

A review and classification of fossil didemnid ascidian spicules

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ABSTRACT – This study discusses and classifies fossil didemnid ascidian spicules. Three new fossil genera and nine new fossil species are described based on spicule morphology. The genera are *Bonetia* gen. nov., *Rigaudia* gen. nov. and *Monniotia* gen. nov. The species are *Bonetia acuta* sp. nov., *B. brevis* sp. nov., *B. quasitruncata* sp. nov., *B. truncata* sp. nov., *Rigaudia multiradiata* sp. nov., *R. praecisa* sp. nov., *Micrascidites pauciradiatus* sp. nov., *Monniotia acuformis* sp. nov., and *M. fasciculata* sp. nov. Recognizing these distinctive fossil didemnid spicules in fine-grained sediments should provide useful palaeoenvironmental information and may stimulate interest in their biostratigraphy. *J. Micropalaeontol.* 15(2): 135–149, October, 1996.

INTRODUCTION

Ascidians, often called sea squirts, are sessile, filter feeding tunicates (subphylum Urochordata) which are important members of marine benthonic communities throughout shelf seas. Living ascidians have attracted a widespread interest from biologists because of their evolutionary position as close relatives of the vertebrate (Plough, 1978).

Although most ascidians are soft-bodied, some species secrete distinctive aragonitic spicules. Didemnid spicules are often found in slides prepared for calcareous nannofossil examination. These stellate or spherical-shaped spicules range in size between 10 and 70 μm and, more rarely up to 125 μm . Although living didemnid ascidians are well known from the continental shelves throughout the world, fossil didemnid spicules are very rarely reported by palaeontologists and, therefore, at present are of little use as palaeoenvironmental or biostratigraphic markers.

This study summarizes the present knowledge of ascidians in relation to didemnid ascidians and fossil ascidian spicules. All type material has been deposited in the Department of Palaeontology, Natural History Museum.

SCOPE OF STUDY

This study is based on observations by the authors during investigations of nannofossil assemblages from worldwide localities, ranging from Asia, the Middle East, North Africa, Europe and the Gulf of Mexico, over a period of fifteen years. Additionally, the published records of ascidian spicule distribution have been compiled.

BIOLOGY AND ECOLOGY OF ASCIDIANS

Forms belonging to the subphylum Tunicata have a body (zooid) covered by a complex tunic (from which the name tunicate is derived) containing a substance chemically almost identical with cellulose. The tunicates consist of three classes: the sessile Ascidiacea and the free-floating Thalaliacea and Larvacea. Over 1300 species of Tunicata have been described; the great majority of which belong to the Ascidiacea (Barnes, 1980).

The class Ascidiacea, also known as sea-squirts, are sessile, mostly colonial tunicates and are common marine invertebrates worldwide. The sack-like zooids range in size from 1 to 10 cm. Most (c. 95%) ascidians form colonies in the shallow water of the continental shelf where they are attached to rocks and shells; or they are occasionally fixed in mud and sand by filaments or stalks. Colonial organization varies within the class, but although the colony itself may grow to a considerable size, usually the individuals forming it are very small (see Plough, 1978, plate VII).

Ascidians are filter feeders and extract plankton from water which passes through the pharynx. The water currents are drawn in through branchial slits by ciliary action. Some deep-sea ascidians obtain their food from the surrounding sediments. Other deep-sea ascidians feed on minute animals (nematodes and epibenthic crustaceans) which are caught with lobes situated around the buccal siphon. Ascidians are hermaphroditic, each individual having male and female gonads. When the eggs are externally fertilized they hatch into free-swimming larvae similar in appearance to tadpoles. However, as the larvae mature, they usually attach themselves to some suitable object and lose their tail.

DIDEMNID ASCIDIANS

All didemnid ascidians are sessile and colonial, they are common and have a global distribution ranging from the Arctic to the Antarctic (Plough, 1978). Most are found in shallow water (0–50 m) attached to rocks, shells and other hard surfaces. They are rarely found in deep water, exceptions include *Leptoclinides faroensis* (1500 m) and *Didemnum albiu polare* (1430 m). Didemnid ascidians are depth-sensitive and different species occupy well-defined areas on the sea bottom, conditioned by ocean currents and water temperatures. Ascidians are usually very vulnerable to prolonged freshwater influences. Heavy cyclonic rainfall regularly kills large colonies of ascidians close to the Australian coastline (P. Mather, pers. comm. in Heckel, 1973). Dead ascidian bodies may float on the surface of the sea, where wind, tides and current drift may play a part in their distribution.

DIDEMNID ASCIDIAN SPICULES

Ascidians are soft-bodied animals and, with the exception of spicules in didemnid and polycitorid ascidians, they are rarely found as fossils. Monniot (1970) described *Cystodytes* (Polycitorida) from Pliocene deposits of Brittany, France. Didemnid ascidians secrete fibrous spicules which, according to Matthews (1966), are composed of aragonite with high levels of strontium (6.5%). In this study, several specimens recovered in sediments from the Red Sea (DSDP Leg 23, Site 229A) were analysed using energy dispersive X-rays (EDAX) to identify the strontium level. However, only traces of strontium (<1%) were observed in the spicules.

The origin of the spicules remains unknown. Loewig & Koelliker (1846), Hardman (1886), Woodland (1907) and Prenant (1925) suggested that the spicules were developed independently of the zooid, whereas Michelsen (1919), Pérès (1947) and Van Name (1952) indicated that the spicules were products of the zooid and originated in the lateral organs. In living ascidians, the spicules are surrounded by a double-layered membrane (Lafargue & Kniprath, 1978). Spicule formation is therefore not simply the result of physico-chemical processes.

Spicule characteristics have not been used by biologists for generic level taxonomy of living ascidians. Classification is based instead on a range of soft body elements (see Elredge, 1966). However, at specific level, spicules and their characteristics have been used by many authors as the primary diagnostic feature, in conjunction with characteristics of the zooids.

Presence or absence of spicules, their diameter, ray count, arrangement, distribution and density of rays are usually considered as primary diagnostic criteria, in conjunction with the characteristics of the zooid. However, Berrill (1950) and Elredge (1966) treated these criteria as of secondary importance or disregarded them as given species can be spicular or aspicular depending on environmental controls.

Variations in spicule presence in ascidians could, however, be the result of confusing more than one species whose definitions are only based on the characteristics of the zooid. In a given colony, spicules are usually identical. Van Name (1945) states in a discussion on *Didemnum canidum* that 'I am far from being able to overcome the fear that I am confusing more than one species, but after the examination of a large amount material from various American localities I am at a loss to find a reliable basis for dividing it by studying museum specimens'.

Spicule distribution and density of cover may vary widely not only within a given species, but also occasionally within the same colony. Van Name (1952) suggested that variable distribution and density occurs when colonies undergo a certain amount of regression during unfavourable periods. At such times the spicule remains fixed within the tunic while the zooids degenerate and are added to when new zooids develop.

Waters rich in carbonate, particularly coral reef areas, are especially favourable for the development of didemnid colonies with large spicules with elongated and well-formed conical rays. The attachment of colonies to some rigid object

also favours spicule secretion, whereas attachment to a flexible object which allows even slight bending or movement of the test, frequently results in secretion of smaller types of spicules with shorter and less well-formed rays or points. Didemnid spicules secreted in polar and subpolar species are frequently only sparsely distributed in the surface layer of the test and are burr-like with poorly-developed spicule rays (Van Name, 1945; Kott, 1969). Fossil didemnid ascidian spicules of varying shape have been recorded in sediments of Jurassic to Quaternary age (Boekschoten, 1981). Living didemnid ascidians are classified primarily on the characteristics of the zooid; so it is difficult to assign individual spicules to living species. Until now, therefore, Tertiary didemnid spicules which are spherical in shape have been placed in *Micrascidites* and those which are disc-shaped are assigned to *Neanthozoitites* (produced by Polycitoridae).

If a direct relationship can be established between fossil spicules and living species, the information obtained from living forms may be applied to fossil spicules, assuming they have not changed their habitat with time, and provide useful palaeoenvironmental information.

The occurrence of recent didemnid-spicule-rich sediments seems to be restricted to tropical and subtropical carbonate-rich sediments. Heckel (1973) found high concentrations of didemnid spicules (>10% of the nannoplankton fractions) occurred around the main carbonate reef areas of the Great Barrier Reef. Heckel concluded that the spatial distribution of the spicules in the sediments was controlled by selective preservation of the aragonitic spicule rays. Freshwater discharge into the basin severely reduced the preservation potential of the spicules in the sediments.

When studying fossil occurrences of didemnid spicules, special attention must be taken to distinguish *in situ* occurrences. The durability of didemnid spicules to the processes of erosion, transport and deposition in warm waters is shown by their occurrence in turbidite deposits adjacent to carbonate-rich shelf environments (Beall & Fischer, 1963; Wei, 1993). Didemnid spicules also survive digestion and have been reported in fish guts (Rac, 1967) confirming fish predation and indicating another method of dispersal of the spicules from their sessile habitat into soft sediments.

Spicules are composed of aragonite and thus are highly susceptible to dissolution. Stieglitz (1972) recorded strongly etched didemnid spicules from Recent sediments from the Bimini Lagoon, Bahamas. Aragonite dissolution in freshwater phreatic environments in tropical areas has also been well documented (Land, 1970). The recovery of spicules in sediments therefore suggests high sedimentation rates and/or rapid sealing of sediments soon after deposition (Houghton & Jenkins, 1988).

The susceptibility of ascidian spicules to dissolution and diagenesis may restrict their value as biostratigraphic indicators. However, although ascidians are mainly benthic, they also have a free-swimming (tadpole) larval phase. This initial pelagic life cycle, coupled with a reported cosmopolitan distribution of many species (Knott, 1969;

Plough, 1970) may yet indicate that ascidian spicules have potential interbasin correlation in well-preserved sections.

Hypersaline lagoonal and shallow water carbonate platform sequences should provide fruitful starting materials. Ascidian spicules are reported to be particularly common in faecal pellets and other carbonate mud aggregates of the Great Bahamas Bank (Purdy, 1963). Significantly, as diagenesis proceeded, only ascidian spicules were found to remain as the non-recrystallized constituents within the pellets. Didemnid spicules also occur in carbonate muds deposited in lagoons and carbonate shoals from Belize (Matthews, 1966) and in the Bimini Lagoon, Bahamas (Stieglitz, 1972).

The stratigraphical and geographical distribution of ascidian spicules for the Mesozoic and Tertiary-Quaternary are given in Tables 1 to 2. The biostratigraphical potential of didemnid spicules has still to be explored, and full stratigraphic ranges of the species are yet to be established. However, a few are already known to be moderately good

zonal markers. For example, *Kokia*, a possible ascidian spicule, has so far been documented from Valanginian to Berriasian sediments of the North Sea area. However, van Niel (1994) suggests that *Kokia* specimens show a construction similar to calcareous pentolith genera in the Braarudosphaeraceae; but because of their high number of rays, *Kokia* should still be considered 'incertae sedis'. *Didemnum minutum* seems to be restricted to the Middle and Upper Jurassic and has a wide geographical distribution. High frequency variations of spicule abundance could also be used for local biostratigraphic correlation (cf. Heckel, 1973).

Wei (1993) studied tunicate spicule abundances in sediments from the Great Barrier Reef and Queensland Plateau (ODP Leg 133 sites) and concluded that tunicate spicules do not appear to be promising biostratigraphic markers for the Pliocene-Pleistocene. However, listed below are the tentative ranges of the genera described here:
 (a) *Monniotia* recorded range Pleistocene
 (b) *Rigaudia* recorded range Pliocene-Pleistocene

AGE	AUTHORS	AREA
<i>Micrascidites vulgaris</i>		
Quaternary - Pliocene	Durand, 1948 & 1955	France
	Chauvel, 1952	France
	Durand & Pelhate, 1961	France
	Bonet & Beneviste-Velasquez, 1971	Mexico
	Cita, 1973	Mediterranean
	Houghton & Jenkins, 1988	Celtic Sea
	Wei, 1993	Great Barrier Reef
Miocene	Deflandre & Deflandre-Rigaud, 1956	Australia
	Deflandre-Rigaud, 1968	Australia
	Monniot & Buge, 1971	France
	Heckel, 1973	Australia
	Varol, 1985	Turkey
Eocene	Deflandre-Rigaud, 1949; 1956 & 1968	France
	Durand, 1952	France
	Deflandre & Deflandre-Rigaud, 1956	France
	Bouche, 1962	France
	Lezaud, 1966	France
<i>Rigaudia</i>		
Pleistocene	Edwards, 1973 (described as <i>Micrascidites vulgaris</i>)	Coral Sea
	Wei, 1993 (described as Tunicate spicules)	Great Barrier Reef
<i>Bonetia</i>		
Pleistocene - Pliocene	Wei, 1993 (described as Tunicate spicules)	Great Barrier Reef
<i>Monniotia</i>		
Pleistocene - Pliocene	Wei, 1993 (described as Tunicate spicules)	Great Barrier Reef

Table 1. Stratigraphical and geographical distribution of Tertiary and Quaternary ascidian spicules.

SPECIES	AGE	AREA	AUTHORS
<i>Ascidites dubius</i>	Sinemurian - Tithonian	Mexico	Bonet & Benveniste-Velasquez, 1971
<i>Micrascidites irregularis</i>	Toarcian	Mexico	Buge & Monniot, 1972
<i>Cystodites</i> sp.	Toarcian	France	Buge & Monniot, 1972
<i>Didemnum minutum</i>	Callovian	Mexico Britain	Bonet & Benveniste-Velasquez, 1971 Varol & Girgis, 1994
<i>Didemnooides rosetta</i>	Kimmeridgian - Hauterivian	Mexico	Bonet & Benveniste-Velasquez, 1971
<i>Didemnum shetlandensis</i>	Valanginian	North Sea	Perch-Nielsen, 1988 Varol & Girgis, 1994
<i>Didemnum cascianum</i>	Carnian	Germany	Jafar, 1983
	Rhaetian	Irian Jaya	Varol & Girgis, 1994
	Carnian - Rhaetian	Indian Ocean	Bralower <i>et al.</i> , 1991
<i>Didemnum pseudotrifidum</i>	Rhaetian	Germany Irian Jaya	Jafar, 1983 Varol & Girgis, 1994
<i>Rucinolithus? magnus</i>	Campanian	Atlantic	Cita & Gartner, 1971
	Campanian	NW Pacific	Bukry, 1975
	Campanian	Turkey	Varol, 1983
	Campanian - Eocene	Pacific	Bergen, 1985
Tentative ascidian spicules			
<i>Kokia borealis</i>	Berriasian	North Sea	Perch-Nielsen, 1988
	Valanginian		Kok, 1985
	Valanginian-upper Ryazanian upper Ryazanian		Varol & Girgis, 1994 van Niel, 1994
<i>Kokia curvata</i>	Valanginian	North Sea	Perch-Nielsen, 1988
<i>Kokia</i> sp.A	upper Ryazanian	North Sea	van Niel, 1994
<i>Kokia</i> sp.1	Hauterivian	North Sea	Perch-Nielsen, 1988

Table 2. Stratigraphic and geographical distribution of Mesozoic ascidian spicules and other possibly related spicules.

- (c) *Bonetia* recorded range Middle Miocene–Pleistocene
 (d) *Micrascidites* recorded range Lower Eocene–Pleistocene.

MORPHOLOGY OF SPICULES

The arrangement and shape of the rays in spicules can be utilized as diagnostic features for the identification of genera. The ratio of the length of the free part of the ray to that of the joined part, together with the number and density of rays, are used for the determination of the species. The stellate spicules are assigned to the genus *Micrascidites* and the spherical spicules assigned to the new genera *Bonetia*, *Rigaudia* and *Monniotia*.

Spicule rays are defined as the parts in which a spicule is naturally separated or divided. Each ray therefore has two parts: the joined part (where each ray joins to the next) and the free part. The joined inner parts of the rays are always conical with their apices towards the centre, whereas the free parts of the rays may be conical, truncated conical or cylindrical.

In this study, four major types of ray were identified and this led to the recognition of three new genera (Fig. 1).

- Micrascidites*-type rays are biconical or rhomboid in axial section, without an inflection between the free and joined parts of the rays.
- Bonetia*-type rays are biconical, but with a distinct inflection between the joined and free parts. The rays are

widest in diameter along the jointed part of the rays. The free part is always narrower and is conical or truncated conical.

- Rigaudia*-type rays resemble a sharpened pencil. Their free lengths are cylindrical, with parallel sides to the ray and a truncated peripheral end.
- Monniotia*-type rays are unequal in length, composite and are constructed of needle-like elements forming bundle-like structures with or without a free part.

Two major types of spicule construction have been recognized in this study: (a) stellate spicules; (b) spherical spicules.

Stellate spicules are composite spicules constructed of several layers of petaloid units which may be flat or concavo-convex. In these petaloid layers each spicule ray radiates from the centre of the unit. Adjacent petaloid cycles are then joined in a saddle-like manner to form a complete spicule (Fig. 2). The number of rays is reduced towards the outermost cycle. Stellate spicules are found in *Micrascidites*.

Spherical spicules are constructed from rays which radiate from the centre of the spicule and are found in *Bonetia*, *Rigaudia* and *Monniotia*. All the rays in the spicules are approximately the same length.

An advantage of using spicule morphology as a system of classification is that individual species may be identified even if only isolated rays are preserved rather than complete spicules.

Fossil didemnid ascidian spicules

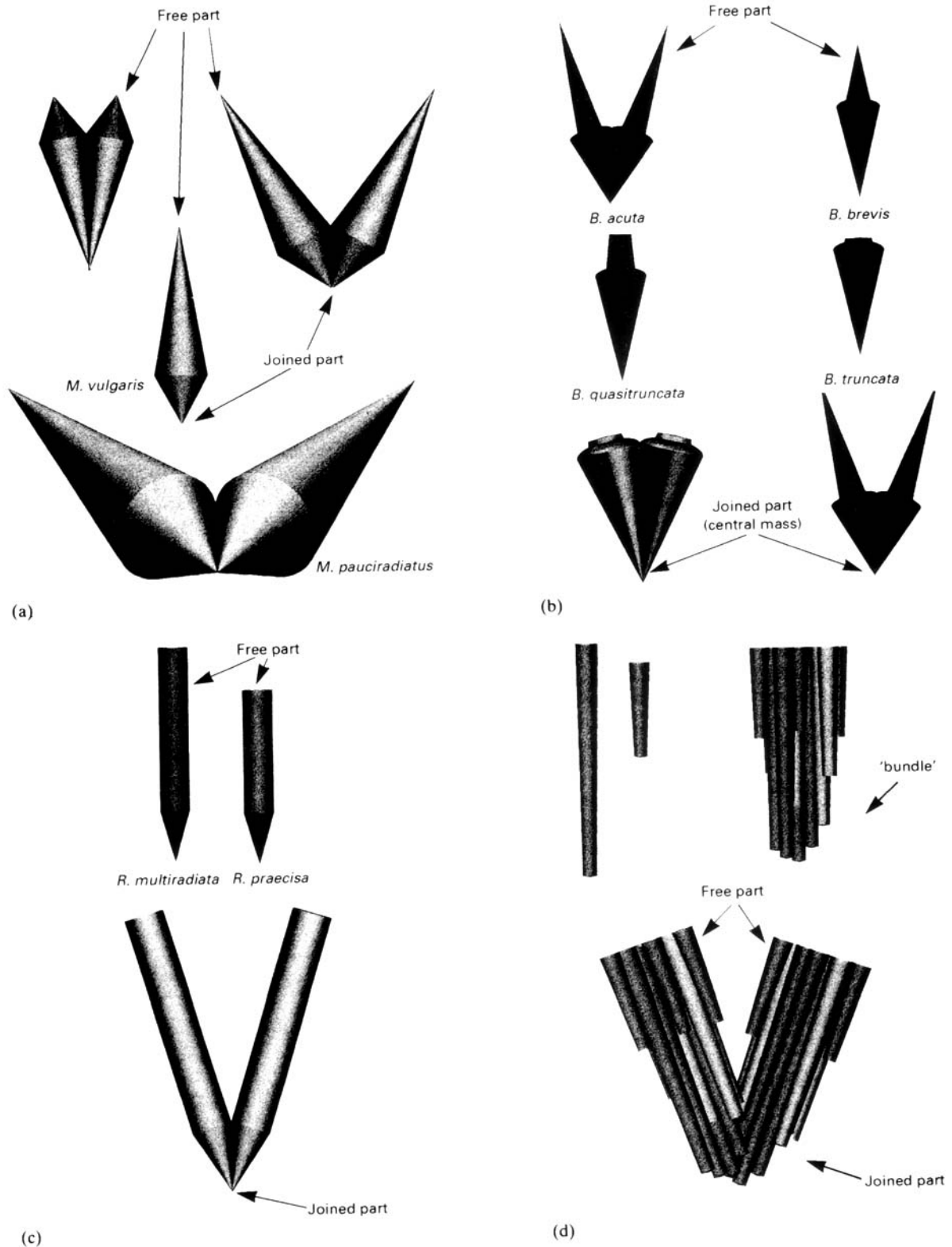


Fig. 1. *Micrascidites*-type, *Bonettia*-type, *Rigaudia*-type and *Monniotia*-type spicule rays.

CONCLUSIONS

Didemnid ascidian spicules should have been more widely reported in the fossil record, but have probably been

overlooked by many palaeontologists because of their small size, their tendency to break up in to individual spicule rays, and possible confusion as to their organic origin. Future

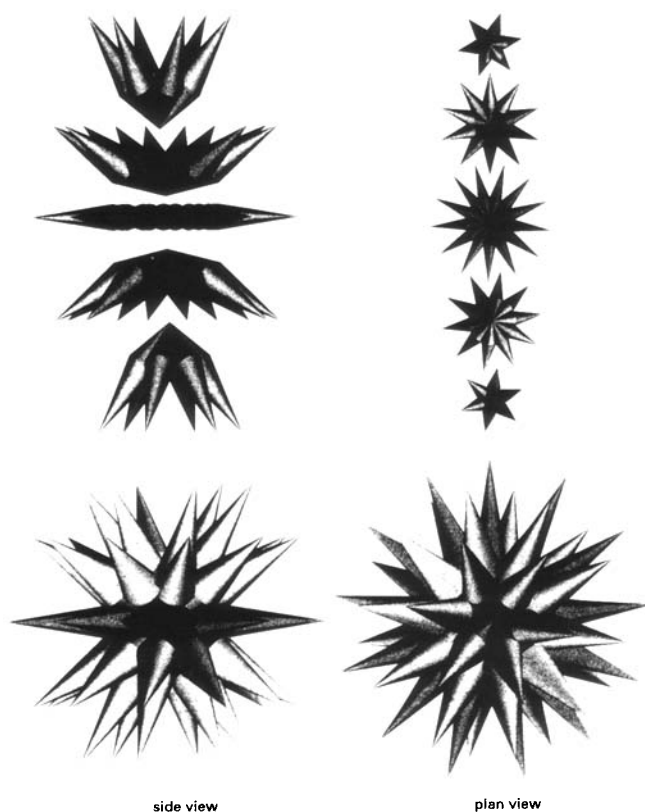


Fig. 2. Structural units of *Micrascidites*.

studies on didemnic spicules should concentrate on mapping their areal distribution in sediments and also provide detailed morphological descriptions. Such studies should be particularly useful in palaeoenvironmental analysis of fine-grained sediments and also should determine their value as biostratigraphical markers.

The aragonitic spicules of didemnid ascidians are more susceptible to solution than the calcitic remains of coccoliths and foraminifera. The didemnid spicules, like aragonitic pteropods, are therefore likely to be better preserved in basins having high bottom water temperatures, sluggish circulation, and rapid sedimentation rates such as the Mediterranean Sea, Red Sea and the Persian Gulf.

SYSTEMATIC DESCRIPTIONS

Subphyllum **Tonicata** Lamarck, 1816

Class **Asciacea** Blainville, 1825

Order **Enterogona** Perrier, 1898

Suborder **Aplousobranchia** Lahille, 1886

Family **Didemnidae** Milne Edwards, 1891

Genus **Bonetia** Varol & Houghton, gen. nov.

Type species. *Bonetia brevis* sp. nov.

Derivation of name. In honour of Dr. F. Bonet, Mexico.

Diagnosis. Spherical spicules with conical or truncated

conical rays which have a greater diameter in the joined part of the ray than the free part (*Bonetia*-type rays). These rays radiate from the centre of the spicule. Different species of this genus are distinguished by the number of rays, shape of the free part, and ratio of the length of the free part to that of the joined part of the rays.

Remarks. *Bonetia* differs from *Micrascidites* by having rays which are greater in diameter along the joined part of the ray, whilst the latter has rhomboidal rays. *Bonetia* is a spherical spicule, whereas *Micrascidites* is a stellate spicule. Other spherical spicules, *Rigaudia* and *Monniotia*, are distinguished from *Bonetia* by having rays with a cylindrical free length and needle-like bundle rays respectively.

Bonetia acuta sp. nov.

(Pl. 1, fig. 9; Pl. 2, figs 6, 9; Pl. 3, fig. 4; Pl. 4, fig. 14)

1993 Tunicate spicules Wei: pl. 1, figs 1–2.

Derivation of name. From latin *acutus* (= sharpened).

Diagnosis. Species of *Bonetia* with spicules containing 20–30 rays in which the free part is conical with a length greater than that of the joined part.

Holotype. Pl. 2, fig. 9. (NF514/Neg. 9).

Type level and locality. Late Pleistocene (Zone NN21), Red Sea (DSDP Leg 23, Site 229A, Core 2, Section 5, 40–45 cm).

Dimensions of holotype. Diameter of spicule = 29.0 μm length of free part of rays = 8.5 μm .

Remarks. *B. acuta* is distinguished from *B. brevis* by having fewer rays (20–30) and by the length of the free part of the rays always being greater than that of the joined part. *B. truncata* and *B. quasitruncata* have rays with truncated free parts.

Occurrence. Pliocene to Pleistocene of the Red Sea, Middle Miocene of southern Turkey, and middle Miocene to Pleistocene of Indonesia, India, West Africa and Egypt.

Bonetia brevis sp. nov.

(Pl. 2, fig. 8; Pl. 3, fig. 5; Pl. 4, figs 11–12)

Derivation of name. From Latin *brevis* (= short).

Diagnosis. Species of *Bonetia* with 40–60 rays per spicule which have the conical free parts shorter than the joined part of each ray.

Holotype. Pl. 2, fig. 8 (NF514/Neg. 8).

Type level and locality. Late Pleistocene (Zone NN21), Red Sea (DSDP Leg 23, Site 229A Core 2, Section 5, 40–45 cm).

Dimensions of holotype. Diameter of spicule 21.0 μm ; length of free part of rays 3.0 μm .

Occurrence. Late Pleistocene sediments of the Red Sea and Middle Miocene sediments of southern Turkey.

Bonetia quasitruncata sp. nov.

(Pl. 2, fig. 5; Pl. 4, figs 9–10)

Derivation of name. From latin *quasi* (= almost).

Explanation of Plate 1

Note that all SEM micrographs are from the Late Pleistocene of the Red Sea (DSDP Leg 23, Site 229A), unless otherwise stated.

Figs 1–4. *Micrascidites vulgaris*: **fig. 1**, $\times 4200$; **Fig. 2**, $\times 4900$; **Fig. 3**, $\times 6300$; **Fig. 4**, $\times 9800$. **Figs 5–8.** *Rigaudia multiradiata* sp. nov. Holotype (Fig. 5): **Fig. 5**, $\times 4900$; **Fig. 6**, $\times 14\ 700$; **Fig. 7**, $\times 5600$; **Fig. 8**, $\times 12\ 600$. **Fig. 9.** *Bonetia acuta* sp. nov. $\times 7700$.

Fossil didemnid ascidian spicules

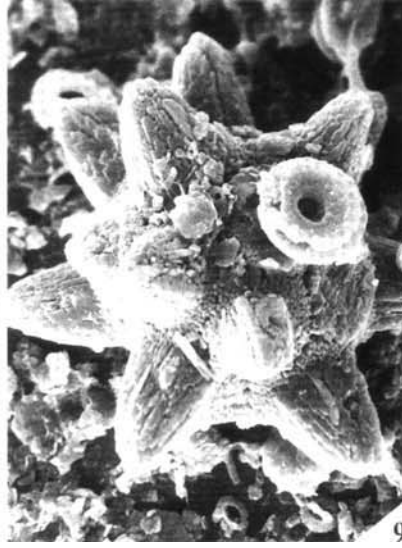
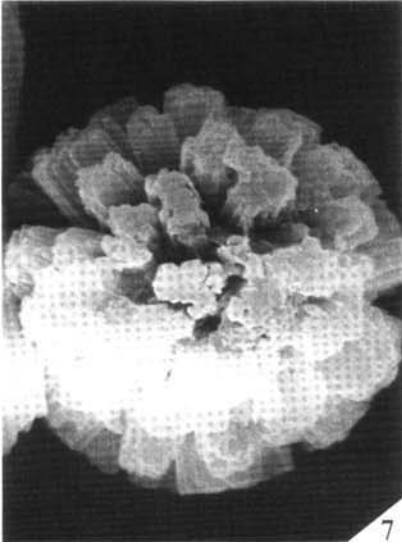
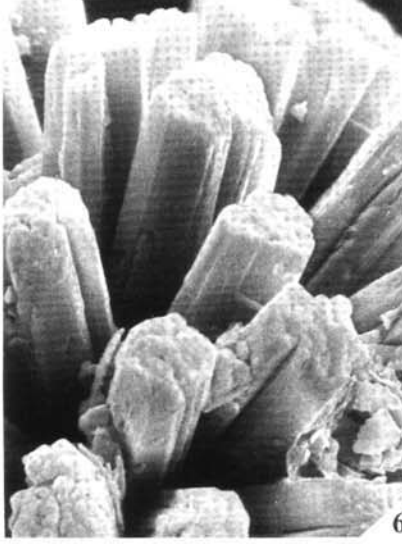
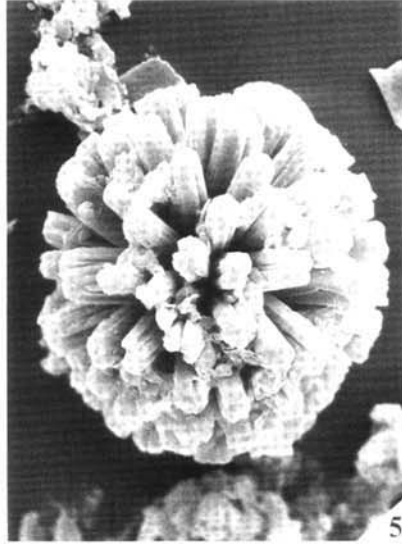
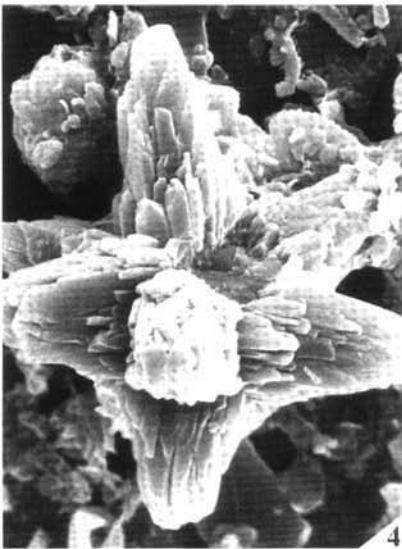
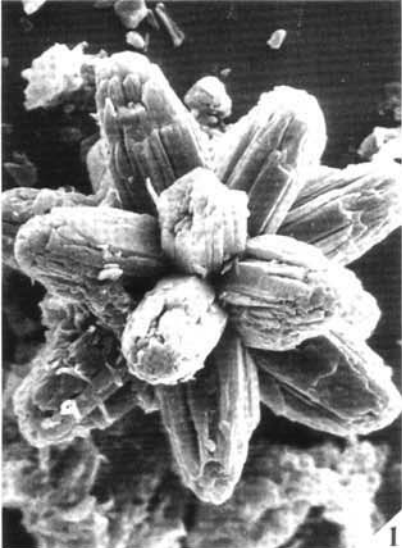


Plate 1

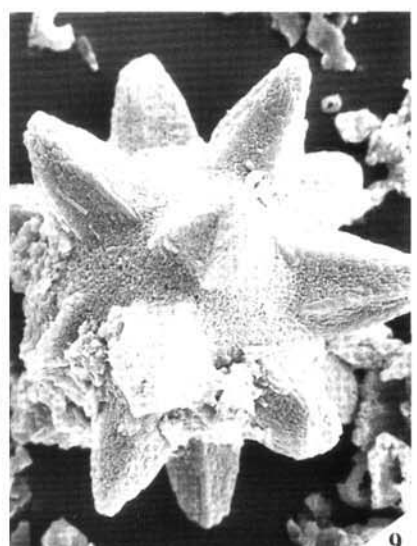
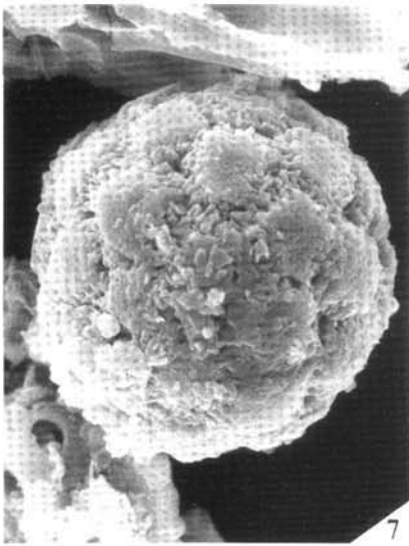
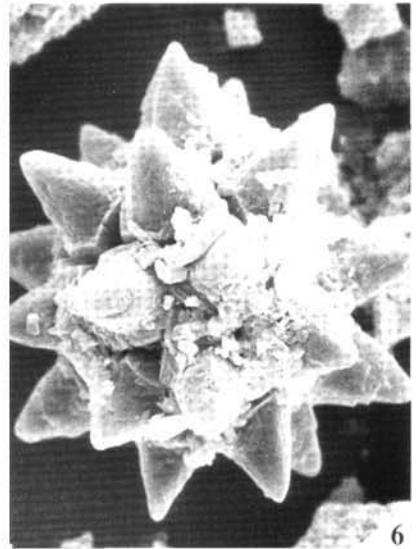
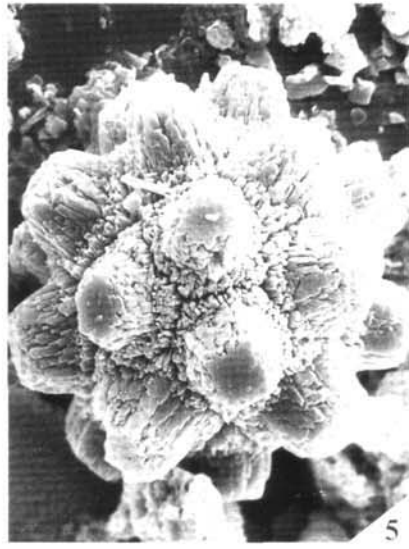
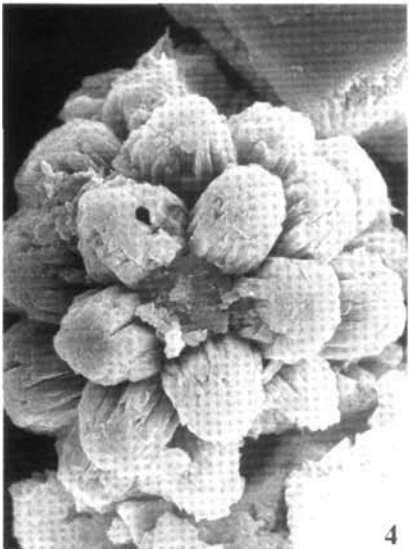
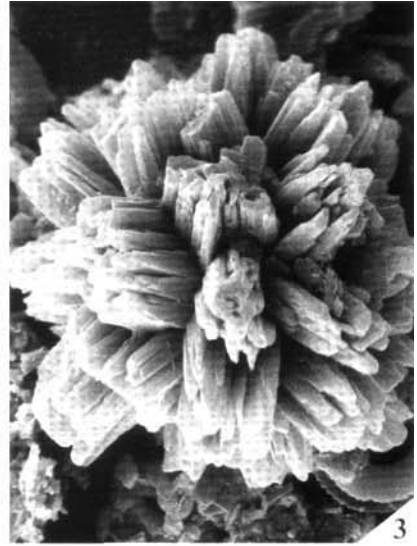


Plate 2

Diagnosis. Species of *Bonetia* with 20–30 rays per spicule in which the free part is a truncated cone in shape.

Holotype. Pl. 2, figs 5 (NF514/Neg. 6)

Type level and locality. Late Pleistocene (Zone NN21), Red Sea (DSDP Leg 23, Site 229A, Core 2, Section 5, 40–45 cm).

Dimensions of holotype. Diameter of spicule = 21.0 μm ; length of the free part of the rays 2.5 μm .

Remarks. *B. quasitruncata* differs from *B. truncata* by having rays with distinct truncated cone-shaped free parts, whereas the latter has a higher number of rays that are practically without a free part.

Occurrence. Pleistocene sediments of the Red Sea and the Gulf of Aden.

Bonetia truncata sp. nov.

(Pl. 2, fig. 7)

Derivation of name. Latin *truncatus* (= cut off), referring to the truncated free part of the rays.

Diagnosis. Species of *Bonetia* having spicules containing 35–50 rays without free parts.

Holotype. Pl. 2, fig. 7 (NF414/Neg. 5)

Type level and locality. Late Pleistocene (Zone NN21), Red Sea (DSDP Leg 23, Site 229A, Core 2, Section 5, 40–45 cm).

Dimensions of holotype. Diameter of spicule = 12.0 μm , maximum diameter of rays = 2.0 μm .

Remarks. *B. truncata* is distinguished from other species of *Bonetia* by having spicules with rays practically without a free part.

Occurrence. Pleistocene sediments of the Red Sea and Gulf of Aden.

Genus *Rigaudia* Varol & Houghton gen. nov.

Type species. *Rigaudia multiradiata* sp. nov.

Derivation of name. In honour of Dr M. Deflandre-Rigaud, Paris.

Diagnosis. Spherical spicule having numerous rays in which the free part is cylindrical with a truncated distal end. These rays radiate from the centre of the sphere. The rays are partly joined and the inter-ray areas are usually narrow. Species of this genus are distinguished the length, diameter, number and density of rays.

Rigaudia multiradiata sp. nov.

(Pl. 1, figs 5–8; Pl. 5, fig 1–4)

1973 *Micrascidites vulgaris* 1956 Edwards: 663, Pl. 2, figs 1, 3–4.

1993 Tunicate spicules Wei: Pl. 2, figs 12, 14–15.

Derivation of name. From latin *multus* (= many); *radius* (= ray), referring to the high number of rays.

Diagnosis. Species of *Rigaudia* with 70–90 thin cylindrical pencil-like rays which leave narrow inter-ray spaces.

Holotype. Pl. 1, fig. 5 (NF514/Negs. 1).

Type level and locality. Late Pleistocene (Zone NN21), Red Sea (DSDP Leg 23, Site 229A, Core 2, Section 5, depth 40–45 cm).

Dimensions of holotype. Diameter of spicule = 19.5 μm ; maximum diameter of rays = 1.7 μm .

Remarks. *R. multiradiata* differs from *R. praecisa* by having a greater number (70–90) of thinner and longer rays, than the latter which has 30–45 thicker and shorter rays.

Occurrence. Pleistocene sediments of the Red Sea and the Gulf of Aden. Also recorded by Edwards (1973) in Pleistocene sediments from Leg 21 of DSDP in the southwest Pacific.

Rigaudia praecisa sp. nov.

(Pl. 2, fig. 4; Pl. 4, figs 15–17)

Derivation of name. From latin *praecisa*, (= cut off), referring to the truncated peripheral ends of the rays.

Diagnosis. species of *Rigaudia* having 30–45 moderately thick and short pencil-like rays radiating from the centre of the sphere.

Holotype. Pl. 2, fig. 4 (NF514/Neg. 4).

Type level and locality. Late Pleistocene (Zone NN21), Red Sea (DSDP Leg 23, Site 22A, Core 2, Section 5, 40–45 cm).

Dimensions of holotype. Diameter of spicule = 14.5 μm ; maximum diameter of rays = 2.7 μm .

Occurrence. Pleistocene of the Red Sea, Gulf of Aden, Indonesia and Egypt.

Genus *Micrascidites* Deflandre & Deflandre-Rigaud, 1956
Type species. *Micrascidites vulgaris* Deflandre & Deflandre-Rigaud, 1956.

Remarks. Stellate spicules with rhomboidal or biconical rays.

Micrascidites pauciradiatus sp. nov.

(Pl. 3, fig. 2; Pl. 5, figs 11–12)

1993 Tunicate spicules Wei: pl. 2, figs 1–3, 8.

Derivation of name. From Latin *paucis* (= few in number), referring to the low number of rays.

Diagnosis. species of *Micrascidites* having three to five large rhomboidal rays in which the length of the free part is at least five times, and maximum diameter is at least two times, greater than the length of the jointed part.

Holotype. Pl. 5, fig. 11 (NF514/Neg. 11).

Type level and locality. Late Pleistocene (Zone NN21), Red Sea (DSDP Leg 23, Site 229A, Core 2, Section 5, depth 40–45 cm).

Dimensions of holotype. Diameter of spicule = 21.5 μm ; maximum length of rays = 11.0 μm , maximum width 5.0 μm , maximum length of joined part = 2.0 μm .

Explanation of Plate 2

Figs 1–3. *Monniotia fasciculata* sp. nov. Holotype (Fig. 3): **Fig. 1**, $\times 4200$; **Fig. 2**, $\times 16100$; **Fig. 3**, $\times 7700$. **Fig. 4.** *Rigaudia praecisa* sp. nov. Holotype; $\times 7700$. **Fig. 5.** *Bonetia quasitruncata* sp. nov. Holotype; $\times 4900$. **Figs 6, 9.** *Bonetia acuta* sp. nov. Holotype (Fig. 9): **Fig. 6**, $\times 4900$; **Fig. 9**, $\times 4200$. **Fig. 7.** *Bonetia truncata* sp. nov. Holotype; $\times 7700$. **Fig. 8.** *Bonetia brevis* sp. nov. Holotype; $\times 4900$.

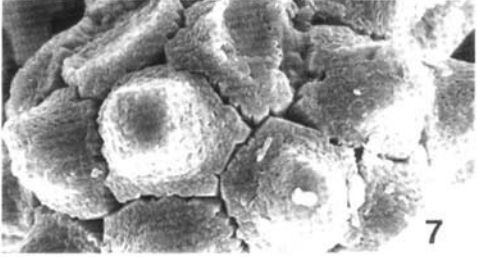
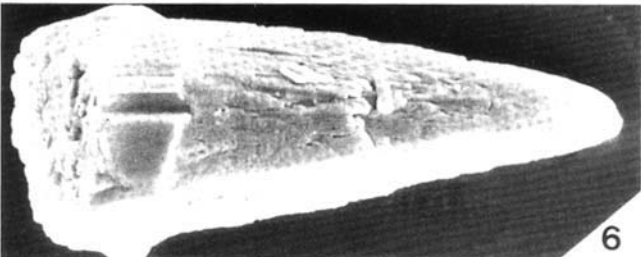
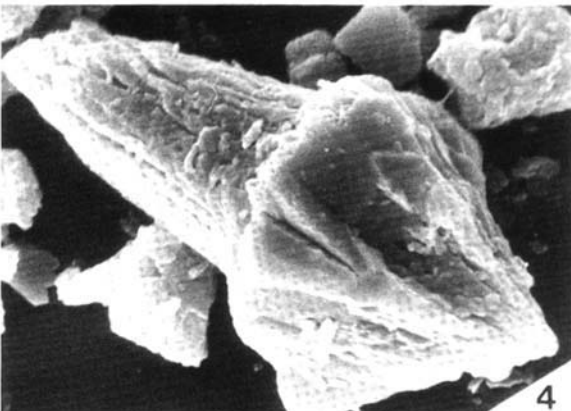
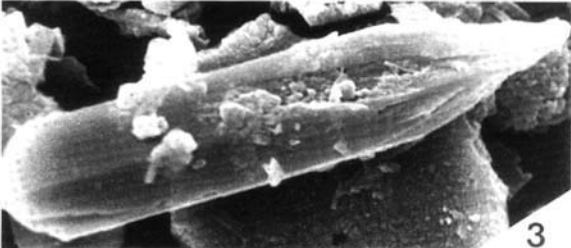
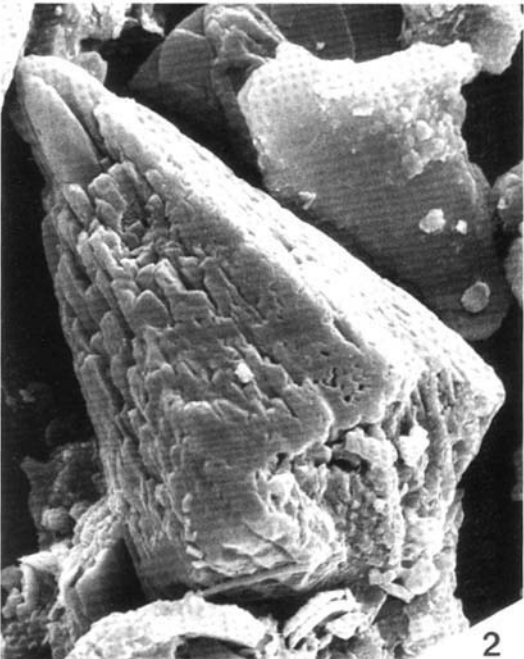
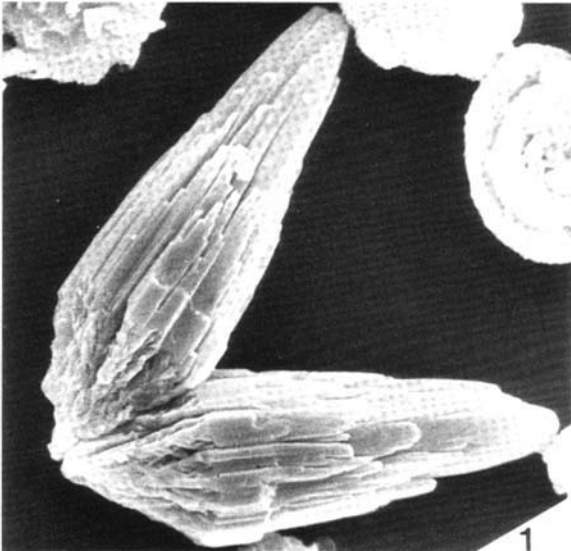


Plate 3

Remarks. *M. pauciradiatus* is distinguished from *M. vulgaris* by having fewer rays (3–5) and a greater ratio of length of free part to that of the jointed part of the ray. This ratio is more than 4:1 in *M. pauciradiatus* whereas it is less than 3:1 in *M. vulgaris*.

Occurrence. Middle Miocene sediments of southern Turkey and Indonesia, and Pliocene to Pleistocene sediments of the Red Sea, Gulf of Aden, Indonesia and Egypt.

Micrascidites vulgaris Deflandre & Deflandre-Rigaund, 1956
(Pl. 1, figs 1–4; Pl. 3, fig. 1; Pl. 5, figs 5–9)

Remarks. The number of rays varies between 8 and 30. The free parts of the rays are conical with bluntly pointed peripheral ends. Further subdivision of this species may be possible using number of rays and ratio of the length of the free part to that of the jointed part.

Occurrence. This species has been reported from Eocene to quaternary sediments (Table 2). In the present study it is also recorded from deposits of similar age worldwide.

Genus *Monniotia* Varol & Houghton gen. nov.

Type species. *Monniotia fasciculata* sp. nov.

Derivation of name. In honour of Dr F. Monniot, Paris.

Diagnosis. Spherical spicules having rays which are needle-like and unequal in length, only some of which extend to the centre of the sphere. The rays may or may not have a free part.

Remarks. *Monniotia* differs from other spherical spicules such as *Bonetia* and *Rigaudia* by having rays constructed of needle-like elements (*Monniotia*-type), which taper towards the centre of the spicule. The composite *Monniotia* spicule rays all radiate from the centre of the sphere. In contrast, the genera *Bonetia* and *Rigaudia* have conical or truncated conical rays and truncated cylindrical rays which all radiate from the centre of the sphere respectively.

Monniotia fasciculata sp. nov.
(Pl. 2, figs 1–3; Pl. 4, figs 1–4)

1993 Tunicate spicules Wei: Pl. 1, fig. 1.

Derivation of name. From Latin *fasciculatus*, (= joined in small bundles), referring to the construction of rays from needle-like elements.

Diagnosis. Species of *Monniotia* having spicules with rays which are arranged in bundles and which have no free parts.

Holotype. Pl. 2, fig. 3 (NF514/Neg. 3).

Type level and locality. Late Pleistocene (Zone NN21), Red Sea (DSDP Leg 23, Site 229A, Core 2, Section 5, depth 40–45 cm).

Description. Spherical spicules containing 20–40 bundle-like spicule rays. Each spicule ray is constructed of 10–20 needle-like elements which are unequal in length. Each ray consists of a free part and joined part. Only a few of

the spicule rays extend to the centre of the spherical spicule.

Dimensions of holotype. Diameter of spicule 15.0 μm ; maximum diameter of bundle = 3.5 μm ; maximum diameter of rays = 0.7 μm .

Remarks. *M. fasciculata* is distinguished from *M. aciformis* by having rays constructed from bundle-like elements and with a free part. *M. aciformis* lacks bundle-like structures and has a greater number of rays.

Monniotia aciformis sp. nov.
(Pl. 4, figs 5–7)

1993 Tunicate spicules Wei: pl. 2, fig. 13.

Derivation of name. From Latin *acus*, (= needle), and *forma* (= form) referring to the shape of the rays.

Diagnosis. Species of *Monniotia* having innumerable needle-like unequal rays without any free part. Only some of the longest rays extend to the centre of the sphere.

Holotype. Pl. 4, fig. 5 (NF514/Neg. 10).

Type and locality. Late Pleistocene (Zone NN21), Red Sea (DSDP Leg 23, Site 229A, Core 2, Section 5, depth 40–45 cm).

Dimensions of holotype. Diameter of spicule = 10.5 μm .

Remarks. *M. aciformis* is distinguished from *M. fasciculata* by having a greater number of rays and the absence of bundle-like elements. In addition, the rays in *M. aciformis* have no free part.

Occurrence. *M. aciformis* occurs in Pleistocene sediments of the Red Sea.

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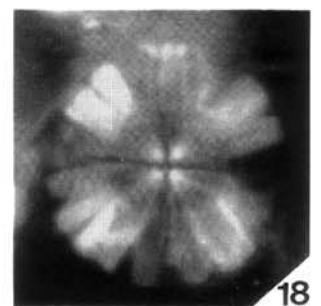
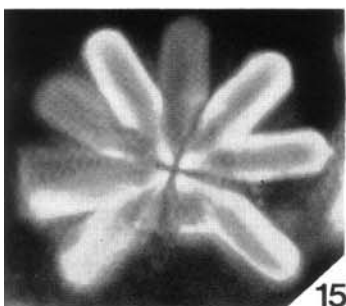
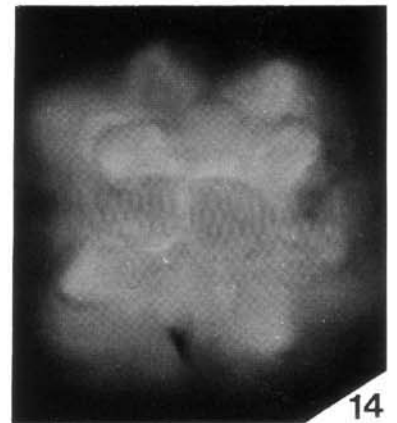
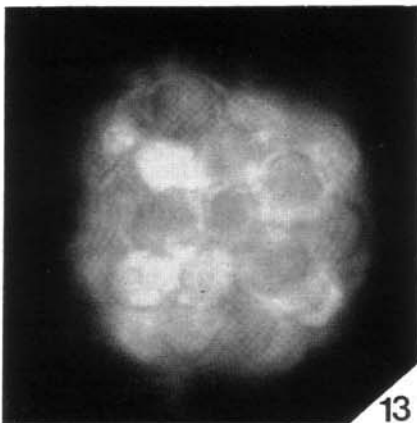
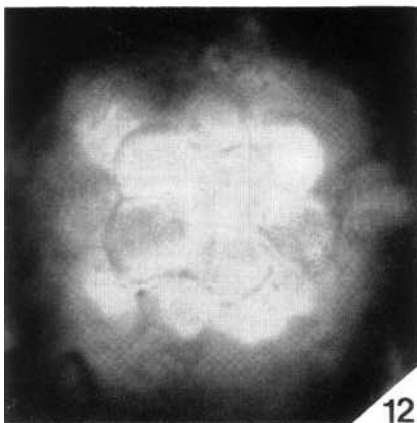
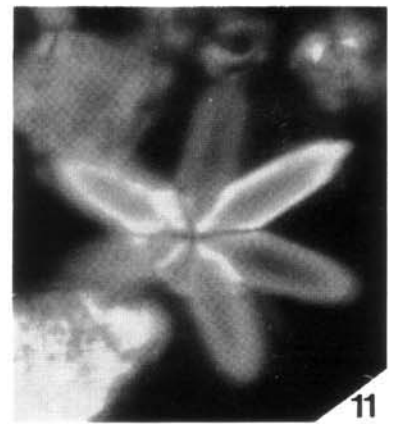
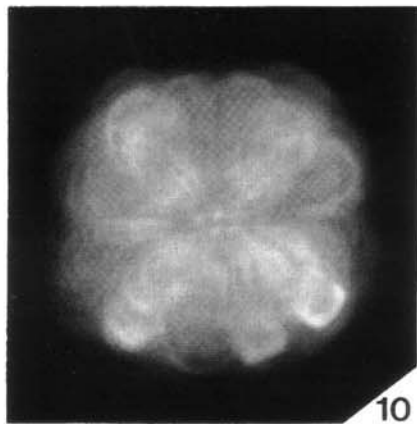
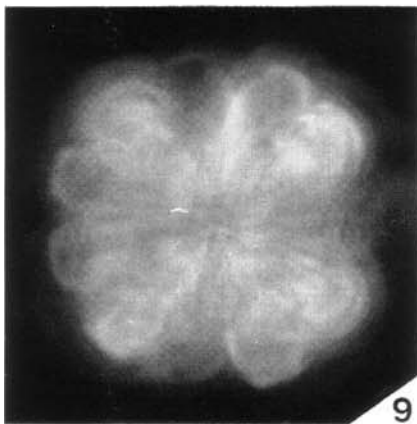
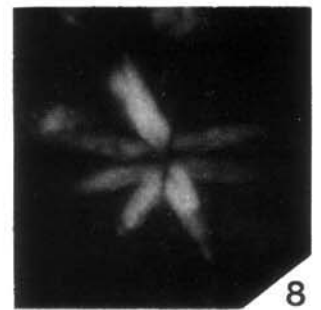
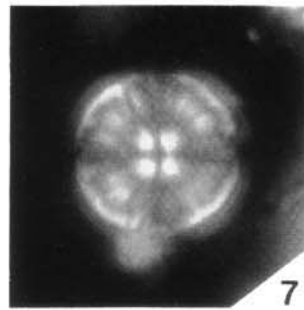
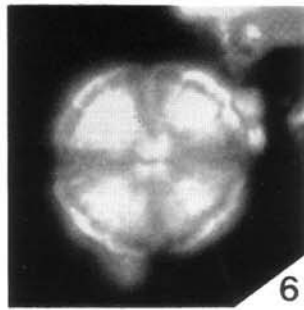
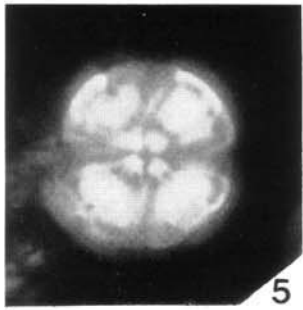
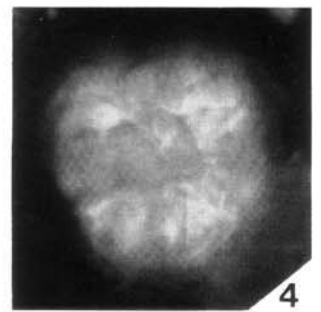
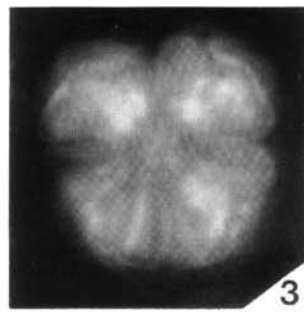
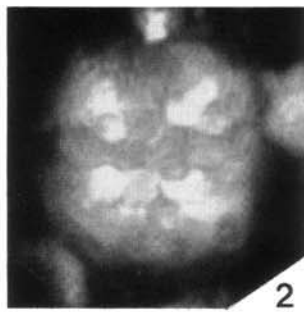
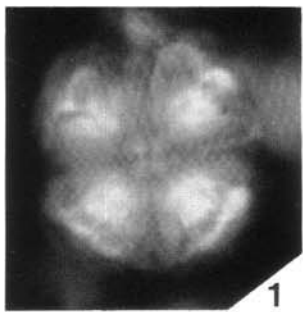
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Explanation of Plate 3

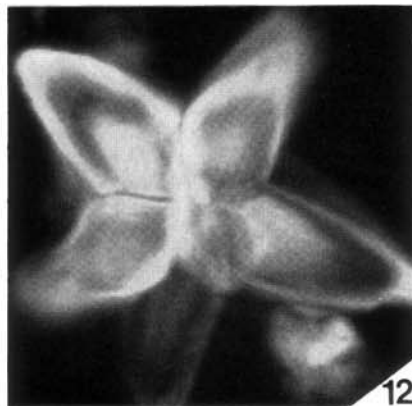
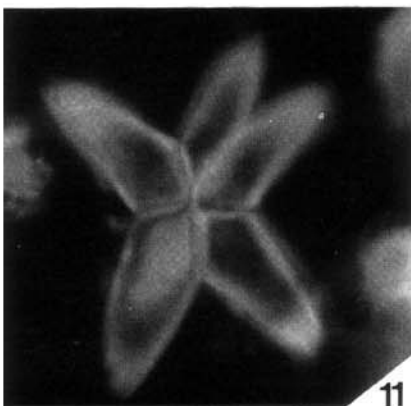
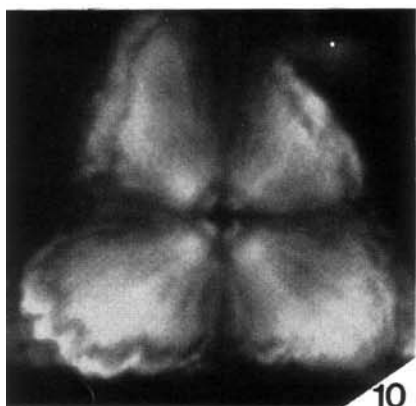
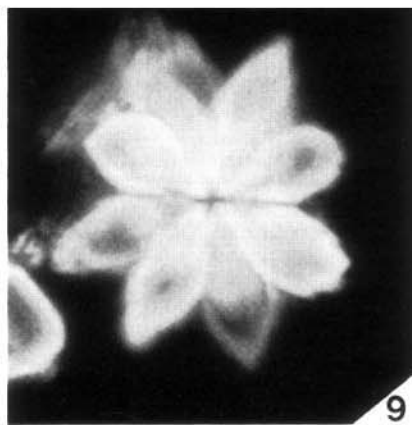
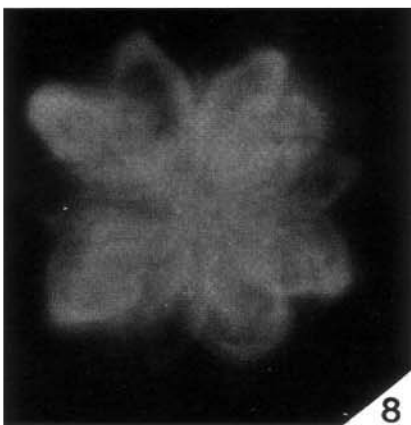
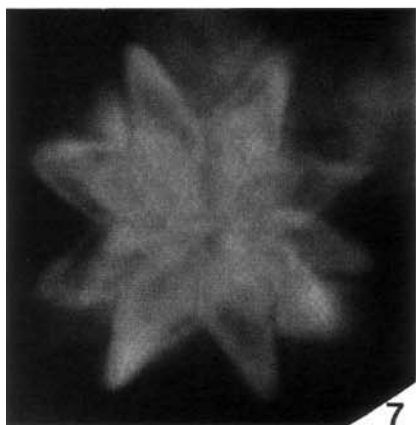
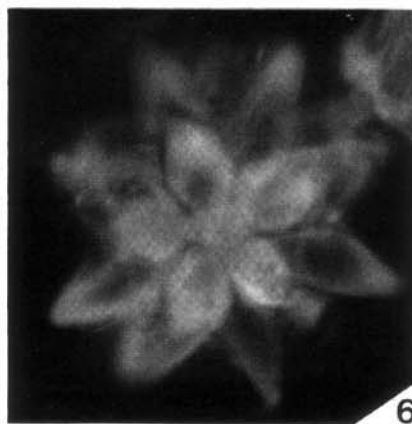
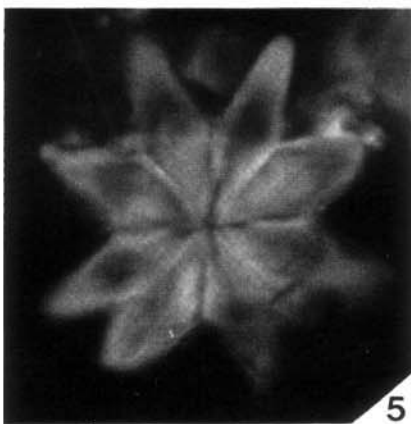
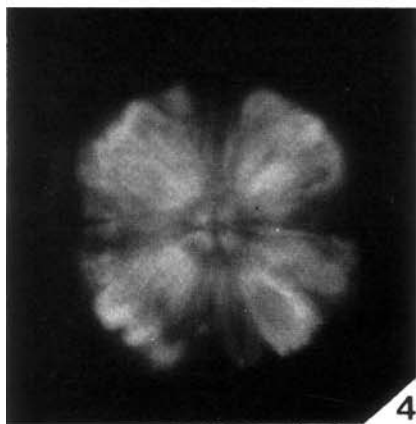
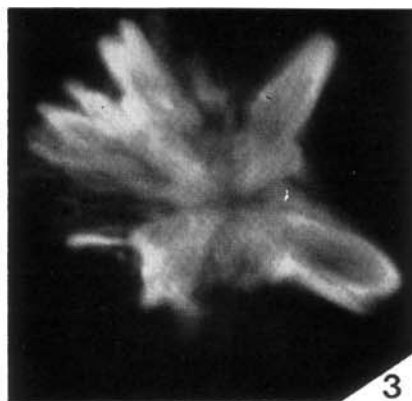
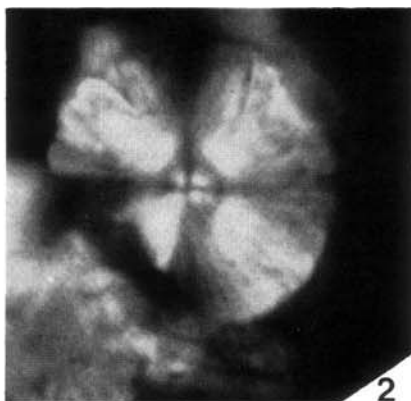
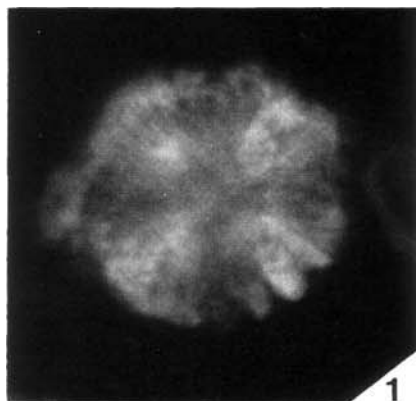
Fig. 1. *Micrascidites vulgaris* sp. nov. $\times 12\,000$. **Fig. 2.** *Micrascidites pauciradiatus* sp. nov. $\times 11\,000$. **Fig. 3.** *Rigaudia* cf. *praecisia* sp. nov. $\times 12\,000$. **Fig. 4.** *Bonetia acuta* sp. nov. $\times 15\,000$. **Fig. 5.** *Bonetia brevis* sp. nov. From middle miocene of southern Turkey $\times 14\,000$. **Fig. 6.** *Bonetia?* sp. sp. nov. $\times 6800$. **Fig. 7.** *Bonetia quasitruncata* sp. nov. $\times 3500$.



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Explanation of Plate 4

All figs $\times 2400$. **Figs 1–4.** *Monniotia fasciculata*. **Figs 5–7.** *Monniotia aciformis*. Holotype (Fig. 5). **Fig. 8.** *Micrascidites* sp. (Upper Oligocene India). **Figs 9–10.** *Bonetia quasitruncata*. **Fig. 11.** *Micrascidites* sp. **Figs 12–13.** *Bonetia brevis*. **Fig. 14.** *Bonetia acuta*. **Figs 15–17.** *Rigaudia praecisa*. **Fig. 18.** *Rigaudia* cf. *multiradiata*.



Fossil didemnid ascidian spicules

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Explanation of Plate 5

All figs $\times 2400$. **Figs 1–4.** *Rigaudia multiradiata* sp. nov. **Figs 5–9.** *Micrascidites vulgaris* sp. nov. **Fig. 10.** species and genus indeterminate sp. nov. **Figs 11–12.** *Micrascidites pauciradiatus* sp. nov. Holotype (Fig. 11).