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SILICEOUS SPONGE SPICULES FROM THE MIOCENE MEM MONIZ MARLS (PORTUGAL) AND THEIR ENVIRONMENTAL SIGNIFICANCE

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Abstract. The Miocene (middle Serravalian) Mem Moniz marls from Algarve (Portugal) contain a rich and well preserved assemblage of siliceous sponge spicules, which is described here for the first time. The assemblage indicates that the sponge fauna was dominated by Astrophorida, and in particular by Geodiidae. The presence of *Eurylus* sp. and probably *Geodia* sp. (both Astrophorida), *Samus* sp. (Spirophorida) and *Alectona wallichii* (Hadromerida) is also reported. *Samus* sp. and *Alectona wallichii* are reported from the fossil record for the first time. Additionally, the occurrence of lithistid demosponges (represented by Theonellidae and rhizomorinids), Hadromerida, Spirophorida and Hexactinellida is also shown. Ancorinidae, Pachastrellidae (and/or Cathropellidae), both Astrophorida, were also clearly recognized. Less certain is the occurrence, in the Mem Moniz marls, of Tethyidae (Hadromerida). Bathymetric reconstructions based on sponges are imprecise due to the fact that these organisms often have very wide bathymetric ranges. However, the studied sponge assemblage is clearly neither characteristic of very shallow nor very deep marine environments. The dominance of astrophorids and the presence of lithistids and hexactinellids suggest a depth of at least several tens to one hundred metres, or even more.

Riassunto. Le marne mioceniche di Mem Moniz (Serravaliano medio) dell'Algarve (Portogallo) contengono una associazione a spicole di spugne silicee, ricca e ben conservata. Essa viene qui descritta per la prima volta. L'associazione è dominata dagli Astrophorida, in particolare dalle Geodiidae. Viene pure ricordata la presenza di *Eurylus* sp. e probabilmente di *Geodia* sp. (entrambi appartenenti agli Astrophorida), *Samus* sp. (Spirophorida) e *Alectona wallichii* (Hadromerida). Queste ultime due forme sono descritte per la prima volta allo stato fossile. Viene pure indicata la presenza di desmosponge lithistidi (rappresentate da Theonellidae e rhizomorinidi), di Hadromerida, Spirophorida e Hexactinellida. Ugualmente viene riconosciuta la presenza di Ancorinidae, Pachastrellidae (e/o Cathropellidae), entrambe appartenenti agli Astrophorida. È invece meno certa la presenza nelle marne di Mem Moniz delle Tethyidae (Hadromerida). Le ricostruzioni batimetrice basate sille spugne sono solitamente imprecise a causa della grande estensione batimetrica della maggior parte dei taxa. Tuttavia, l'associazione studiata è chiaramente né poco, né molto profonda. Il prevalere degli astrophoridi e la presenza di lithistidi e hexactinellidi suggerisce una profondità compresa tra alcune decine di metri sino a circa 100 metri di profondità, se non di più.

Introduction

The whitish marls of Mem Moniz are a sedimentary unit of Miocene age outcropping in a restricted area north of the locality of Albufeira, in Algarve, Southern Portugal (Fig. 1). These marls are almost completely devoid of macrofossils. On the other hand it has a rich microfossil content, in which siliceous sponge spicules are plentiful and one of the most common biogenic elements present. Apart from them, calcareous nannofossils, diatoms, benthic and planktic foraminifera and rare ostracods occur.

Ever since their discovery, the spicule-rich Mem Moniz deposits have been involved in sizzling controversy. Their stratigraphic positioning, first, and palaeoenvironmental significance, later, fueled a seemingly never ending debate (see, eg. Romariz et al. 1979; Cachão 1995; Antunes et al. 1997; Cachão et al. 1998)

The abundant and well preserved siliceous sponge spicules of Mem Moniz therefore are of considerably palaeontological and palaeoenvironmental interest. Their study is crucial for the interpretation of the environmental setting in which these deposits where formed.

The excellent preservation of these fossil spicules should enable their clear identification and assignment

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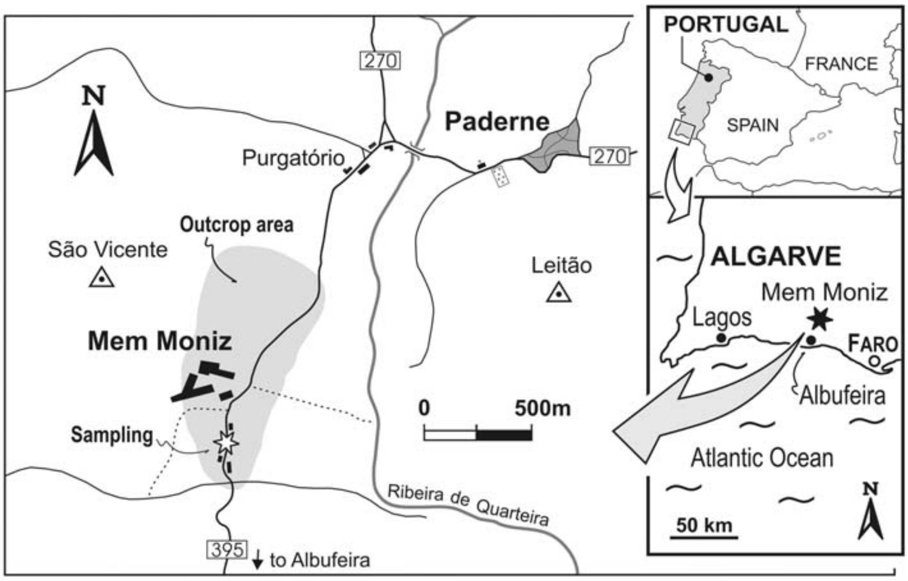

Fig. 1 - Location of the studied outcrop.

to sponge taxa at a family level and hopefully even to specific level. This would represent an important contribution to the history of the siliceous sponges, especially to the as yet poorly known Caenozoic history of nonlithistid demosponges.

Geological setting and stratigraphy

The whitish marls of Mem Moniz crop out in the central sector of Algarve (Southern Portugal), approximately 9 km to the North-Northeast of Albufeira. The Mem Moniz outcrop is limited to a relatively small elliptical area of about 1 km^2 at the present day altitude of 70-80 m above mean sea level (Fig. 1). The marls lay generally subhorizontal. Nontheless, a section of the outcrop located between faults, tilted approximately 20^0 SE, displays a 17 m continous sequence that was sampled for the present study (Fig. 2). They overlie, with unconformity, Lower Cretaceous marls and sandstones.

Formerly considered a Cretaceous outcrop, the Mem Moniz marls were recognised as a Miocene marine deposit only in the early 1970's (Romariz et al. 1979). Since its Miocene assignment, this outcrop has attracted considerable interest due to its litho- and biofacies uniqueness, namely the almost complete absence of macrofossils (both body fossils and ichnofossils) so abundantly found in its surrounding Miocene marine sedimentary units of Algarve. On the other hand, its fine marly texture seems paradoxical due to its inland position relative to the majority of the other Southern Portuguese shallow marine Miocene deposits, typically clustered along the present day coastal area (Cachão 1995).

Lithostratigraphically, the marls of Mem Moniz are part of the Middle Member of the Lagos-Portimão Formation commonly represented, in the coastal area of Algarve, by macrofossiliferous biocalcarenites (Cachão 1995; Cachão et al. 1998). The Lagos-Portimão Formation makes up part of the first main sedimentary carbonate Portuguese Neogene sequence (Cachão & Silva 2000), represented in the entire Algarve region, but having a larger cartographic expression on the coastal region west of Albufeira (Cachão 1995). This formation is separated from an upper siliciclastic sequence (Cacela and Ludo Formations; Cachão et al. 1998) by an important regional unconformity (Cachão & Silva 2000).

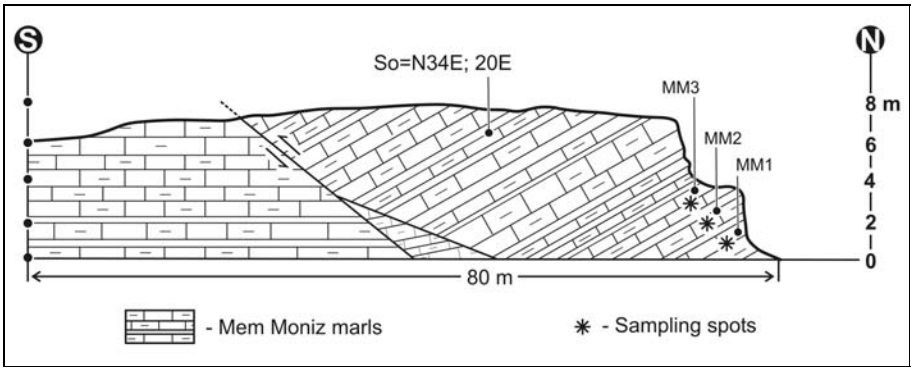

Fig. 2 - Simplified geological section of the investigated outcrop; samples position indicated by arrows.

The calcareous nannofossils assemblage in the Mem Moniz marls indicates their placement in the Okada & Bukry's (1980) subzone CN5a, being compatible with a Middle Serravalian age (Cachão 1995). $^{87}Sr/^{86}Sr$ isotopic dating permorfed on planctic foraminifera tests from this unit indicates an age of 12.5 (+0.7-1.7) Ma (Antunes et al. 1997).

The Mem Moniz marls are interpreted as a deposit formed during a relatively rapid transgressive episode, over a polygenic surface, cut by coastal encroachment on top of a Mesozoic basement (Cachão 1995). The existence of important tectonic deformation (the Algibre flexure of Kullberg et al. 1992) in this area may have pre-adapted it to be preferentially eroded into a more or less depressed and restricted sub-basin defined on a generally open shallow marine platform.

A significant part of the 40% of carbonate content of the white marls of Mem Moniz is biogenic (calcareous nannofossils, benthic and planktic foraminifera and rare ostracods) associated with a less important siliceous biogenic component (around 10%) mainly constituted by diatoms and sponge spicules (Romariz et al. 1979; Cachão 1992). Rare fish remains, mainly scales and isolated bones, can also be found.

Material and methods

Previous sampling for calcareous nannoplankton research scanned the entire sequence and determined that diagenesis increases upwards while diatom and spicule content decreases in that same direction. Thus three samples from the lowermost sector were selected for the present study (Fig. 2). Rock bulk samples were dissolved in weak hydrochloric acid and siliceous spicules picked-up under binocular microscope. The spicules were mounted on a stub and investigated under SEM. No significant difference in spicule composition was found between the various samples. The identification of the sponges was performed by comparison with characteristic spicules of Recent sponges. Terminology of spicules can be found in Boury-Esnault & Rützler (1997) and Hooper & Van Soest (2002).

All the investigated material of sponge spicules is housed in the Institute of Paleobiology, Polish Academy of Sciences, Warszawa, under the collection number ZPAL Pf.19.

The sponge spicules of Mem Moniz

Hexactinellid spicules

Hexactinellida, Schmidt, 1870 (for basic taxonomy of Recent and fossil hexactinellid sponges see Reiswig 2002 and Krautter 2002) are characterized by triaxial spicules (= hexactines) or their derivatives. Hexactinellid spicules are very rare in our samples. They are represented only by loose hexactines and pentactines. The pentactines (Fig. 3A-D) are ectosmal spicules (outer surface or spongocel surface), while hexactines (Fig. 3E-G) are most probably choanosomal spicules, but may in part belong to the ectosome as well. None of these spicules are characteristic of any particular group of hexactinellids, but absence of fragments of fused choanosomal skeleton, suggest that we are dealing, most probably, with Lyssacinosa Schulze, 1886 (Hexasterophora Schulze, 1886). Similar spicules occur in Amphidiscophora, but this is a bathyal/abyssal group today and most probably it was in the Miocene, its presence being rather improbable in the Mem Moniz deposits.

Today, all hexactinellid sponges inhabit deep water environments (Reid 1968; Vacelet 1988), with the exception of such specific habitats as submarine caves (Vacelet et al. 1994) and fjords (Vacelet 1988; Leys et al. 2004) where they may be found in shallow water, what is associated with their preference of stable environments and low and turbulence (Mehl 1992). There are no data specific to the Miocene, but there is no indication that this situation was different than today.

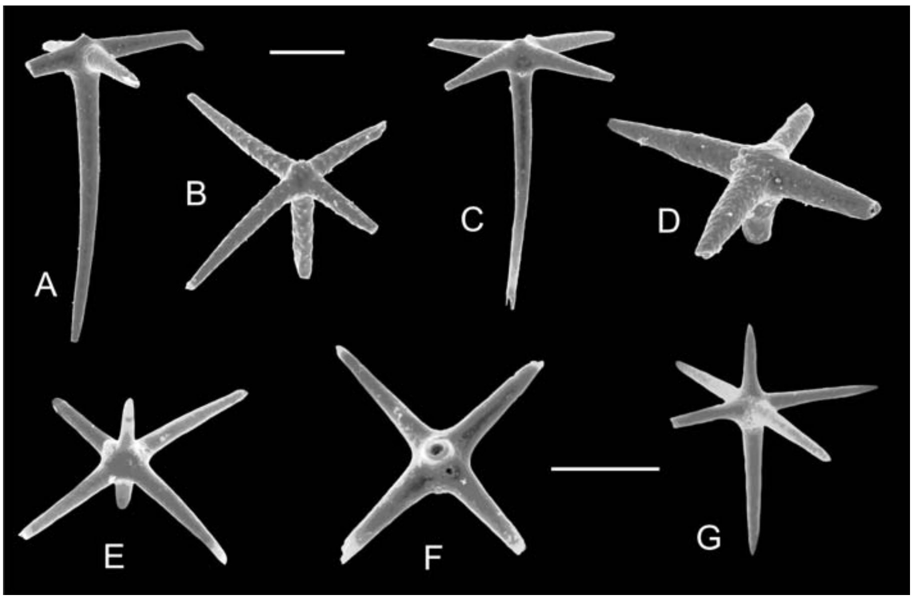

Fig. 3 - Hexactinellid spicules (most probbaly Lyssacinosa); A-D.?ectosomal pentactines; E-G. hexactines, Scale bars 100 µm.

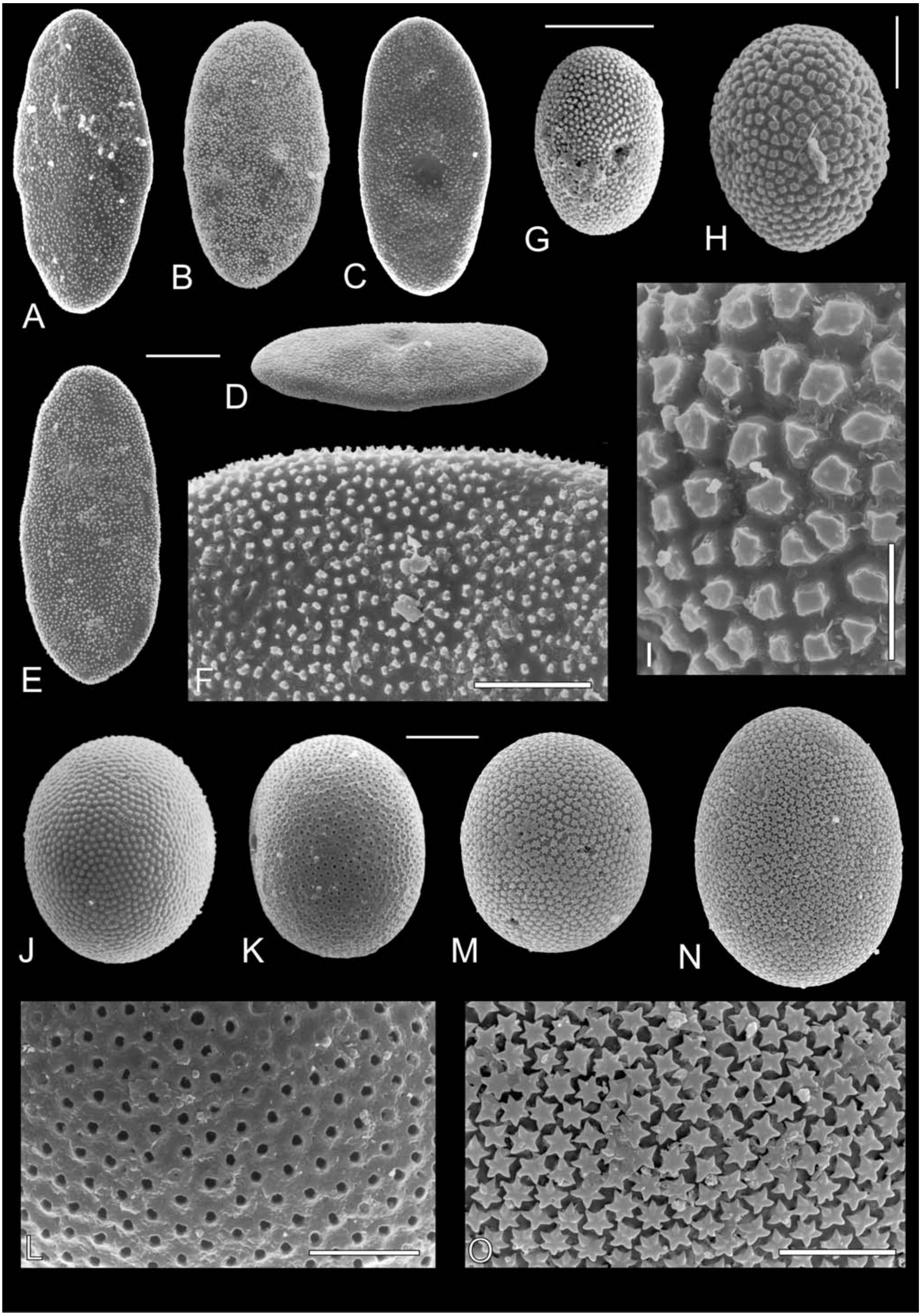

Fig. 4 - Geodiidid (Astrophorida) spicules. A-F. Aspidasters of *Eurylus* sp.; A-E: scale bar 50 µm; F: scale bar 20 µm; G-O. Sterrasters of?*Geodia*. G. scale bar 100 µm. L. details of, scale bar 20 µm; O. scale bar 20 µm.

Demosponge spicules

Demosponges are characterised by spicules (loose or articulated, in the case of lithistids), which may be tetraxial and/or monaxial, but are never triaxial (see Hooper & Van Soest 2002). Demosponge spicules are the most common in the investigated deposits. Some of the more morphologically complex spicules are very characteristic, allowing a more or less precise taxonomic assignment. Others, usually morphologically simpler, have no diagnostic value, and may belong to various groups of soft demosponges. They are described and illustrated here without attribution to lower taxonomic groups.

Geodiid spicules. The family Geodiidae Gray, 1867 (Astrophorida Sollas, 1888) is characterised by the presence of large oxeas and triaenes among megascleres; microscleres are sterrasters, euasters or microrhabds (Uriz 2002a). Spicules undoubtedly assigned to the family Geodiidae are represented in the examined material by various spherrasters, and their variant called aspidaster. These spicules occur in the outermost layer of a sponge, forming a very dense layer. They are the most common demosponge spicules in our samples. Aspidasters (Fig. 4A-F), which are a flattened version of spheraster, are characteristic of the Recent genus *Eurylus* Gray, 1867 (Uriz 2002a). Typical spherasters are represented in our material by three morphological types, which differ in size and, particularly, in surface sculpture: type 1 (Fig. 4G, M-O), type 2 (Fig. 4H-I) and type 3 (Fig. 4J-L). The type 3, however, may as well simply be an early developmental stage of the other spherasters types. The observed differences exceed, however, those observed today in one species, suggesting we most probably are dealing with several different species in our material.

Unfortunately, the taxonomy of Recent geodiid sponges is based on the sponge structure and on the assemblage of spicules (one sponge contains several different types of spicules) (Uriz 2002a), not on the morphology of spherasters. In Recent forms spherasters with various sculptures may be assigned to the same genus, whereas spicules with similar spheraster sculpture may occur in different genera. This is clearly a matter in need of further investigation based on Recent material. Thus, in the case of disassociated fossil spicules, it is impossible to determine with certainty the genus they belong to. However, in this case, it most probably was *Geodia* Lamarck, 1815, as suggested by its shape.

Geodiid demosponges have also various styles, oxeas and triaenes, but in the isolated form they are not characteristic enough to be recognized as belonging to geodiids. Thus, one cannot exclude that some oxeas and styles and triaenes from the investigated material may indeed belong to geodiid sponges. Similar spicules occur in other astrophorid sponges as well. Geodiid sponges occur world-wide and have wide bathymetric ranges, but are typical of bathyal depths and soft bottoms (Uriz 2002a). The species *Erylus euastrum* (Schmidt, 1868), known from the Atlantic and the Mediterranean was reported, for example, from a depth between 3 m and 1384 m (Boury-Esnault et al. 1994). The genus *Geodia* has an intertidal to bathyal (-2840 m) distribution (Vacelet 1988). Therefore spherasters cannot be used as reliable bathymetric indicators.

Questionable fossil sterrasters of Geodiidae have been reported, in thin sections, from rocks as old as Cambrian (Reitner & Mehl 1995), but well preserved sterrasters are known only since the Jurassic (Reiff 1967; Wiedenmayer 1994). A Miocene geodiid sponge, bodily preserved, was described from Spain by Brimaud & Vachard (1986). Isolated geodiid sterasters were described from the Paleocene of the Alabama by Rigby & Smith (1992), from th Lévi e Eocene of Australia (Hinde 1910) and New Zealand (Hinde & Holmes 1892), from the Miocene of Italy (Bonci et al. 1990, 1997; Queirolo et al. 2002), and Moravia (Riha 1982; Pisera & Hladilova 2003). In paleontological papers, spicules morphologically similar to sterrasters, but monaxial (spherasters are polyactinal), the selenasters, typical of Recent Placospongidae Gray, 1867, are often erroneously ascribed to Geodidae. Selenasters are very common, for example, in the Upper Jurassic sponge facies in Europe (see e.g., Pisera 1997). The oldest known aspidasters of *Eurylus* are known from the Upper Cretaceous of Germany (Wiedenmayer 1994). Eocene aspidasters were reported by Hinde & Holmes (1892) from New Zealand.

Lithistid spicules. Lithistid sponges are a polyphyletic group of demosponges sharing one common character: they have a choanosmal skeleton composed of articulated, more or less irregular spicules called desmas (Pisera & Lévi 2002a). Lithistid sponges, however, differ in the type of desmas as well as the type of ectosomal spicules and associated microscleres. Both choanosomal desmas and ectosomal spicules occur in the investigated material. The most common are ectosomal phyllotriaenes (Fig. 5A-H). Discotriaenes are very rare (Fig. 5I). Both are characteristic of lithistid sponges of the family Theonellidae Lendenfeld, 1903 (Pisera & Lévi 2002a, b). Morphological variability of phyllotriaenes is rather low and probably they belong to one species; discotriaene may belong to a second, different species. Tetraclone desmas are rare (Fig. 5J-K). They occur, among others, in the Theonellidae (Pisera & Lévi 2002a, b), thus they probably are conspecific with the ectosomal phyllotriaenes. The most common choanosmal desmas in our material are the rhizoclones (Fig. 5L-O), which occur in various Recent families (Pisera & Lévi 2002a). In the palaeontological literature they usually are assigned to Rhizomorina (Pisera 2002).

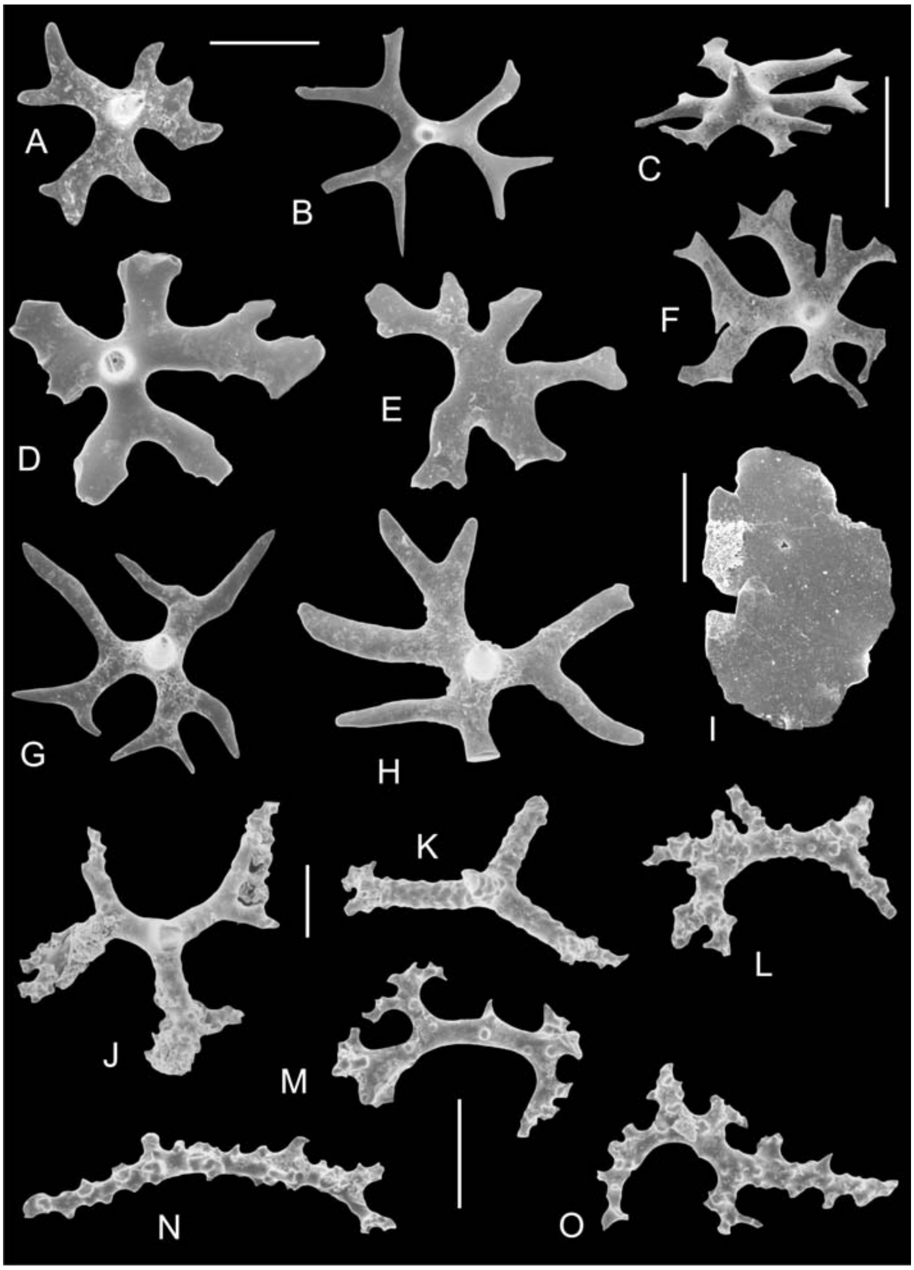

Fig. 5 - Lithistid spicules. A-H. Theonellid ectosomal phyllotriaenes; A-B, D-E, G-H, sclae 200 µm; C, F, scale bars 500 µm. I. Theonellid discotriaen; scale bar 200 µm J-K. Theonellid? tetraclone desmas, scale bar 200 µm; L-O. rhizoclone desmas, scale bar 200 µm.

loose phyllotrianes are already present in Triassic sediments (Mostler 1978; Wiedenmayer 1994).

Samid spicules. Samidae Sollas, 1888 are a monotypic demosponge group assigned on the basis of sigmaspire microscleres to Spirophorida Berquist & Hogg, 1969 (Van Soest & Hooper 2002). In our material amphitriaenes are common (Fig. 6), closely resembling the only known recent species *Samus anonymus* Gray, 1867. The first undoubted fossil occurrence of the genus *Samus* was reported from the upper Aquitanian-Burdigalian of Italy, and erroneously described as 'dichotriaene spicule" by Bonci et al. (1990, pl. 8, fig. 12). However, Wiedenmayer (1994) suggested that the Eocene spicules assigned by Hinde & Holmes (1892) to *Ditriaenella*, from the Eocene Oamaru Diatomite (New Zealand), should also be ascribed to this genus. *S. anonymus* is a neritic sponge with excavating habit, reported from various regions of the world (Wiedenmayer 1994; Van Soest & Hooper 2002), including the Mediterranean where it occurs in shallow submarine caves (Pulitzer Finali 1983). The palaeoenvironment associated with the fossil occurrence from Italy was interpreted, based on forams, diatoms, and facies analysis, as an outer shelf to upper slope open marine environment (Bonci et al. 1990).

Today, litihistid sponges are common in rather deep water (see Vacelet 1988; Pisera 1997; and Pomponi et al. 2001) (from 100 m down to several hundred meters depth), but in submarine caves they may also occur in shallow water (Vacelet & Vasseur 1965; Pouliquen 1971). Theonellids may occur also in shallow water (Vacelet 1988). Most Recent lithistids live attached to hard bottom or hard objects on the bottom, but some Upper Cretaceous lithistids show adaptations to soft chalky sediments (Pisera 2004).

Theonellids are known in the fossil record since Upper Jurassic (Pisera 1999, 2002), on the other hand,

Alectonid spicules. The family Alectonidae Rosell, 1996 (Hadromerida Topsent, 1894) is represented among the studied spicules by rare acanthoxeas (Fig. 7N), and another characteristically tuberculated oxeas (Fig. 7O-R). The acanthoxeas closely resemble the ones from the Recent species *Alectona milliari* Carter, 1879 (Rützler 2002), whereas the tuberculated oxeas are identical to the spicules of the Recent species *A. wallichii* (Carter, 1874) (Bavastrello et al. 1998; Rützler 2002). Noteworthy is the case of this last species. So far, *A. wallichii* had been reported only from the Indo-Pacific, but recently it was also discovered in a submarine cave

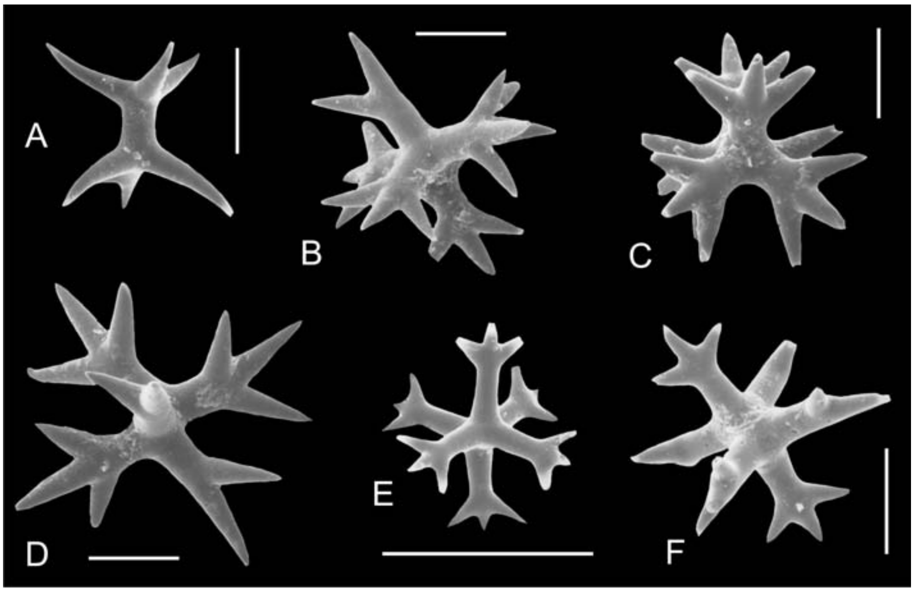

Fig. 6 - Amphitriaenes of Samidae Sollas, 1888, (Spirophorida) in various orientation; scale bars 100 µm.

on the Lebanese coast (J. Vacelet, 2004, pers. comm.). Such distribution, fossil and Recent, may be another example of the Tethyan relict (cf. Boury-Esnault et al. 1992).

The predominantly circumtropical genus *Alectona* Carter, 1879 is excavating in habit and known from the Indo-Pacific, Atlantic and the Mediterranean, from very shallow water down to depths of 664 m (Bavestrello et al. 1998).

Other "soft" demosponge spicules. By "soft" demosponges we understand those sponges which have no articulated chaonosomal spicules, *i.e*., all non-lithistid demosponges with siliceous spicules.

The family Ancorinidae Schmidt, 1870 (Astrophorida Sollas, 1888) is characterised by the presence of various triaenes with long rhabdome and oxeas. Characteristic microscleres are euasters, sanidasters and microrhabds. Some of the plagiotriaenes (Fig. 8A-D, J) and orthotriaenes (Fig. 8I) present in our material belong, most probably, to Ancorinidae. Some of the oxyasters (Pl. 9E-F) and dichotriaenes (Fig. 10H-I) are very similar to those known form some *Stellata* species (e.g., Lévi & Lévi 1983, figs. 23-25). Anthasters (Fig. 9J-K) also occur among ancorinid sponges (e.g., Lévi 1958, fig. 3), but their attribution is less certain, because similar spicules may be found in other demosponge groups. Wiedenmayer (1994) attributed fossil anthasters to spirastellid (Hadromerida, Spirastellidae Ridley & Dendy, 1886) and/or chondrillid demosponges (Chondrosida Boury-Esnault & Lopes, 1985; Chondrillidae Gray, 1872). Anthasters were described from the Eocene of New Zealand by Hinde & Holmes (1892). Some large oxeas, already mentioned when discussing geodiid sponges, may in part belong to ancorinids as well. Today Ancorinidae are known from soft to hard bottom and from shallow to bathyal depths (Uriz 2002b).

Triaenes of calthrop type (Fig. 10A-F), or their modifications, are also very common in the investigated deposits. They characterize two Recent families: Pachastrellidae Carter, 1875, and Calthropellidae Lendenfeld, 1907 (both Astrophorida) (see Maldonado 2002; Van Soest & Hooper 2002). Unfortunately, the difference between representatives of these families lies in other spicular elements, thus it is impossible to tell to which group they belong for sure. Some of the ectosomal dichotriaenes (Fig. 10G-I) found in the same samples may also belong to pachastrellid and/or calthropellid sponges. However, similar spicules also occur in ancorinids (especially Fig. 10H-I) or lithistids (Fig. 10G).

Very common in the investigated material are protriaenes, short shafted triaenes (Fig. 8E-G) which may occur in various astrophorid demosponges.

Large oxyasters (Fig. 9E-F) and spherasters (Fig. 9G-H) resemble megasters known from the family Tethyidae (Hadromerida Topsent, 1894) (Sara & Bavastrello 1996), but similar spicules may occur also in Ancorinidae (see *Stelleta hyperoxea* in Lévi & Lévi 1983). Other spherasters (Fig. 9A-D, I) common in the studied material may also belong to hadromerid sponges.

Oxeas (Fig. 7A-C, G-H, J-K) are a very generalised type of spicules and, as such, are not characteristic of any particular demosponges, occurring as main and/or accessory spicules in nearly all demosponge groups. Bearing in mind the undoubted presence (see above) of geodiid and ancorinid demosponges in the investigated material, the large oxeas (Fig. 7A-C) present in the studied assemblage belong, most probably, to these sponges. A similar problem is posed by strongyloxeas (Fig. 7D-E), styles (Fig. 7F, I), and diaen (Fig. 7L) which are too generalized to be attributed to any particular demosponge group. Nonetheless, some sculptured ox-

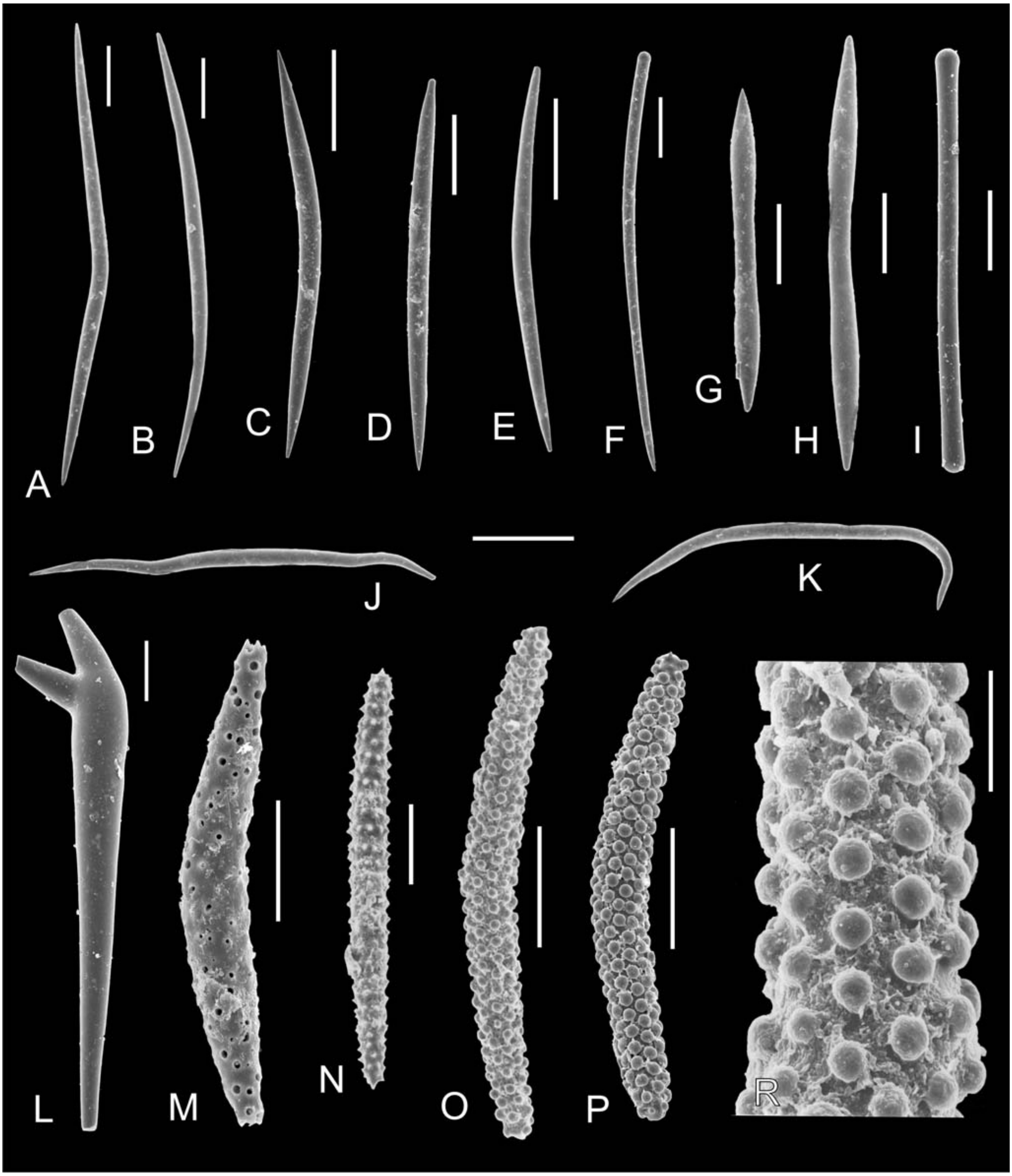

Fig. 7 - Various "soft" demosponge spicules. A-C, G-H. Amphioxeas; D-E. Strongyloxeas; F, Style; I-amphityl; J-K. Flexuous oxeas; L-diaen; M-N, acanthoxeas (M, probably *Acanthotetilla,* N, probably *Alectona*); O-R, tuberculate oxeas of *Alectona wallichi*, R- details of sculpture; A-B, D, F-I, L, O-P, scale bars 200 μm; C, E, J-K, scale bars 500 μm; M-N, scale bars 100 μm; R, scale bar 50 μm.

eote spicules may be very characteristic and even allow a rather precise attribution. The acanthoxea illustrated in the Fig. 7: M is identical to those occurring in sponges of Recent genus *Acanthotetilla* Burton, 1959 (see fig. 1 and pl. 2c-d in Van Soest 1977 and Van Soest & Rützler 2002).

The paleoenvironment of the Mem Moniz marls

The almost complete absence of macrofossils, namely of benthic organisms, quite common in almost all other Southern Portuguese Miocene shallow marine facies, together with the absence of bioturbation may be

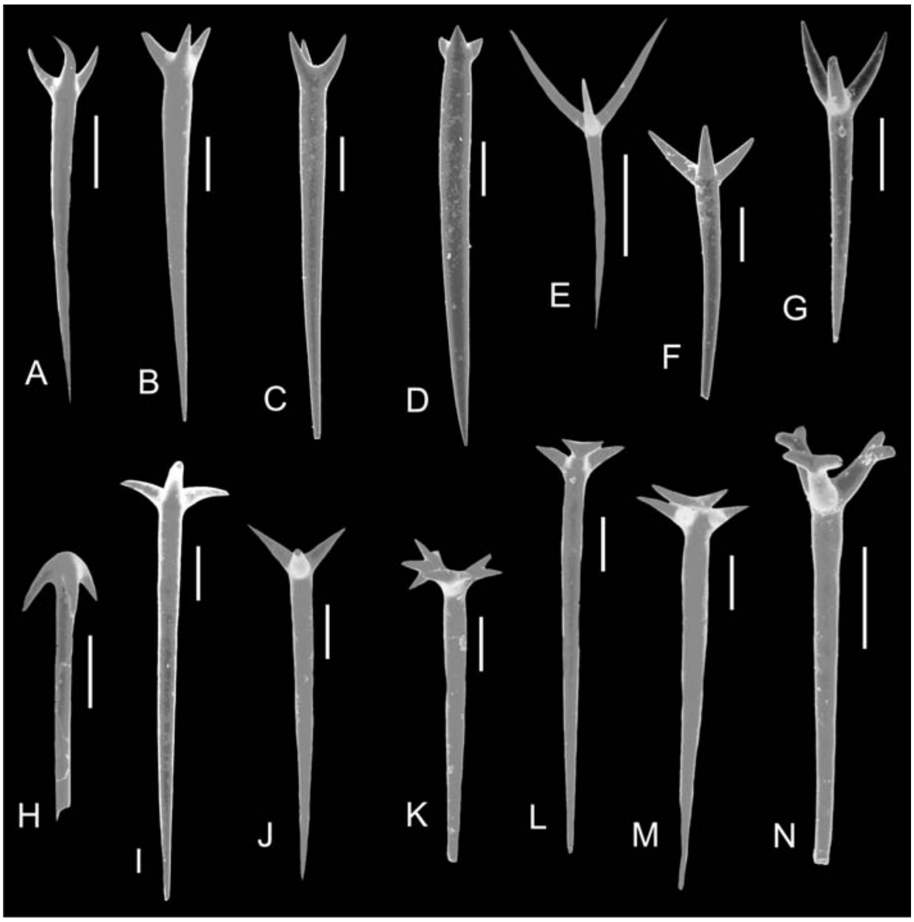

Fig. 8 - Various "soft" demosponge triaenes (Astrophorida); A-D, J, plagiotriaenes (probably Ancorinida); E-F, protriaenes; H, anatriaen; I, orthotriaene; K-M, plagiodichotriaenes. A-G, I- N, scale bars 200 µm; H, scale bars 100 µm.

interpreted as reflecting anoxic or suboxic bottom conditions. This interpretation is sustained by the occurrence of benthic Foraminifera of the families Buliminidae, Bolivinidae and Uvigerinidae (Antunes et al. 1990). These taxa are typical of environments rich in organic matter that accumulated in more or less restricted bottom conditions, thus generating oxygen poor bottom environment conditions and their presence in these deposits suggest that similar conditions prevailed in the Mem Moniz palaeoenvironment. The high ratio of benthic versus planktic Foraminifera, and the dominance of the coastal genera *Nonion, Ammonia* and *Cibicides* (Romariz et al. 1979) suggest a shallow marine environment for this sector of the Algarve platform during Middle Miocene times.

The siliceous flora is dominated by *Chaetoceros* RS, *Paralia sulcata* and *Thalassionema nitzschioides*, meroplanktonic and planktic species commonly occurring in coastal upwelling areas. The calcareous nannoplankton assemblage is dominated by Noelaerhabdaceae (mainly Reticulofenestrids) followed by Coccolithaceae (mainly *Coccolithus pelagicus* s.l.) and Helicosphaeraceae. The presence of these groups, together with the absence of asteroliths, are indicative of shallow marine productive environmental conditions (Cachão 1995).

It seems that many sponge spicules found in the investigated rocks came from animals living outside the area of their final deposition. The studied assemblage shows evidences of some sorting (lack of larger spicules which occur in the same sponges as here recognized), suggesting that at least some spicules were washed in from the surrounding environments. This interpretation is also supported by the fact that lithistid sponges usually colonize hard substrata, which are lacking in the Mem Moniz marls outcrop. The presence of *Samus* sp., sponges, which bore into hard carbonate substrata, equally supports this interpretation. The soft demosponge spicules atributable to *Alectona* (a boring sponge), again, tell a similar story: no calcareous hard substrate which could be bored was found in this outcrop. Moreover, lithistid sponges, due to their articulated choanosomal skeleton, have a relatively high preservation potential. Therefore, if such sponges inhabited the Mem Moniz marls area during its deposition (which clearly occurred under low hydrodynamic conditions), then we should find at least some body fragments of these sponges, not only isolated spicules.

Taking into account the excellent preservation shown by all the examined material, the spicules, most probably, were subjected to a transport over a short distance. At least part of the spicules were washed in from surrounding environments which had the hard

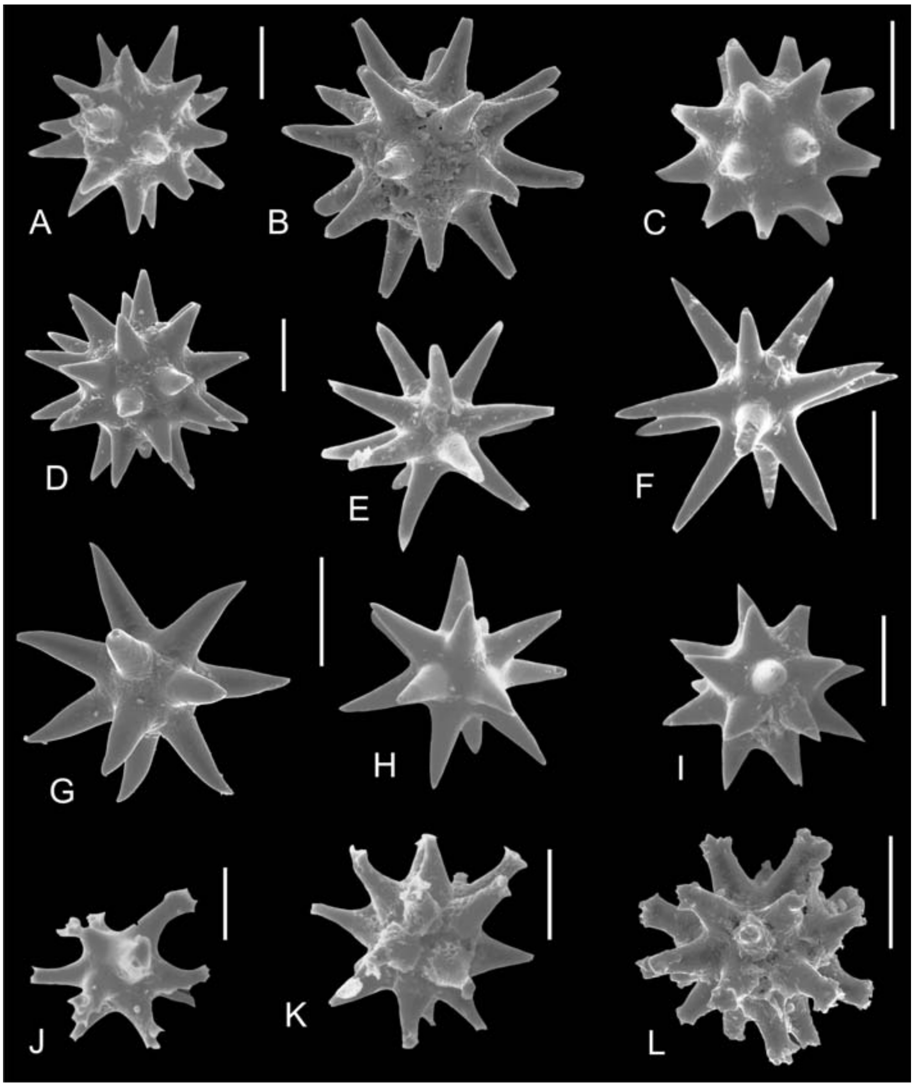

Fig. 9 - Demosponge asters. A-D, I. Spherasters; E-H. Oxyasters (E-F may belong to Ancorinidae); J-L. Anthasters; A-E, I-L, scale bars 50 µm; F-H, scale bars 100 µm.

carbonate substrate (shells of molluscs, for example) necessary for some of the identified sponges. This idea is supported by the common presence of sponge borings in the molluscan bioclasts in other correlative Miocene units that surround the Mem Moniz marls.

The bathymetric situation of the Mem Moniz marls palaeoenvironment is difficult to estimate based solely on sponge spicules, because most of the identified sponges show very wide bathymetric ranges (see above). However, due to the presence of of lithistid and (although rare) of hexactinellid sponges we can be sure that it was not an infralittoral assemblage. Hexactinellid sponges are characteristic of depths of at least several tens of meters. Furthermore, lithistid sponges, if we exclude the special case of submarine caves and/or fjords, are typical of depths of at least several tens, if not hundreds of meters or more. This bathymetric interpretation is also supported by the astrophorid dominance which in Recent oceans characterize deeper water environments (Maldonado 1992; Maldonado & Young 1996). Taking into consideration all the available data a depth below the storm wave base can be envisaged for the palaeoenviroment of deposition of the Mem Moniz marls.

Conclusions

The Middle Serravalian Mem Moniz marls (Algarve, Portugal) contain a rich and diversified siliceous sponge spicules assemblage, indicating the existence of a diverse sponge fauna, mainly of demosponges, that were dominated by astrophorids and including lithistids. Hexactinellids are relatively rare and represented by Lyssacinosa.

Among the sponges identified, the most common are geodiids, including *Eurylus* sp. and probably *Geodia* sp. (Astrophorida). *Samus* sp. (Spirophorida) and *Alectona wallichii* (Hadromerida) were also identified, both until now unknown in the fossil record. Less certain is the identification of *A. milliari.* Among the lithistids, the theonellids and rhizomorinids were present. Other demosponges are represented by ancorinids (Astrophorida) and, hadromerids (among them probably

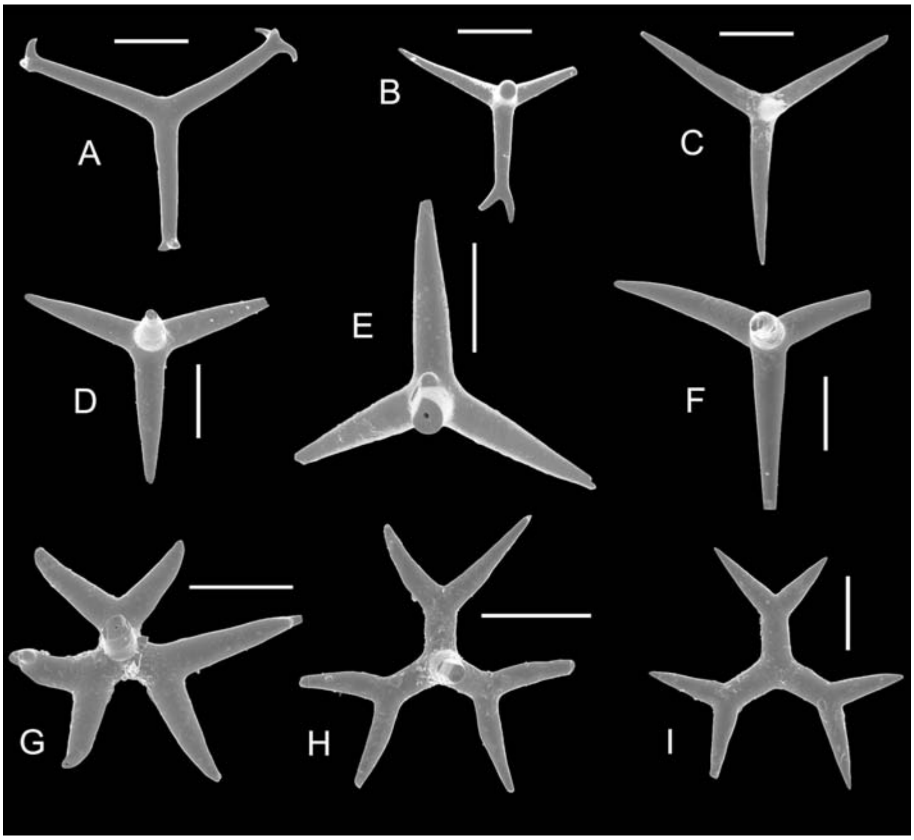

Fig. 10 - Various demosponge triaenes. A-F. Choanosomal calthrops, probably Pachastrellidae and/or Calthropellidae (Astrophorida). G-I. Ectosomal dichotriaenes (H-I may belong to Ancorinidae). All scale bars 200 µm.

Tethyidae), as well as pachastrellids (and/or calthropellids) (Astrophorida). The sponge assemblage of the type occurring in the Mem Moniz marls is characteristic neither of very shallow nor very deep environment and most indicates a depth of below the storm wave base (probably 100 meters or more).

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