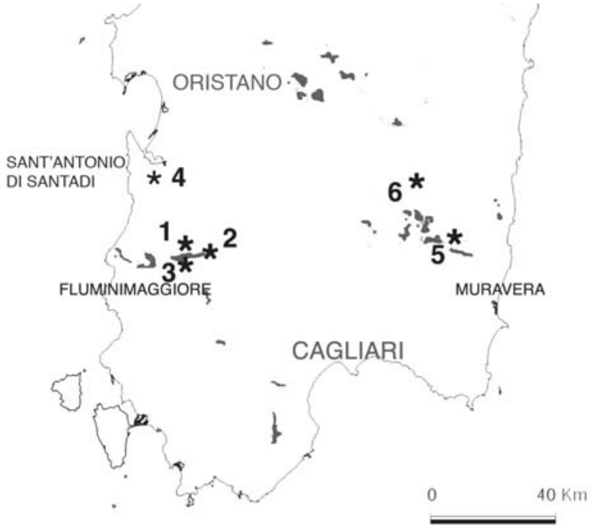

Fig. 1 - Outcrops of the Silurian-Lower Devonian succession in the External Zone and the External Nappe with location map of the sites cited in the text. 1) Fluminimaggiore Path (Sentiero Fluminimaggiore) in Xea San'Antonio locality. 2) Fluminimaggiore, Galemmu locality. 3) Fluminimaggiore, Mason Porcus. 4) Sant'Antonio di Santadi (S. Antonio Donigala). 5) Rio Ollastu. 6) Goni.

The chitinozoan assemblages have been studied in samples coming from sections and also from loose blocks (Fig. 1). Of particular significance are the sections exposed at Riu Ollastu (Pittau et al., 2003), Goni (Pittau et al., 2000) and Mason Porcus near Fluminimaggiore (Dufka & Gnoli, 1996).

Loose limestone blocks, coming from several localities of the External Zone of the basement, contained few or long-ranging graptolites, some samples yielded conodonts, and have been discussed with regard to their bivalve communities by Kriz & Serpagli (1993). Here we refer to displaced blocks, which were positive for chitinozoans, as listed in Dufka & Gnoli (1996).

1) In the Fluminimaggiore area, just outside the village, numerous block samples have been collected:

- at Galemmu (site map 1 of Fig. 1), with positive blocks 2/7, 2/9, 2/15, 2/17, 2/30, 2/46.
- at Xea Sant'Antonio (site map 3 of Fig. 1), otherwise called "Sentiero Fluminimaggiore", with the positive block 1/X.
- Chitinozoan bearing samples, labelled 3/MP5 and 3/MP6, come also from the Mason Porcus section, near Fluminimaggiore, (site map 2 of Fig.1).

2) In the central-west coast, Arburese-Capo Frasca area, near Sant'Antonio di Santadi, one positive block labelled 6/7 originated from the locality called Sant'Antonio Donigala (site map 4 of Fig. 1) .

Chitinozoan assemblages identified from southeastern Sardinia come from the Lower Graptolitic Shales Fm outcropping at Rio Ollastu in the Sarrabus area, near Muravera (site map 5, of Fig.1) and from the historical section of Goni, situated in the Gerrei area, at site map 6, Fig 1. The Lower Graptolitic Shales has been extensively studied for its graptolite faunas (Meneghini, 1857; Gortani, 1922; Schneider, 1972; Jaeger, 1976; 1991; Barca & Jaeger, 1991; Rickards et alii, 1995; Piras et al., 2009) and its chitinozoan biozones and assemblages have been calibrated by graptolite stratigraphic data. The studied intervals of the succession are shown in Fig. 2.

Stratigraphically, the overall chitinozoan assemblages of Sardinia, are representatives of the Early and Late Silurian to Lochkovian and, up to now, have been encountered from a limited number of graptolite zones.

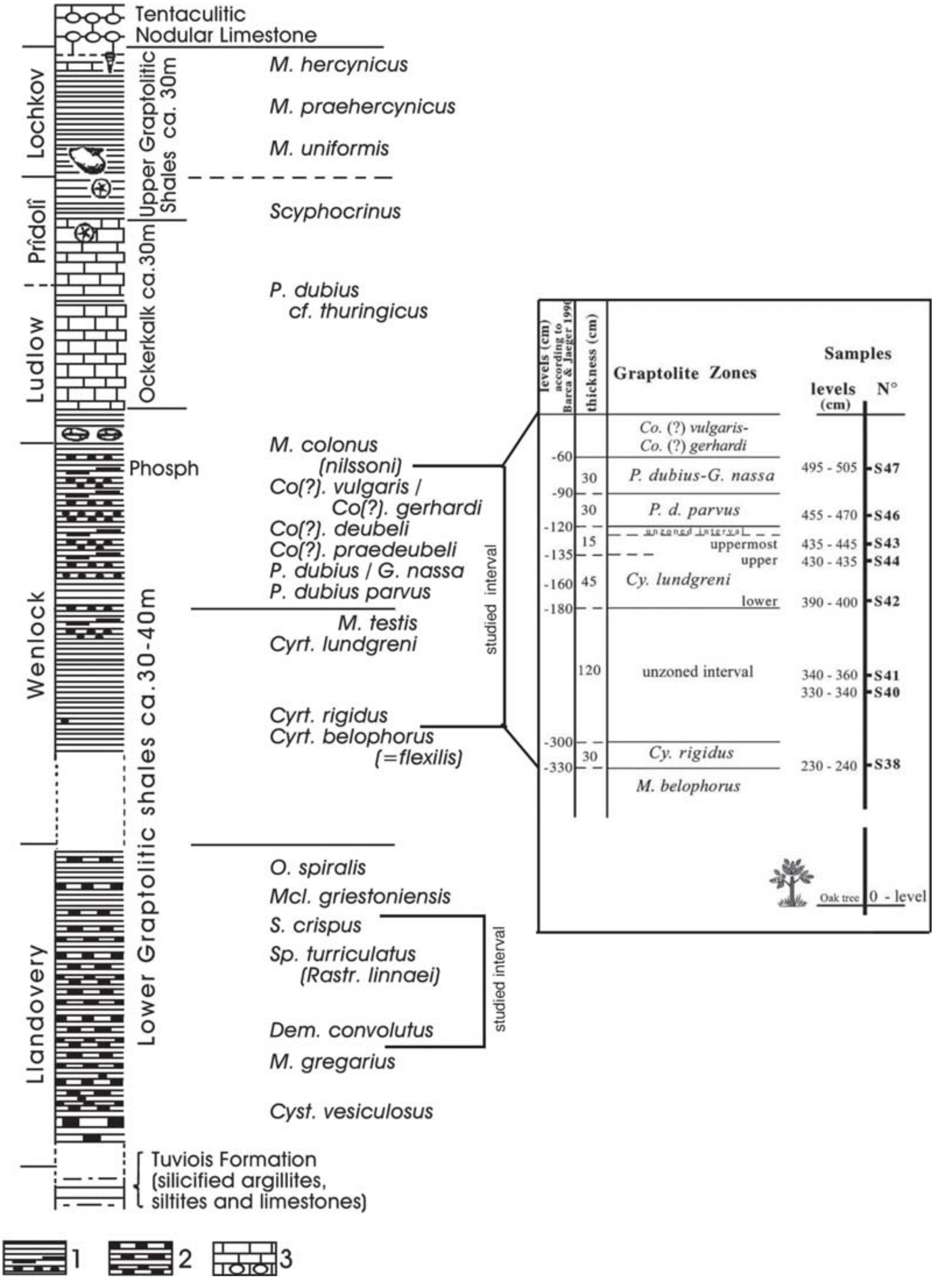

Fig. 2 - Chrono- bio- lithostratigraphic log for the Silurian and the transition to Devonian succession in the south-eastern part of Sardinia (External Nappe Zone). Location of the study samples in the Lower Graptolitic Shales Fm at Rio Ollastu and Goni. Thickness and stratigraphic data are from Jaeger & Barca (1990) and (Pittau et al. 2000; 2003; 2006). 1) alum shales with nodules, lenses and layers of phosphorite; 2) black lydites and graptolitic shales; 3) nodular limestones.

## CHITINOZOANS

Chitinozoans are missing in the Rhuddanian and lower Aeronian (lower Llandovery) black shales and lydites. Upper Aeronian and Telychian (upper Llandovery) black graptolitic silty shales of the *Lituigraptus convolutus* to *Streptograptus crispus* graptolite biozones, interchanging with massive lydite beds, have yielded nearly monospecific chitinozoan assemblages. In the upper Sheinwoodian (Wenlock) beds, in *Pristiograptus dubius* to (?)*Cyrtograptus ellesae* biozones, the chitinozoan assemblages are dominated by *Conochitina*. In the Homerian (upper Wenlock), *Cyrtograptus lundgreni* Zone, the assemblages are dominated by *Conochitina,* in the lower part, and *Sphaerochitina* in the upper part (*Cy. testis* Subzone). From the upper Homerian (*Colonograptus ludensis-Colonograptus gerhardi* graptolite zone) through to the lower-middle Ludlow limestone's with *Cardiola docens, Cardiola donigala* bivalve communities, *Conochitina* prevails in the assemblages. In the black micritic samples of latest Pridoli (*Oulodus elegans detortus* conodont biozone*)* black micritic samples, *Urnochitina* is a predominant form. In the Lochkovian micritic samples *(Icriodus woschmidti* Zone and *Pterinopecten-Cybele nesiotes* and *Patrocardia evolvens* bivalve communities, *Eisenackitina* and *Bulbochitina* predominate.

The complete list of chitinozoan taxa recognized is the following:

*Ancyrochitina ancyrea* (Eisenack, 1931)
*Ancyrochitina* sp.
*Angochitina* cf. *echinata*, (Eisenack, 1931)
*Angochitina* cf. *elongata* (Eisenack, 1931)
*Angochitina* sp.
*Belonechitina* cf *latifrons* (Eisenack, 1964)
*Bulbochitina* sp. (aff. *B. bulbosa* or aff. *B. suchomastensis*)
*Cingulochitina* cf. *wronai* Paris & Krìz, 1984
*Conochitina* aff. *proboscifera,* Eisenack, 1937
*Conochitina* cf. *pachycephala* Eisenack, 1964
*Conochitina* cf. *tuba* Eisenack, 1932

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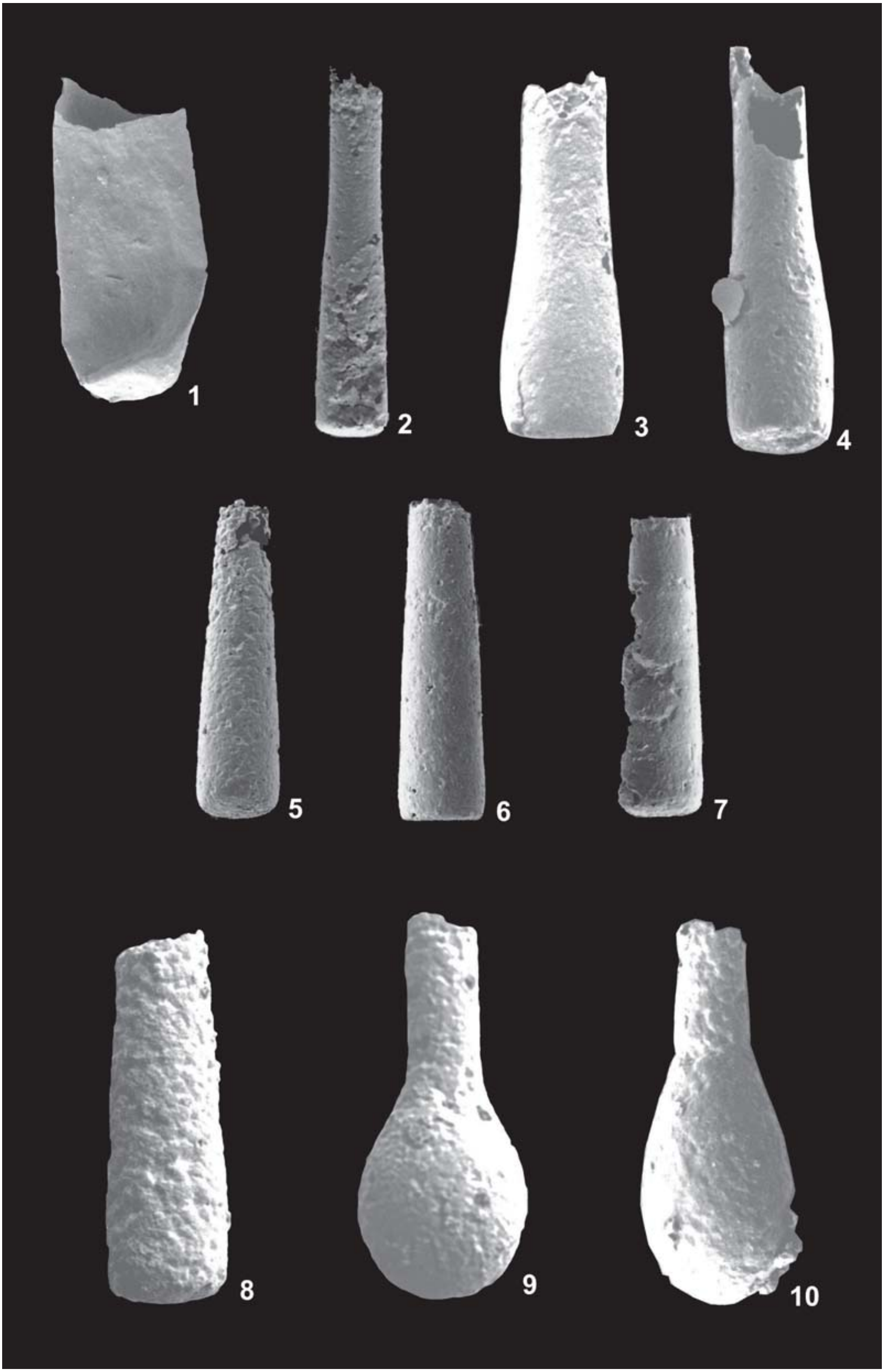
## Plate 1

Fig. 1 - *Conochitina emmastensis* Nestor, 1994; Rio Ollastu, *crispus* Biozone; L = 240 µm.
Fig. 2 - *Conochitina* sp. a; Goni section, *lundgreni* Biozone; L = 286 µm.
Figs. 3-4 - *Conochitina subcyatha* Nestor, 1982; Goni section, *lundgreni* Biozone;
3. L = 240 µm;
4. L = 320 µm
Figs. 5-8 - *Conochitina goniensis* Pittau 2000. Goni section, *lundgreni* Biozone;
5. L = 226 µm;
6. L = 265 µm;
7. L = 260 µm;
8. L = 175 µm.
Fig. 9 - *Sphaerochitina ichnussae* Pittau, 2000. Goni section, *lundgreni* Biozone; L = 180 µm.
Fig. 10 - *Sphaerochitina serpaglii* Pittau, 2000. Goni section, *lundgreni* Biozone; L = 160 µm.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*Conochitina claviformis* Eisenack, 1931
*Conochitina emmastensis* Nestor 1994
*Conochitina goniensis* Pittau, 2000
*Conochitina pachycephala* Eisenack, 1964
*Conochitina* sp. 4 Nestor, 1994
*Conochitina* sp. aff. *C elegans* Eisenack, 1931
*Conochitina* sp.a
*Conochitina subcyatha* Nestor, 1982
*Conochitina* sp.
*Eisenackitina bohemica* (Eisenack, 1934)
*Eisenackitina* cf. *bohemica* (Eisenack, 1934)
*Eisenackitina lagenomorpha* (Eisenack, 1931)
*Eisenackitina* sp. C (? *E. bohemica*)
*Eisenackitina*? sp. A (aff. *E. lagena*)
*Eisenackitina*? sp. B (aff. *E. intermedia* or *E. barrandei*)
?*Eisenachitina ampulla* Pittau , 2000
*Gotlandochitina* ? sp.
*Rhabdochitina* sp. a
*Spaerochitina jaegeri* Pittau, 2000
*Spaerochitina serpaglii* Pittau, 2000
*Sphaerochitina ichnussae* Pittau, 2000
*Tanuchitina* sp.a
*Urnochitina urna* (Eisenack, 1934).

## Chitinozoan biostratigraphy

The chitinozoan microfaunas so far encountered from Silurian formations of southeastern and southwestern Sardinia, and biozones already established, are listed below:

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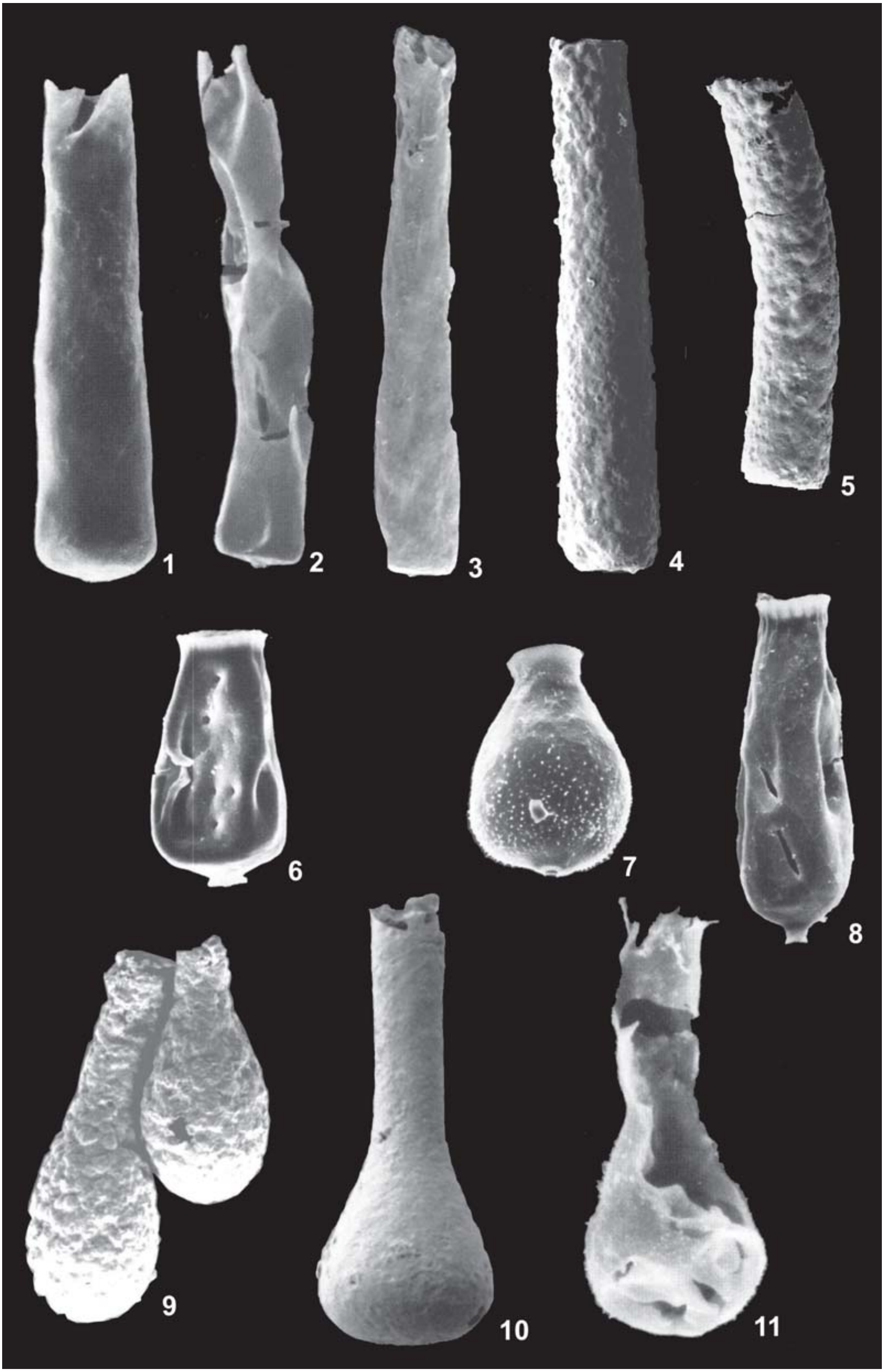
## Plate 2

Figs. 1-2 - *Conochitina pachycephala* Eisenack, 1964.
1. Galemmu, *Cardiola docens* bivalves community; L = 210 µm;
2. Sant'Antonio Donigala, *Cardiola donigala* bivalves community; L = 270 µm;

Fig. 3 - *Conochitina* sp., Rio Ollastu, *crispus* Biozone; L 390 µm.
Fig. 4 - *Tanuchitina* sp. a.; Goni section, *lundgreni* Biozone; L = 193 µm.
Fig. 5 - *Rhabdochitina* sp.a.; Goni section, *lundgreni* Biozone; L = 210 µm.
Figs. 6, 8 - *Urnochitina urna* (Eisenack, 1934); Fluminimaggiore, *Cheiopteria-Patrocardia-Cardiolinka* bivalves community;
6. L = 126 µm;
8. L = 210 µm.

Fig. 7 - *Eisenackitina bohemica* (Eisenack, 1934); Galemmu, *Cardiola docens* community; L = 142 µm.
Fig. 9 - *Sphaerochitina serpaglii* Pittau, 2000; Goni section, *lundgreni* Biozone; specimen on the left, L = 182 µm; specimen on the right, L = 129 µm.
Fig. 10 - *Sphaerochitina jaegeri* Pittau, 2000; Goni section, *lundgreni* Biozone; L = 180 µm.
Fig. 11 - *Angochitina* cf. *echinata* Eisenacks, 1931; Galemmu, *Cardiola docens* bivalves community; L = 185 µm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### *RO ASSEMBLAGE*

Chitinozoan assemblage with *Conochitina emmastensis* Nestor 1994 and *Conochitina claviformis* Eisenack, 1931. Its base is within the *turriculatus* graptolite Biozone and the assemblage ranges into the *crispus* Biozone. It is recorded from the Riu Ollastu section (Pittau et al.,2003). Presumed depositional environment was deep basinal.

### *IG BIOZONE* (Pittau & Del Rio, 2000)

The distinctive event is the appearance of *Conochitina goniensis* Pittau, 2000 and the co-presence of *Conochitina subcyatha* Nestor, 1982. Numerous large *Conochitininae* occur in the assemblage. In the type-section, at Goni, the IG Biozone is represented by samples S38 and S41 (Fig. 2); it matches with the *Cy. rigidus* graptolite Biozone and the unzoned interval in the succession, between the *Cy. rigidus* and *Cy. lundgreni* biozones. The presumed depositional environment was deep basinal.

### *IIG BIOZONE* (Pittau & Del Rio, 2000)

Acme biozone of *Conochitina goniensis* Pittau, 2000. Other characteristic species are *Sphaerochitina jaegeri* Pittau, 2000, *Sphaerochitina ichnussae* Pttau, 2000, *Sphaerochitina serpaglii* Pittau, 2000 and *Conochitina subcyatha* Nestor, 1982. In the type-section, at Goni, the IIG Biozone is represented by sample S42 and matches the lower portion of the *Cy. lundgreni* Biozone (Early Homerian). The depositional environment was deep basinal.

### *IIIG BIOZONE* (Pittau & Del Rio, 2000)

Acme biozone of *Sphaerochitina serpaglii* Pittau 2000 and *S. ichnussae* Pittau, 2000. Its lower limit is the last occurrence (LO) of *Conochitina subcyatha* Nestor, 1982 and the FAD of ?*Eisenackitina ampulla* Pittau, 2000. Biozone IIIG matches the upper portion of the *Cy. lundgreni* graptolite biozone (*M. testis* Subzone). The presumed depositional environment was deep basinal.

### *IV-G BIOZONE*

Distinctive species is *Conochitina pachycephala* Eisenack, 1964. It is, up to now, the only species present in the chitinozoan assemblage. It occurs after an interval devoid of chitinozoans (Extinction Datum III, Pittau et al., 2006) at the end of the *testis* Biozone. The IV-G biozone matches the *vulgaris-gerhardi* graptolite biozone in the Goni section. The depositional environment is likely basinal, transitional to shelf. This biozone is, very likely, equivalent to the GADa Assemblage of the shelf depositional setting (see below).

### *GADA ASSEMBLAGE* (based on Dufka & Gnoli, 1996)

Distinctive species is *Conochitina pachycephala* Eisenack, 1964. The chitinozoan assemblage is poor in number of species and represented by *Conochitininae*. Ecostratigraphically, it matches the *Cardiola docens* and *Cardiola donigala* bivalves communities (Kriz & Serpagli, 1993) and likely ranges from upper Sheinwoodian (upper lower Wenlock) to lower(?) Ludlow according to the range of the *Conochitina pachycephala* Biozone of the "global biozonation" (Verniers et al., 1995). This chitinozoan assemblage derives from microfaunas recovered from limestone blocks at Galemmu, in the Fluminimaggiore area, and Sant'Antonio Donigala, in the Arburese area. The depositional environment was a carbonatic and muddy shelf. Biostratigraphically GAD a Assemblage fits the IV-G Biozone of the Lower Graptolitic Shales.

| | | | GRAPTOLITES ZONES | CHITINOZOANS ZONES | | | |
|---|---|---|---|---|---|---|---|
| | | | | Basin | Transition | Shelf | Index species |
| DEV. | LOCH. | | uniformis | | | GAL 2 | Eis. bohemica |
| SILURIAN | PRIDOLI | | transgrediens | | | | U. urna |
| | | | bouceki | | | | |
| | | | branikensis-lochkoviensis | | | | |
| | | | parultimus-ultimus | | | | |
| | LUDLOW | LUDFORDIAN | fragmentalis | | | | A. cf. elongata |
| | | | kozlowskii | | | | |
| | | | inexpectatus | | | | |
| | | | bohemicus | | | | |
| | | | linearis-leintwardinensis | | | | |
| | | GORST. | chimaera | | | | |
| | | | nilssoni-colonus | | | GADa | C. pachycephala |
| | WENLOCK | HOMERIAN | ludensis-gerhardi | | IV-G | | |
| | | | praedeubeli-deubeli | | | | |
| | | | parvus-nassa | | | | |
| | | | lundgreni-testis | III-G<br>II-G | | | C. serpaglii<br>C. goniensis |
| | | SHEINWOODIAN | ramosus-ellesae | I-G | | | C. goniensis<br>C. subcyatha |
| | | | belophorus-rigidus | | | | |
| | | | riccartonensis | | | | |
| | | | murchisoni | | | | |
| | | | centrifugus | | | | |
| | LLANDOVERY | TELYCHIAN | insectus | | | | |
| | | | lapworthi | | | | |
| | | | spiralis | | | | |
| | | | "tullbergi" | | | | |
| | | | griestonensis | | | | |
| | | | turriculatus-crispus | RO Assemb. | | | C. emmastensis |
| | | | linnei | | | | |
| | | AERONIAN | sedgwickii | | | | |
| | | | leptotheca - convolutus | | | | |
| | | | triangulatus-pectinatus | | | | |
| | | RHUDDANIAN | cyphus | | | | |
| | | | vesiculosus | | | | |
| | | | ascensus - acuminatus | | | | |

Fig. 3 - Biozonal scheme for western and eastern Sardinia Silurian succession in relation to the graptolites biozonation and depositional facies.

### *GADb* ASSEMBLAGE (based on Dufka & Gnoli, 1996)

A small group of species characterize this assemblage: *Angochitina* cf. *elongata* Eisenack, 1931, *A.* cf. *echinata*, few representatives of *Eisenacklitina, Conochitina* and *Belonechitina* (Dufka & Gnoli, 1996). The authors highlighted that *Angochitina* specimens, recovered in Sardinia, are slightly different from the holotypes, nevertheless, this assemblage suite is comparable with the *A. elongata* Biozone of the "global biozonation" (Verniers et al., 1995). GADb assemblage matches with the *Cardiola docens* bivalves community (Kriz & Serpagli, 1993) and, according the maximum stratigraphic range of the *elongata* chitinozoan Biozone, it encompasses Ludlow. This chitinozoan assemblage deposited in a carbonatic and muddy shelf.

### *MP* ASSEMBLAGE. (based on Dufka & Gnoli, 1996)

Distinctive species is *Urnochitina urna* (Eisenack, 1934). Accompanying taxa are representatives of *Angochitina, Cingulochitina* and *Eisenackitina*. Ecostratigraphically, this chitinozoan assemblage matches the two bivalve communities studied in the Mason Porcus section, near Fluminimaggiore (Kriz & Serpagli, 1993): those of *Cheiopteria-Patrocardia-Cardiolinka* and *Patrocardia evolvens evolvens- Panenka*. The MP assemblage, according to the stratigraphic range of the distinctive species matches the Pridoli age and the transition to Lochkovian (Silurian Devonian boundary).

### *GAL2* ASSEMBLAGE

The distinctive species *Eisenackitina bohemica* (Eisenack, 1934) unequivocally indicated the Lochkovian age of this assemblage. At Galemmu, where the assemblage has been recovered, the limestone blocks yield also bivalvia communities (*Pterinopecten-Cybele nesiotes* and *Patrocardia evolvens evolvens-Panenka)*. This chitinozoan assemblages developed in a carbonatic and muddy shelf settings.

## ECOLOGICAL REMARKS

It is a general rule that distribution of organisms in the natural environments depends on physico-chemical and biological constraints. It is reasonable that also the distribution of chitinozoans is, at a certain extent, affected by facies control. Thus, the assemblages should be studied with respect to the evolution of the ancient sedimentary basins. It is widely accepted that the Silurian Sardinia basins developed in two different depositional settings: in the western basement, sedimentation occurred at the bottom of an epicontinental sea and, if tectonized and polydeformed, the Silurian succession is substantially autochtonous (Carmignani et al., 2001). The eastern basin formed during crustal extension and its localization was a hundred kilometre apart the present position (Carmignani et al., 2001). Sedimentation there, was mainly pelagic. The lower portion of the Lower Graptolitic Shale was characterized by a rhythmic sedimentation of carbonaceous matter-bearing chert, radiolarites, and black silica-argillaceous graptolitic shales with high content of organic matter. The same depositional regime persisted during Aeronian and Telychian, and then passed to possibly isolated basin (upper portion of the Lower Graptolitic Shales) characterized by a more anoxic bottom and a restricted terrigenous input (Barca, pers. com.). Sections of graptolitic shales within the nappe zone are very condensed: 7-8 m of shales representing a duration time of almost 5 million years.

Productivity of chitinozoans is low to very low in the quartzitic facies where the species composition is uniform, consisting of 1-2 species, whilst, a special attention deserves deposits of the so called "condensed facies", in which a number of low-diversity to monospecific chitinozoan associations have been recognized.

Late Wenlock, Ludlow and Pridoli sediments of southwestern Sardinia, belonging to the Fluminimaggiore and Mason Porcus formations, are mostly represented by micritic limestones. In this facies, chitinozoans exhibit low diversity, low abundance or they are completely missing. This could likely be explained by transportation of the floating vesicles from agitated waters into more quiet settings. Moreover, scarcity of chitinozoans in the biomicritic limestone could be also implied from a higher rate of sedimentation in the Iglesiente-Sulcis-Arburese (Dufka & Gnoli, 1996).

Understanding the palaeoecology of the chitinozoans means to provide a precise interpretation of the changing composition of the assemblages and, unlikely, this subject is not conclusive and, further, dependance on facies is expressed in a different way by different chitinozoan taxa. The representatives of the genera *Ancyrochitina* and *Angochitina*, with a prominent and complicated ornamentation of the vesicle, are distributed in the Mason Porcus Fm. These genera are characteristic of the transitional or the slope facies (Laufeld, 1974; Miller, 1982; 1996).

Smooth and weakly ornamented simple forms, like those representatives of the genera *Sphaerochitina, Belonechitina, Bulbochitina, Eisenackitina, Urnochitina,* and *Conochitina* are more widespread and sometimes extended into deep basin settings (Nestor, 1994). Abundant *Sphaerochitina* (*S. serpaglii, S. jaegeri, S. ichnussae*) and small and medium sized specimens of *Conochitina* (*C. goniensis)*, in fact, characterize chitinozoan assemblages of the Lower Graptolitic Shales of eastern Sardinia. In the same depositional settings the large *Conochitina* species (*C. proboscifera, C. pachycephala*) are rare, likely because they floated close to the bottom (Miller, 1996). Moreover, the chitinozoan distribution across the Silurian limestone and black-shale formations of Sardinia, has shown that chitinozoans disliked bottom waters enriched with silica, hence their rare occurrence in the early Silurian of the Lower Graptolitic Shales.

The environmental control on chitinozoan taxa is evident, namely in the case of the Silurian assemblages. The Silurian was a period during which severe biological crises occurred, and several scientists dedicated considerable efforts in attempting to achieve a wider and deeper understanding of the natural environmental processes at the base of mass extinctions, touching some selected planctonic organisms (giant graptolites) more than others, but strongly affecting also shelfal communities (Jeppson & Calner, 2003). As this concerns, distribution of chitinozoan taxa was controlled, at least in part, by the environmental pressure. At the lower boundary and within the *Cyrtograptus lundgreni* Zone, chitinozoan microfauna changes three times (Pittau et al., 2006): from the "*Conochitininae* association" to the "*Goniensis* association", "*Serpaglii-ichnussae* association", and "*Goniensis* relict association" respectively. The chitinozoan changeovers succeeded rapidly and two of three associated positive excursions in Cd, Co and Ni concentrations in the organic structured matter and the whole rock (Pittau et al., 2006). The case study carried out in the classical Goni succession, across the *lundgreni* chron, elucidates dynamic effects and compare extinction events in different biological groups (Pittau et al., 2006; Storch et al., 2009).

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