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Finding of *Geodia* (Demospongiae) sterrasters in the Late Miocene of Cappella Montei (Alessandria) and comparison with living forms

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ABSTRACT – The spongiolitic levels of the miocenic Cappella Montei section (Alessandria) bear a particularly rich assemblage of sterraster microscleres, very similar to sterrasters forming the cortical skeleton of sponges of the genus *Geodia*. The comparison between fossil and mediterranean living forms shows good similarities in the external morphology and considerable differences in the internal structures, which can be ascribed to post-depositional dissolution processes.

The fossil record of the genus *Geodia* at Cappella Montei extends its areal distribution to the north-western Mediterranean area.

RIASSUNTO – [Ritrovamento di sterraster di *Geodia* (Demospongiae) nel Miocene superiore di Cappella Montei (Alessandria) e confronto con forme viventi] – I livelli spongiolitici della successione miocenica di Cappella Montei sono particolarmente ricchi di microsclere sterraster, molto simili a quelle che costituiscono lo scheletro corticale di spugne del genere *Geodia*. L'analisi della morfologia e della struttura al SEM, con confronto con le forme mediterranee attuali, ha evidenziato forti somiglianze nella morfologia esterna e notevoli differenze nella struttura interna attribuite a fenomeni post-deposizionali di dissoluzione.

La distribuzione areale delle specie fossili del genere *Geodia* viene allargata alla regione nord-occidentale del Mediterraneo.

INTRODUCTION

Litho and biostratigraphic studies of Miocene and Pliocene sections, from Monferrato and Ligurian Piedmont Basin and from Ligurian area respectively (Bonci *et al.*, 1990; 1991; 1993; 1994), evidenced the presence of levels with very abundant biogenic siliceous content: diatoms, sponge spicules, radiolarians, silicoflagellates, Dinophyceae, Ebriaceae and Archaeomonadaceae. Diatoms are generally dominant, but in the Late Miocene of the Cappella Montei section (Serravalle Scrivia area, Alessandria province) sponge spicules are so abundant to define the bearing levels as «diatomaceous spongiolites» (Bonci *et al.*, 1991; Bonci, 1995).

The spicule assemblage shows a notable variety of forms (Bonci *et al.*, 1991); levels 21, 23, 25 and 28 contain in particular a high percentage of sterraster type microscleres, characteristic of sponge species belonging to the family Geodiidae (genus *Geodia* Lamarck) (Bonci *et al.*, 1991); their peculiar morphologic and structural variability was evidenced by SEM (Scanning Electron Microscope) observation (Bonci *et al.*, 1991). A detailed study of such microscleres variability, considering also type and intensity of the dissolution processes, was portrayed. Microscleres of the same type are present in the other sections in north-western Italy (Early Miocene of Aramengo and Marmorito; Early

Pliocene of Genoa), but their frequency is lower than in Cappella Montei section (Bonci *et al.*, 1990; 1993; 1994).

The comparison of Miocene sterrasters with those of living species from Mediterranean area was portrayed in order to collect data on the paleo-ecologic meaning of their presence in the late Miocene of Cappella Montei and on possible evolutive variations since the Miocene.

At present the genus *Geodia* Lamarck 1815 (Family Geodiidae, Order Astrophorida) encompasses about one hundred species both from tropical and polar waters, with a very wide bathymetric distribution. Four species are present in the Mediterranean Sea (Pulitzer Finali, 1983), three of which along the Italian coasts (Pansini, 1995). *Geodia cydonium* (Jameson, 1862) the most common species, although found also in waters deeper than 300 m, prefers quiet shallow waters (Uriz, 1982). An overwhelming population of *G. cydonium* is present in Porto Cesareo lagoon (Apulian, Ionian coast), where some specimens may exceed 20 cm of diameter (Pl. 1, fig. 1). *G. cydonium* shows a massive, lobate form and is characterized by a stiff consistence owed to a tight cortical layer (Pl. 1, fig. 2) rich in sub-spherical microscleres with spiny surface (sterrasters), whose average diameter is 60-80 µm (Sarà, 1971) (Pl. 2, fig. 1).

METHODS OF STUDY

To prepare the fossil microscleres for SEM observation, the sediment was treated as usually with H_2O_2 and the specimens isolated generally from 180, 125, 75 μm sieves. A Cambridge STEREOSCAN 250 scanning electron microscope was used.

To study the spicule assemblage on the whole, the sediment was treated according to Riedel & Sanfilippo (1977); in order to identify the different types of spicules, samples were observed in light microscopy.

About the living *G. cydonium* collected in Porto Cesareo lagoon, clean siliceous spicules were separated from sponges air-dry tissues by boiling in nitric acid (65%), through rinsing in distilled water and treating in a graded series of ethanols. For SEM observation the spicules were dried at 100°C, mounted on stubs and covered with gold. A Philips EM 515 was used.

To obtain further informations on their internal structure, some sterrasters were crushed before preparation.

THE SPONGOLITIC EVENT IN THE
CAPPELLA MONTEI SECTION

The diatomaceous spongolites levels, pertaining to the S. Agata Fossili Marls Formation (Bonci *et al.*, 1991), are present in the upper part of the Cappella Montei section with a thickness of about 8 m. The analysis of the calcareous and siliceous biogenic assemblages allow to assign this spongolitic event to the Late Miocene and in particular to an interval between 9.9 and 8-7.8 m. y. (Bonci, 1995).

The sponge fauna is represented by isolated spicules or by small fragments, mainly around the nodal areas. Complete skeletal bodies or fragments of valuable size were not observed.

A fair calcareous organic fraction (10-18%) is also present, mainly formed by benthic and planktic foraminifera and by nannoplankton, with subordinate ostracods, echinoid spines, bryozoans and molluscan fragments. Fishes and plants small remains are also found (Bonci *et al.*, 1991).

The spongolitic event begins and ends quite abruptly; the spicules are present in an interval slightly larger than the one of the diatoms: they in fact appear, with a considerable percentage, about 0.5 m below and disappear just above the interval where the diatoms are present.

The spicule assemblage, as the ones of the diatoms and of the foraminifera, does not show significant qualitative and quantitative changes through the spongolitic levels, with the exception of levels 21, 23, 25 and 28 (Bonci *et al.*, 1991) where an increase of sterraster microscleres occurs.

The data obtained from the study of the siliceous and calcareous organisms, especially diatoms and foraminifera, allow to hypothesize a marine environment of internal platform, protected but well in communication with the open sea, in a period of high productivity, without important terrigenous influx and with a tendency to anoxia at the bottom (Bonci *et al.*, 1991; Bonci, 1995).

Diatomaceous episodes, often with a subordinate spongolitic fraction, are present in several Late Miocene sequences of Western Mediterranean area; stratigraphical and/or environmental differences seem to occur between these episodes and the siliceous levels of Cappella Montei (see discussion in Bonci, 1995).

In the Eastern Betic Basin (south of Spain) Tortonian strata with siliceous sponges (genus *Geodia* included) are well-known, but their stratigraphic range only partially fits with the one of the Cappella Montei levels (Brimaud & Vachard, 1985; 1986; Bonci, 1995). Moreover these spongolitic sediments are heavily resedimented with the reworking of the whole fauna and flora (Brimaud & Vachard, 1985).

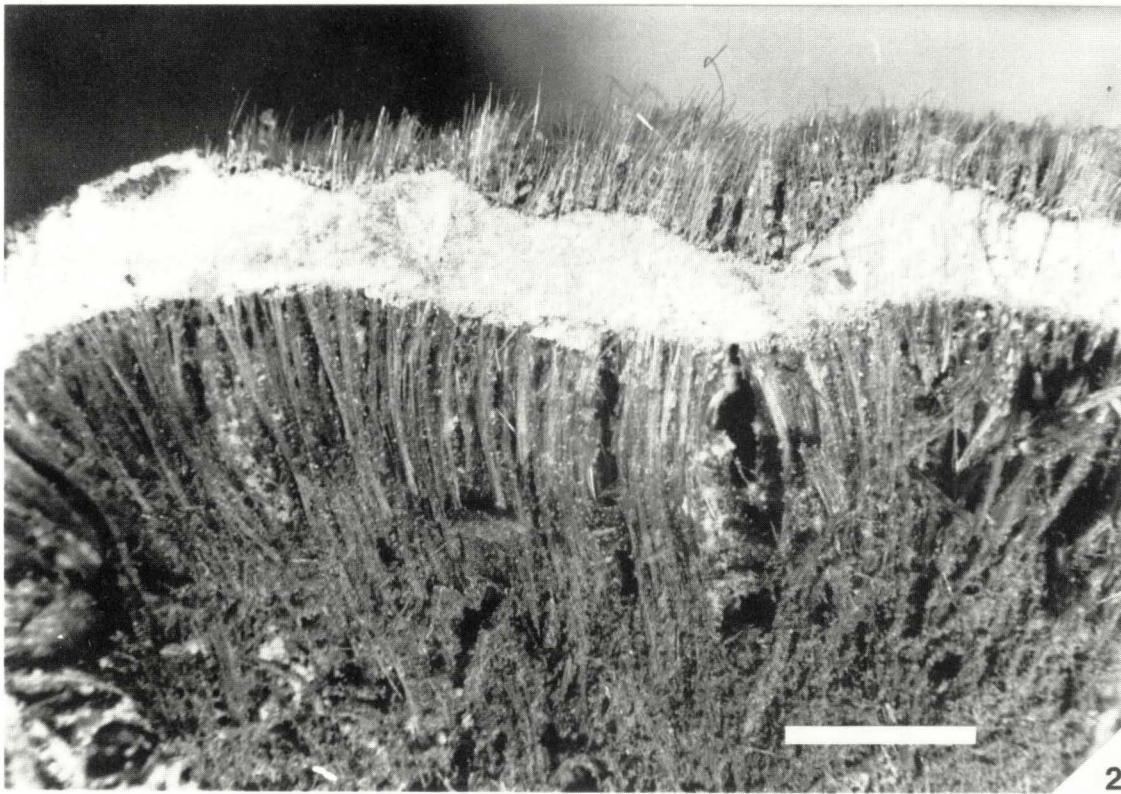
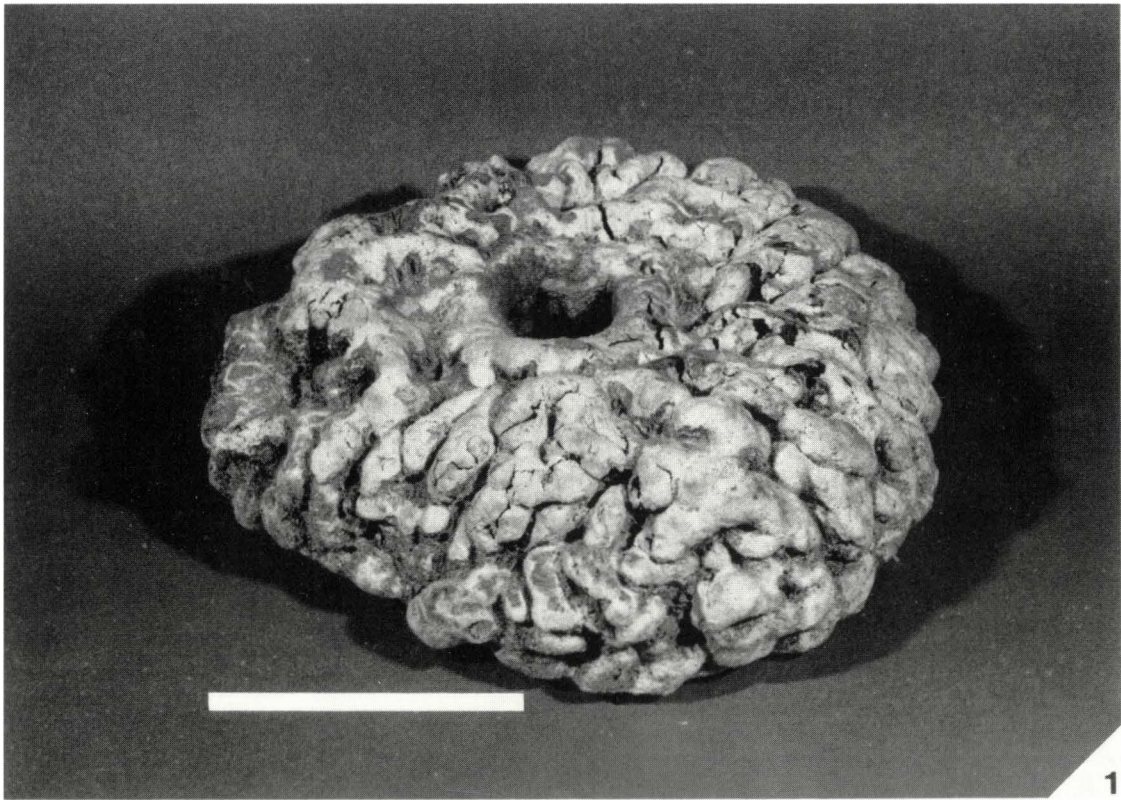
THE SPONGE FAUNA: DESCRIPTION AND DETAILS

THE SPICULES ASSEMBLAGE: GENERAL CHARACTERS

The sediments of Cappella Montei show a high abundance in sponges spicules, ten times larger than those found in present coastal sediments in Ligurian Sea. Spicules are mainly tetraxons, monaxons and desma (Bonci *et al.*, 1991). In particular, the presence

EXPLANATION OF PLATE 1

- Fig. 1 - A specimen of *Geodia cydonium* collected in Porto Cesareo lagoon (bar 10 cm).
 Fig. 2 - Section of *Geodia cydonium*. Note the superficial cortex (lighter color): the high density of sterrasters causes its hard consistence (bar 0,5 cm). Specimen collected in Porto Cesareo lagoon.



of same spicular types (isocheles, anisocheles, palmatae, dichotriaenes, discotriaenes, amphioxeas, acanthoxeas, subtylostyles, styles, strongyles, toxes, sterrasters, tylotes, exotylotes, oxyasters, spirasters, sigmas, spherasters and spheroxyasters) confirmed the presence of following orders: Astrophorida, Hadromerida, Axinellida, Poecilosclerida and Haplosclerida. The families Geodiidae, Clionidae, Axinellidae, Myxillidae, Microcionidae and Adocidae are well represented. These taxa are generally characteristic of temperate shallow waters. The high concentration of sterrasters, very similar to the spicules of the genus *Geodia*, allows to hypothesize a facies dominated by this taxon in a habitat characterized by a scarce terrigenous contribution and quiet waters.

The family Geodiidae, for which sterraster microscleres are diagnostic, is known since the Lower Cambrian (Gruber & Reitner, 1991) and the genus *Geodia* since the Jurassic (Wiedenmayer, 1994). Fossil taxa pertaining to this genus are widespread in Germany, Ural Mountains, Poland, southern Spain, Bahamas, North America and New Zealand (Wiedenmayer, 1994). The here reported finding allows to add north-western Mediterranean area to this list.

THE MICROSCLERES: MORPHOLOGIC CHARACTERS

The shape shows a variability from spherical and subspherical forms to markedly ovoid ones, sometimes quite elongated and with variable roundness degree of the polar zones. A lateral flattening is sometimes observed (Pl. 4, fig. 4).

Measurements conducted on 41 specimens (Tab. 1) show that the maximum diameter (D) ranges from 206.78 µm to 108.72 µm, while the minimum diameter (d) ranges from 177.39 µm to 98.82 µm. The sphericity index (D/d ratio) varies from 1.63 to 1.01 with higher frequency for values between 1.1 and 1.3 (Text-fig. 1).

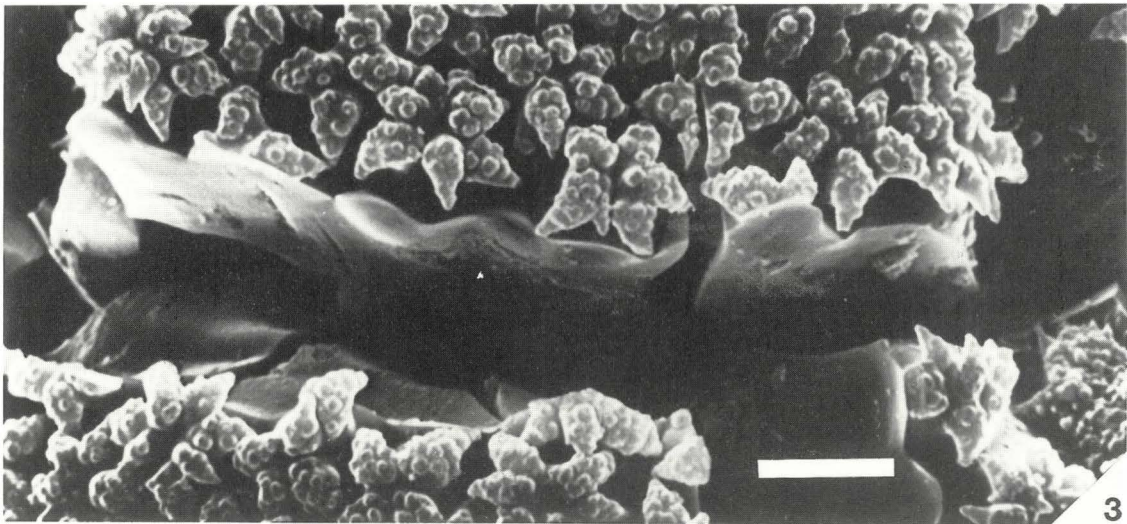
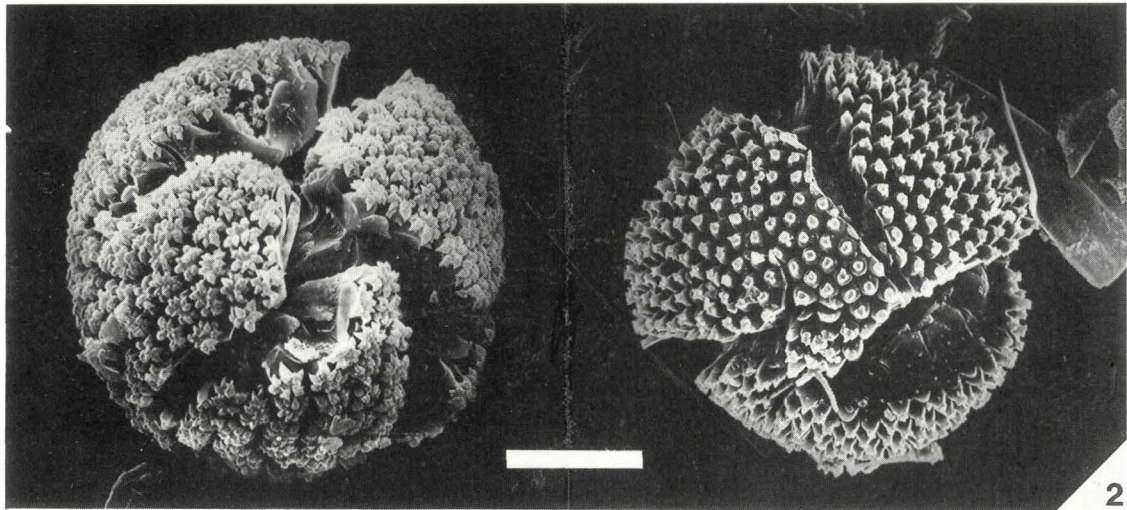
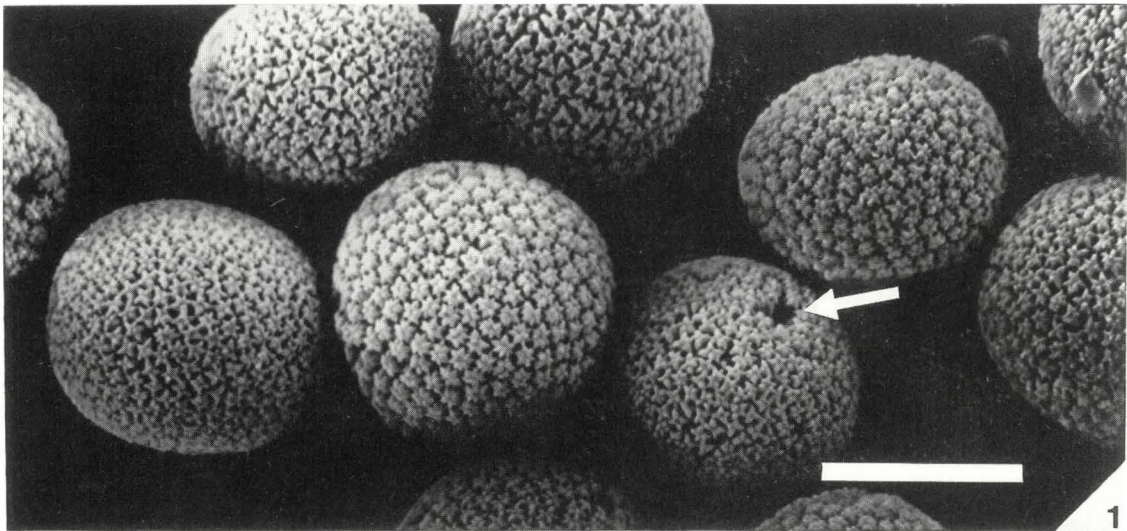
The microscleres are characterized by the presence of a central internal cavity, about half the mean radius wide. The walls are therefore rather thick and

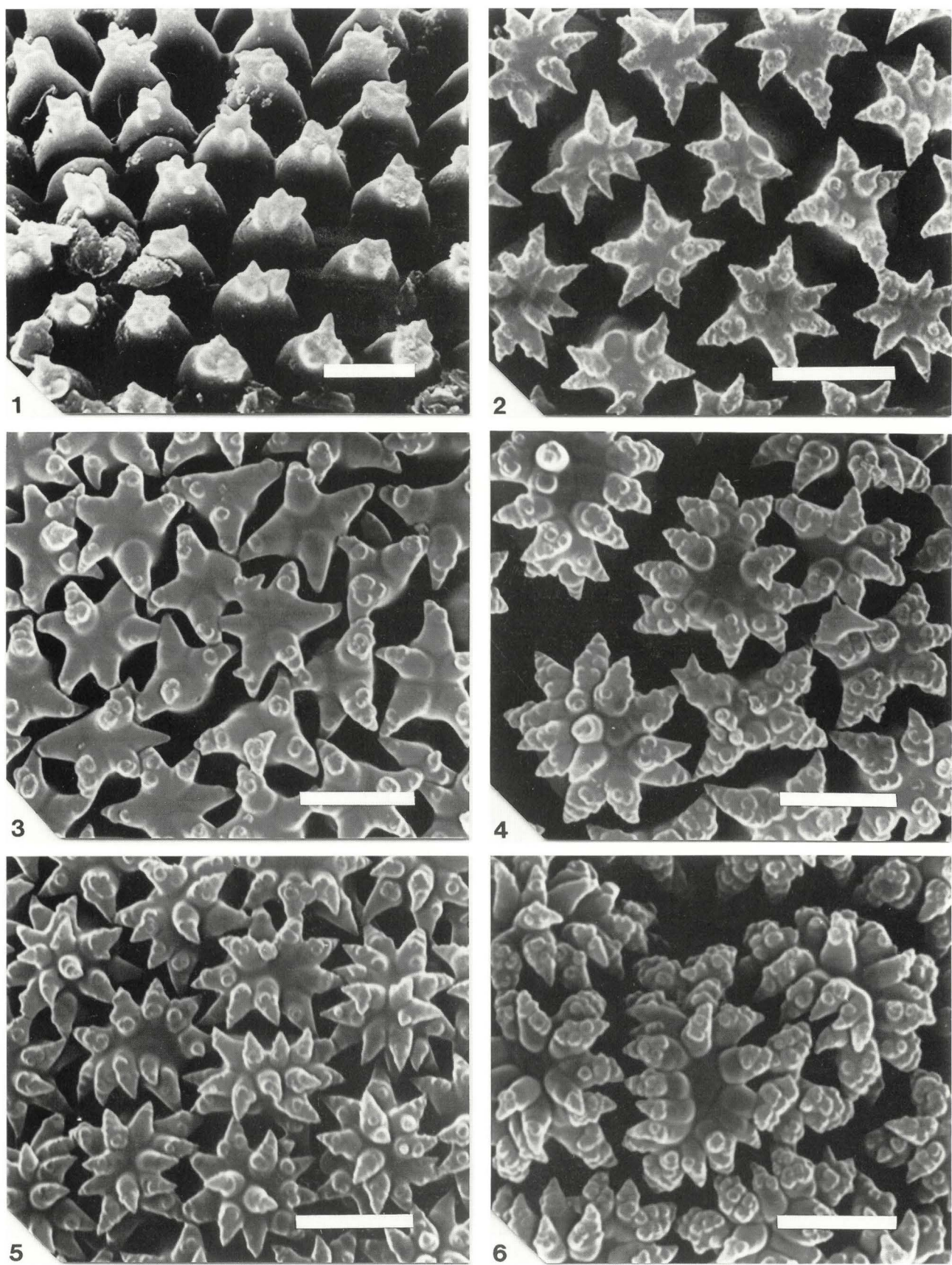
	D (micron)	d (micron)	D/d
Cappella Montei	183.7	112.59	1.63
	154.07	142.22	1.08
	190	140	1.36
	206.78	162.71	1.48
	162.96	143.7	1.13
	151.43	118.57	1.28
	108.72	100.51	1.08
	174.54	156.36	1.12
	172.88	125.42	1.38
	153.85	123.08	1.25
	165.92	145.18	1.14
	169.23	141.53	1.29
	163.48	121.74	1.34
	176.92	152.31	1.16
	193.33	163.33	1.18
	176.66	150	1.18
	160	120	1.33
	194.78	177.39	1.01
	156.66	143.33	1.09
	176.66	156.67	1.13
	160	123.33	1.03
	131.43	107.14	1.23
	152	102.4	1.48
	191.3	151.3	1.26
	185.6	144	1.29
	160	135.38	1.18
	150.77	126.15	1.19
	156.92	129.23	1.21
	148.23	98.82	1.05
	154.07	109.63	1.04
	151.42	100	1.51
	166.66	123.33	1.35
	168.57	122.86	1.37
	154.66	101.33	1.52
	188.46	138.46	1.36
	152.3	141.54	1.08
	151.51	124.24	1.22
	144	104	1.38
Marmorito	154.07	136.3	1.13
	137.5	132.5	1.04
	156.8	144	1.09
Aramengo	114.28	101.43	1.13
	185.6	144	1.29
	128	104	1.23
Genova S.M.	139.26	112.59	1.24
	146.66	112.59	1.03

Tab. 1 - Variability of D (maximum diameter), d (minimum diameter) and D/d (sphericity index) in fossil sterrasters.

EXPLANATION OF PLATE 2

- Figs. 1-3
- Sterrasters collected in Porto Cesareo lagoon.
 - 1 - Sterrasters of *Geodia cydonium*. These microscleres are subspherical, less than 100 µm of span and are characterized by the presence of a depression named hilum (arrow) (bar 50 µm).
 - 2 - The center of sterrasters of *Geodia cydonium* is compact, both in spicules with complete ornamentations (left) and in uncomplete ones (right) (bar 25 µm).
 - 3 - Particular of the compact inner part of sterraster of *Geodia cydonium* (bar 5 µm).





begins to increase but the general shape is similar to that of the «simple star» (Pl. 5, figs. 2-3).

We have to point out that in the living forms these different ornamentations are considered different steps of growth and not a specific character.

DISSOLUTION PATTERNS AND SECONDARY SILICA DEPOSITION ON THE MICROCLERES

The preservation degree is generally good and the microcleres, with few exceptions, are still complete. Sometimes the ornamentation elements are affected by dissolution (Pl. 4, fig. 4; Pl. 5, figs. 5-11). This process is generally not uniform on the microclere surface, since well preserved areas alternate with areas showing various degrees of dissolution (Pl. 4, fig. 4; Pl. 5, figs. 8-10): terminal structures partially (Pl. 5, figs. 5-6) to totally dissolved (Pl. 5, fig. 9) and even exposure of the canals themselves (Pl. 5, figs. 10-11). Rare are however the specimens where the terminal structures are effaced on the whole microclere surface (Pl. 5, fig. 7).

A secondary silica deposition is also present; on the external surface it is observed the filling up of the areas among the terminal structures that in some cases are completely covered by uniform patches (Pl. 4, fig. 5; Pl. 5, fig. 11).

The internal structures are discussed below.

Similar processes (dissolution or secondary silica deposition) were also observed on the diatoms frustules forming the other important component of the biogenic assemblage present in the studied section (Bonci *et al.*, 1991; Bonci, 1995).

COMPARISON WITH THE LIVING FORMS

Sterrasters are produced in a complex process of silica deposition on proteic cores radially organized (Rützler & Macintyre, 1978). The radial canals of proteic origin cannot be identified in the final solid siliceous mass (Pl. 2, figs. 2-3). The last phase of

sterraster building is the formation of an external layer characterized by curved thorns. In living species the complexity and diversity of these ornamentations did not define different kind of spicules but represent different phases, more or less advanced, of their growth (Uriz, 1981) (Pl. 3, figs. 1-6).

Considering only the Mediterranean area, the comparison between sterrasters of *G. cydonium* (presently the most common and widespread species in Mediterranean Sea) and analogous fossil spicules from Cappella Monte allows to ascribe the latter to the genus *Geodia* (Tab. 1) and shows that the latter are more ovoid and larger than the former (60-80 μ m). Miocenic spicules are also larger than that of *G. conchilega* Schmidt, 1862 another Mediterranean species whose sterrasters measure 130-140 μ m of average diameter (Sarà, 1971).

As regards the external surface, sterrasters of *G. cydonium* show generally the same ornamentation types observed in the fossil spicules, except types Ib and IV.

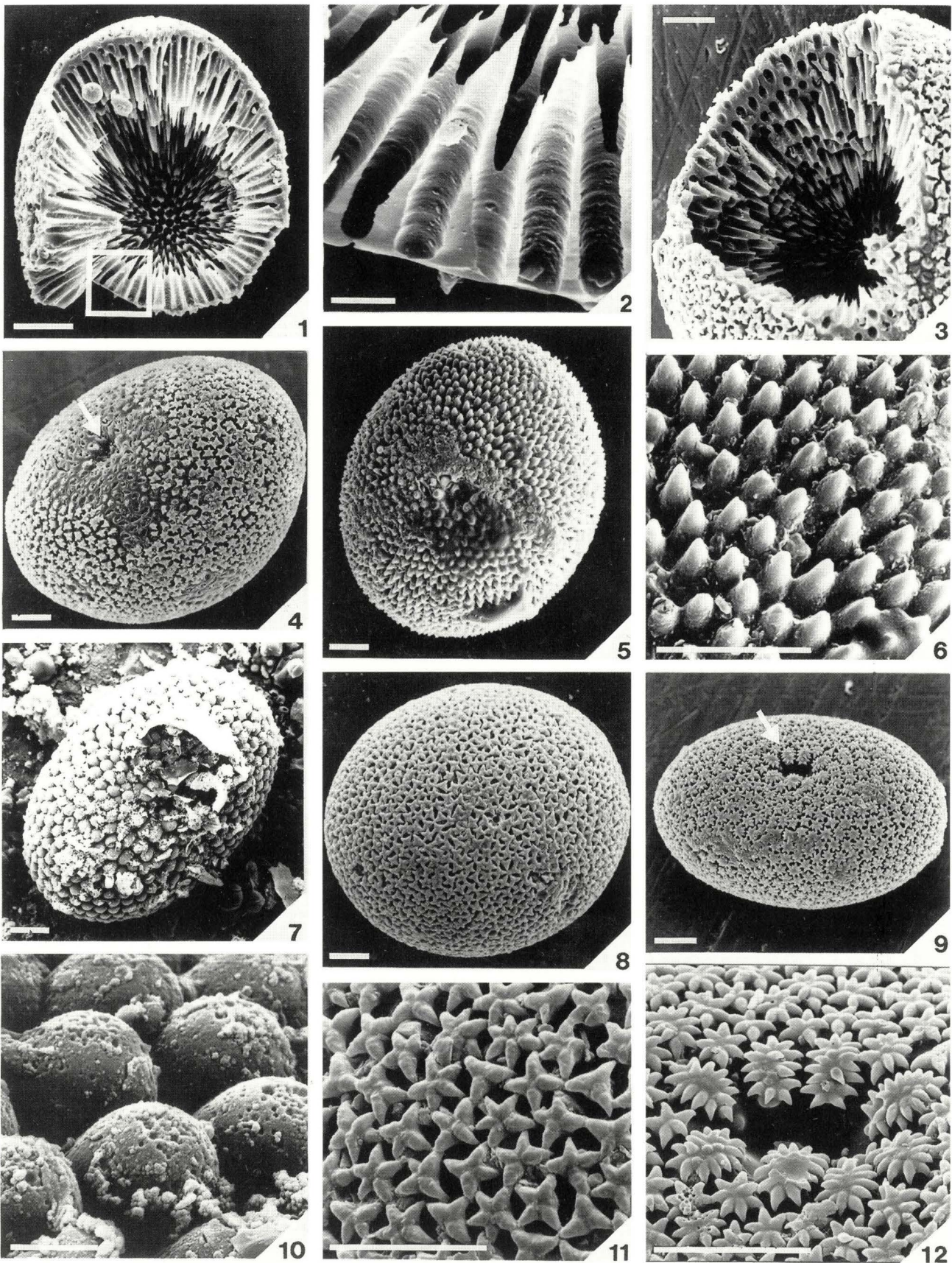
On the contrary the internal part of the miocenic spicules shows great differences in comparison with the living forms. The compactness of internal silica mass is lacking, while a hollow structure, constituted by many radial canals with wide lumen, is evident. These canals are also evident on external layer of spicules whose ornamentation is deeply dissolved.

Rützler & Macintyre (1978), observing spicules found in coral reef sediments or obtained from living sponges treated with Hydrofluoric acid, described an internal structure similar to that of the miocenic sterrasters. According to these Authors the internal cavity and the canalized structures are the result of postdepositional alteration (dissolution), moulding the pattern of the now disappeared proteic filaments of the original scleroblast. The same AA. mention, in Japanese miocenic to recent sediments, the presence of sterrasters, originally called OST, with hollow and radial canals, and at first considered as radiolarians. The process of silica

EXPLANATION OF PLATE 4

Figs. 1-12

- Sterrasters of *Geodia* sp. in the Late Miocene of Cappella Montei.
 - 1-3 - Structure of the internal part. 1) and 3) central cavity and wall canals; 2) particular of the wall.
 - 4 - Ovoid sterraster: the arrow mark the hilum.
 - 5-6 - Ornamentation of the external surface. 5) "Simple" cone shaped terminations (type Ia); 6) particular of Fig. 5.
 - 7, 10 - Ornamentation of the external surface. 7) "Simple" round shape terminations (type Ib); 10) particular of Fig. 7.
 - 8, 11 - Ornamentation of the external surface. 8) "Simple star" terminations (type II); 11) particular of Fig. 8.
 - 9, 12 - Ornamentation of the external surface. 9) "Complex star" terminations (type III); 12) Particular of Fig. 9.
- Bar is 20 μ m except for Figs. 2 and 10 (bar 4 μ m).



dissolution in sponge spicules has been evidenced in living specimens too (Dendy, 1921; Bavestrello *et al.*, 1995).

As after sponge death spicules in sediments dissolve more or less slowly, but uniformly, in relation to the environmental pH and presence of carbonate (Rützler & Macintyre, 1978), it seems possible that miocenic sterraster dissolution took place also in a prediagenetic phase.

We may agree with this hypothesis but we have to point out that the fossil sterrasters are affected, on the external surface, by a strongly dishomogeneous dissolution. This seems in contrast with the clear uniformity of all the observed internal structures that, if not original, are indicative of homogeneous dissolution processes.

On the other hand, even if it cannot be excluded, the assumption that the fossil sterrasters had a hollow internal organization contrasts with the general tendency in the Porifera Phylum to lighten spicular skeleton (Van Soest, 1991).

CONCLUSIONS

The sponge fauna found at Cappella Monte is characterized by a high diversity and by a particular high frequency of sterraster spicules, very similar to those forming the cortical skeleton of sponges belonging to the genus *Geodia*.

The comparison among living forms, mainly from the Mediterranean area, and among various fossil records, allows to draw the following remarks:

a) the miocenic sterrasters of Cappella Monte are larger and generally more ovoidal than the living ones. It is interesting to point out that the sterrasters, pertaining to *Geodia avicula* Brimaud & Vachard, 1986, found in Tortonian successions of the Bethic Basin, have a similar shape, but are even larger (250 µm) (Brimaud & Vachard, 1986)

b) the external surface of the fossil forms shows the same ornamentation observed on the living for-

ms where they represent only different stages in their growth; the dissolution affected this surface much more homogeneously in the living forms than in the fossil ones;

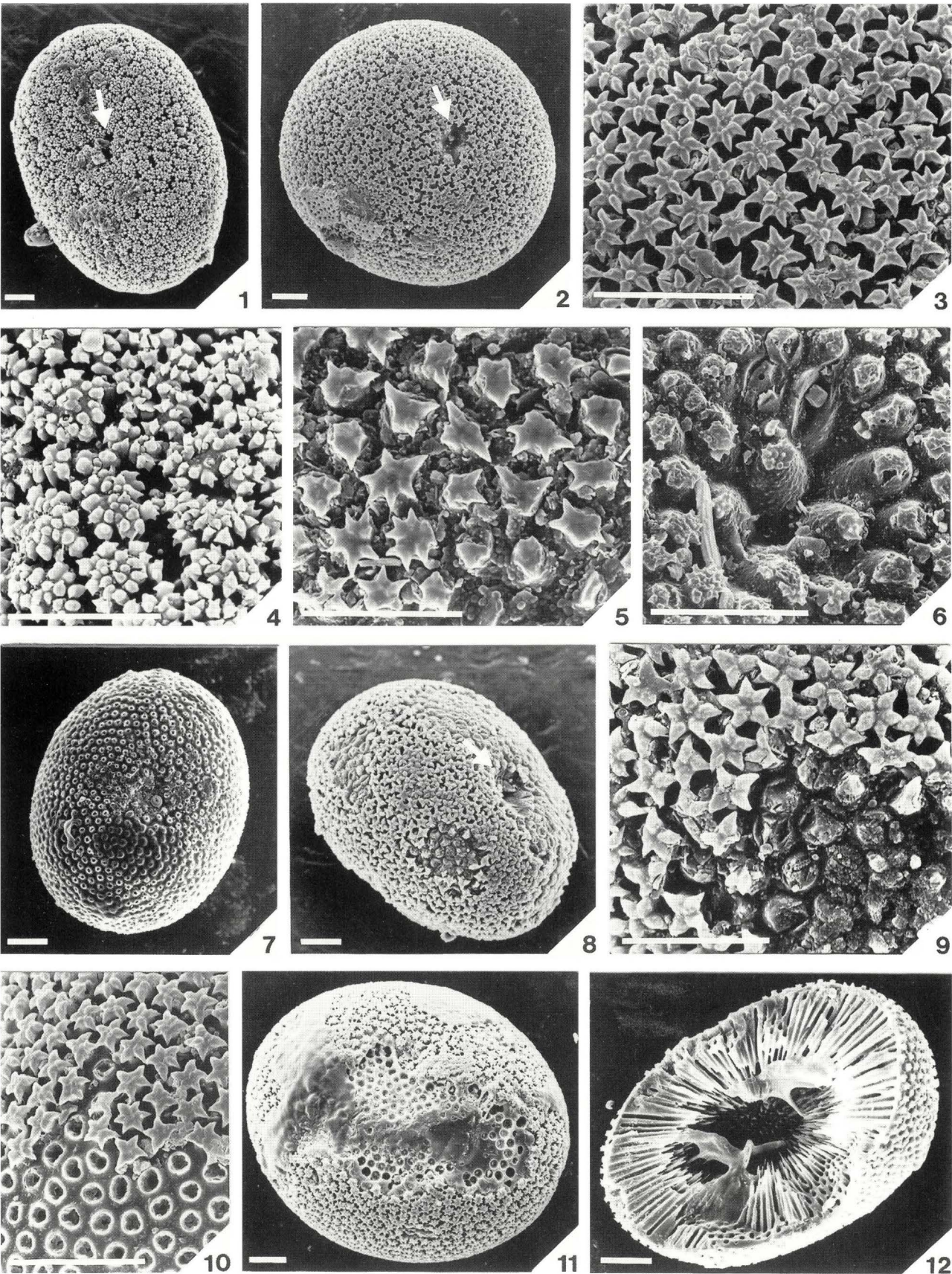
c) the internal structure of the present sterrasters is solid, without cavities, while the fossil sterrasters show an internal cavity and closely canalized walls. This peculiar structure could be explained as the results of dissolution processes, even pre-diagenetic, moulding, and so enhancing, the original proteic structure of the scleroblasts;

d) the sterrasters from the Early Miocene of the Monferrato (Bonci *et al.*, 1990; 1994) and from the Early Pliocene of the Genoa area (Bonci *et al.*, 1993) have the same characteristics of the ones from the Late Miocene of Cappella Monte.

The spicule assemblage on the whole and the abundance of sterrasters belonging to the genus *Geodia* in particular, allow to recognize a moderately shallow water environment, with low hydrodynamism, scarce terrigenous influx and temperate climate. The living Mediterranean *Geodia*, as the other Mediterranean species belonging to the previous reported families, lives in litoral environments. These conclusions are in good agreement with the ecology of the associated siliceous and calcareous organisms (diatoms and foraminifera). In fact the presence of several benthic and meroplanktic taxa in the diatom assemblage suggests an inner-shelf deposition environment widely connected with the open sea, because of fairly good frequency of holoplanktic species (Bonci, 1995). On the whole, diatom and benthic foraminifera assemblages point out temperate-subtropical conditions (Bonci *et al.*, 1991; Bonci, 1995). Sedimentological features are characteristic of a protected environment with negligible continental detritic inflows (Bonci *et al.*, 1991). The preservation of this type of spiculitic deposit, together with the good preservation of the diatomitic flora and with the characteristics of the benthic foraminifera assem-

EXPLANATION OF PLATE 5

- Figs. 1-12 - Sterrasters of *Geodia* sp. in the Upper Miocene of Cappella Monte.
- 1, 4 - Ornamentation of the external surface. 1) "Cluster" terminations (type IV); 4) particular of Fig. 1.
 - 2-3 - Ornamentation of the external surface. 2) "Transitional" terminations; 3) particular of Fig. 2.
 - 5-6 - Different dissolution phases of the ornamentation.
 - 7 - Homogeneous dissolution of the ornamentation on the external surface.
 - 8-9 - Non homogeneous dissolution of the ornamentation on the external surface; 9) particular of Fig. 8.
 - 10 - Dissolution on the external surface: all the terminal structures are effaced and the distal part of the canals is open.
 - 11 - Non omogeneous dissolution and secondary silica deposition on the external surface.
 - 12 - Secondary silica deposition in the inner part of the sterraster.
- Bar is 20 µm.



blage, indicate a depositional environment with reduced oxigenation.

e) It was possible to extend to the north-western Mediterranean area the areal distribution of the fossil species pertaining to the genus *Geodia*.

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