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Didemnid ascidian spicules from the Arabian Peninsula

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Abstract In this study, 15 new didemnid ascidian genera are described: *Acinodidemnum, Bactrolithus, Bicephalodidemnum, Cephalodidemnum, Didemnobijugatus, Didemnotribaculus, Diplinthos, Disechinatus, Geminitrabilis, Hercolithus, Ommalithus, Othniodidemnum, Paleodidemnum, Unabaculus* and *Velasquezia*. Also described are 42 new didemnid ascidian species: *Acinodidemnum arcuatus, A. ecpalesis, A. lineola, Bactrolithus delicatus, Bicephalodidemnum amphicarenon, Cephalodidemnum carenon, C. pseudocarenon, Didemnobijugatus dichotomus, D. zigzag, Didemnoides radiatus, Didemnotribaculus anceps, Diplinthos qatifensis, Disechinatus baculus, D. bicaudatus, D. carinatus, D. clausus, D. mediageminus, D. selenion, Fusellinus brevis, F. elongatus, F. gigas, Geminitrabalis depressus, G. scarabaeous, Hercolithus amplexus, H. cricotus, H. petalus, Ommalithus clarus , Othniodidemnum arabianicus, Paleodidemnum acutus, P. alatus, P. caudatus, P. causianus, P. coniger, P. curvus, P. galbulus, P. marjanensis, P. metaxy, P. phossonion, P. procerus P. pseudoacutus, P. saudicus* and *Unabaculus pseudobscurus*. Two new combinations, *Velasquezia minuta* and *V. praegothica*, are introduced. One new coccolith species, *Cyclagelosphaera riyadhensis*, is described.

Keywords Jurassic, Early Cretaceous, didemnid ascidian spicules, taxonomy

1. Introduction

Didemnid ascidians are soft-bodied animals, with the exception of their spicules. They are all sessile and colonial. Marine waters rich in carbonate, particularly coral reef environments, are especially favourable for the development of didemnid ascidian colonies.

A review and classification of fossil didemnid ascidian spicules, from mainly Tertiary sediments, was originally presented by Varol & Houghton (1996). In addition, several publications have reported fossil didemnid ascidian spicules, either as nannofossils or ascidian spicules (see Varol & Houghton, 1996). Bonet & Benveniste-Velasquez (1971) published the only study to date, from Mexico, which deals with Mesozoic didemnid ascidian spicules. Fossil didemnid ascidian spicules of Pliensbachien to Portlandian age have also been described, as nannofossils, by Noël (1956), whilst Valanginian forms have been reported by Perch-Nielsen (1988) and Rhaetian forms by Jafar (1983). Ascidian spicules are not generally recorded, however, and certainly identification down to species level is very rare.

Didemnid ascidians are rarely reported by specialists for the following reasons: (a) the size of the complete spicules are usually larger than nannofossils, but smaller than microfossils, and so they are commonly overlooked; (b) although constituent spicule rays usually fall into the nannofossil size-range, they are generally ignored, unless they are particularly abundant; (c) their stratigraphic and, to a certain extent, palaeoenvironmental value has yet to be proved; and (d) there is possibly confusion concerning the origin (inorganic/organic) of spicules/rays observed in assemblages.

Living didemnid ascidians display their greatest abundances in the shallow depths of the warm seas of the world, within reefs and embayments. The fossil material tends to reflect a similar palaeoenvironmental distribution; benthic foraminifera from sediments that contain abundant ascidians are typically those that indicate shallow-marine depositional settings. Furthermore, it is notable that nannofossil abundance is reduced when the abundance of didemnid ascidians increases, suggesting shallowing waters.

2. Material and methods

The species described in this study are mainly derived from core samples from exploration and development wells drilled by Saudi Aramco in onshore and offshore eastern Saudi Arabia (the Gawar, Qatif, Berri and Marjan Fields). The Wadi Laban well, and the outcrop sections Diplomat, Hanifa and Hisyan, are situated on the Riyadh-Mecca highway in central Saudi Arabia. Over 1000 core and outcrop samples were taken from selected carbonate formations of Callovian to Early Valanginian age, in order to subdivide the reservoir intervals using assemblage characteristics based on didemnid ascidian spicules. The formations sampled are, in stratigraphical order, the Hisyan Member of the Dhruma Formation, and the Hanifa, Jubaila, Arab D, Sulaiy and Yamama Formations. These mainly limestone samples, taken at a vertical spacing of between 2 and 5 feet, were prepared using the standard smear-slide technique (*e.g.* Bown & Young, 1998). Detailed abundance counts of nannofossils and ascidian spicules, using over 100 fields of view, were made for each sample at x1000 magnification (Figure 1).

The samples and slides, including holotypes, are stored in the Saudi Aramco offices in Dhahran, Saudi Arabia. All the images are digital and stored in the computers of Varol Research, North Wales, UK.

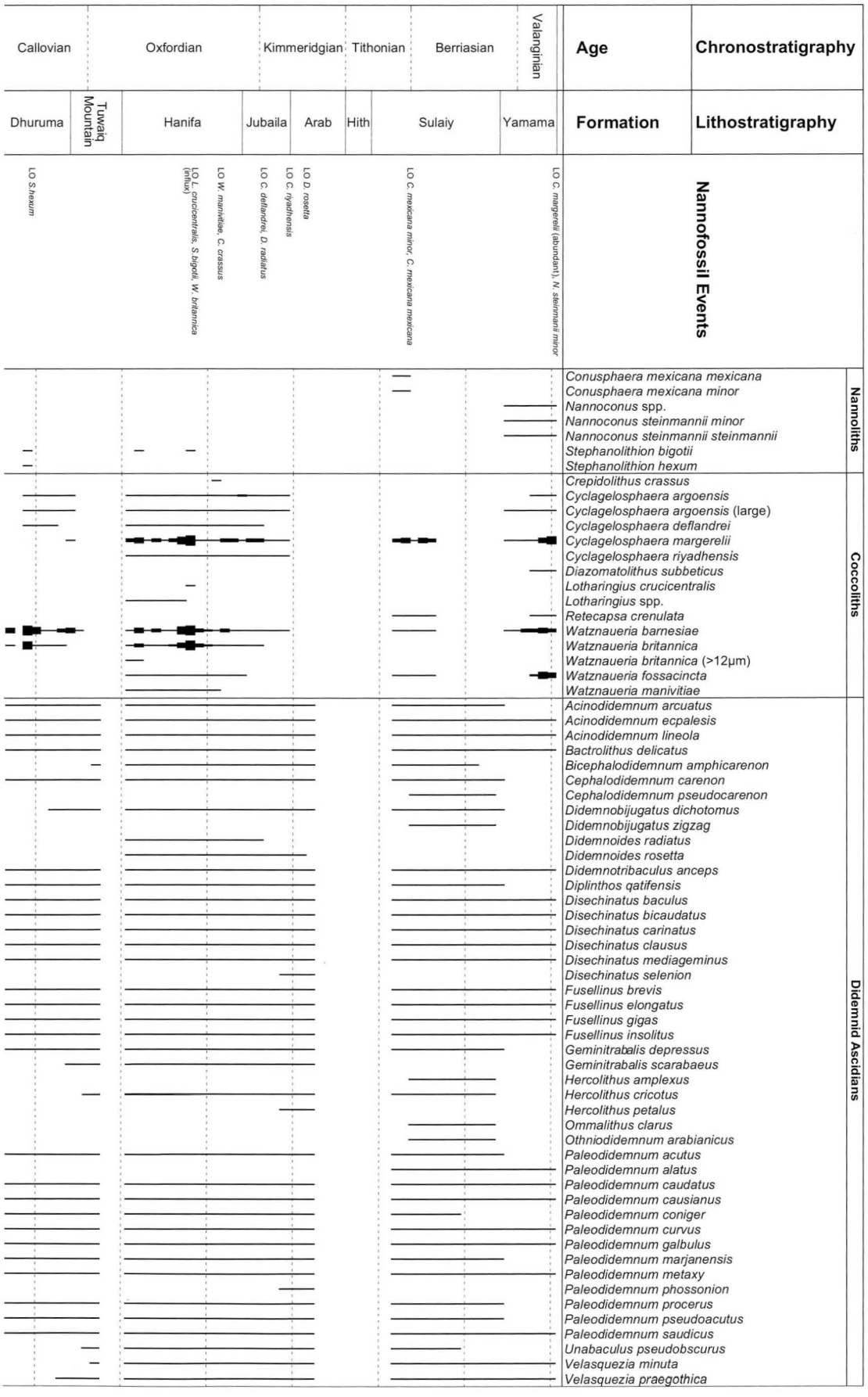

Figure 1: Nannolith, coccolith and didemnid ascidian spicule stratigraphical ranges, Arabian Peninsula

3. Biostratigraphy

So far, little research has been carried out on fossil didemnid ascidian spicules and, consequently, the stratigraphic ranges of individual species cannot yet be determined precisely, and so their biostratigraphic potential is limited. Further research into this group of fossils is also required in order to realise their sequence stratigraphical interpretation potential. Despite this, the first application of combined ascidian and foraminiferal stratigraphy to Jurassic Saudi Arabian sediments was carried out by Hughes *et al.* (2004), whilst Hughes (2004) presented a summary of the ages and palaeoenvironments of the Middle and Late Jurassic formations of Saudi Arabia, also using didemnid ascidians.

The highest stratigraphical occurrence of *Didemnoides rosetta* was found in the upper part of the Arab D Formation. At this level, nannofossils are sparse, but the sporadic occurrence of *Watznaueria barnesiae* was noted. The Arab D Formation has been dated as Kimmeridgian, mostly on ammonoid evidence (Enay, 1987; Sharland *et al.,* 2001; Hughes, 2004).

The highest occurrence of *Cyclagelosphaera riyadhensis* sp. nov. was recorded at the top of the Jubaila Formation, together with rare to frequent nannofossils, including *Watznaueria britannica, W. barnesiae* and *Cyclagelosphaera margerelii*. In the lower part of the Jubaila Formation, the highest occurrences of *Cyclagelosphaera deflandrei* and *Didemnoides radiatus* sp. nov. were determined. The Jubaila Formation is dated as Kimmeridgian on ammonoid and benthic foraminiferal evidence (Sharland *et al.,* 2001; Hughes, 2004). An Early Tithonian age, from palynological evidence (Clarke, 1988), is not considered to be valid.

The highest occurrence of *Watznaueria manivitiae* was recorded in the Hanifa Formation, together with an increased abundance and diversity of nannofossils, including *Crepidolithus crassus*. Manivit (1987) also recorded the highest occurrence of *W. manivitiae* within the Hanifa Formation, assigning it to the Early Oxfordian. *W. manivitiae* has been recorded from stratigraphically higher elsewhere (*e.g.* Bown, 1998), but in the study area was not recorded above the Oxfordian. An influx of *W. britannica* was recorded within the Hanifa Formation, together with the highest occurrences of *Stephanolithion bigotii* and *Lotharingius crucicentralis*. Ammonoid and foraminiferal evidence provide an Early to Late Oxfordian age for the Hanifa Formation (Enay, 1987; Hughes, 2004).

The oldest sediments studied herein are from the Hisyan Member of the Upper Dhruma Formation. Occurrences of *Stephanolithion hexum* and *S. bigotii,* together with *C. deflandrei* and abundant *W. britannica*, indicate a Bathonian age. The abundant occurrence of *W. britannica* was also recorded from the Hisyan Member by Manivit (1987), who assigned it to the basal Callovian to uppermost Bathonian. Ammonoid evidence is absent from the Hisyan Formation, but brachiopod evidence (Cooper, 1987) suggests a Callovian age.

The dominant feature of these data is the high abundance (up to 100% of the assemblages) of didemnid ascidian spicules throughout the well sections. The relative abundances and diversity of the didemnid ascidian spicules have been quantified to allow recognition of correlative events. The association of these correlative events, along with nannofossil and micropalaeontological evidence, provides a robust framework for the correlation of the wells across the region. The correlative value of the quantitative didemnid ascidian spicule events has also been tested using wireline log evidence, where no other fossil groups were recorded. The results were consistent.

Nannofossil recovery in the samples varies greatly but, in general, poorly-preserved and low-diversity assemblages were obtained. This is considered to be the result of the shallow-water setting. Nannofossil abundance increased as the depositional setting deepened, as indicated by benthic foraminifera. The highest stratigraphical occurrences of nannofossils were recorded at flooding surfaces. Only at these levels did diversity and preservation of nannofossils improve. *W. barnesiae, C. margerelii* and *W. britannica* are the most abundant nannofossils recovered.

4. Taxonomy

Below, 15 new didemnid ascidian spicule genera and 42 new species are described, along with one new coccolith species. Two new didemnid ascidian combinations are also introduced.

4.1. Didemnid ascidian spicules

The arrangement and shape of the spicule rays, presence or absence of appendices, and number and position of appendices are utilised as diagnostic features for the identification of didemnid ascidians (Figure 2). The adoption of ray morphology as a system of classification enables the scientist to identify individual species, even if only isolated rays are preserved.

The fossil forms described below are classified as didemnid ascidian spicules for the following reasons: Bonet & Benveniste-Velasquez (1971) have already published some of the species cited in this study, including *Fusellinus insolitus* (as *Ascidites dubius*), *Velasquezia minuta* comb. nov. (as *Didemnoides minutum*), *Velasquezia praegothica* comb. nov. (as *Didemnoides minutum*) and *Didemnoides rosetta*. Furthermore, Noël (1956) presented a scanning electron micrograph and a line-drawing of *Fusellinus insolitus*, from Jurassic sediments, displaying its fibrous structure. This evidence confirms the link between the well-known *Micrascidites vulgaris* Deflandre & Deflandre-Rigaud, 1956 and the newly described forms.

Another common feature between the well-known ascidians and the forms described here is that the spicule rays display a blue colour (when aligned in a NW-SE direction) in cross-polarised light (XPL) with a gypsum

plate. Photographic evidence for a fibrous structure to these forms has been observed in well-preserved samples from Trinidad, but as these are from confidential wells, they are currently unavailable for publication. Within these samples is evidence that indicates that *Fusellinus brevis* sp. nov. forms a spherical spicule.

In the author's experience, inorganic objects typically display sharp edges and simple structures, whilst the forms described here display complex morphologies, with a fibrous structure in well-preserved material. The taxa used in this publication have been applied, by M. Girgis (pers. comm., 2005), in West Africa and found to be of stratigraphic utility.

Most of the species described herein have long stratigraphical ranges. It has been observed, however, that species of *Didemnoides* are not found above the Kimmeridgian, and that species of *Didemnobijugatus* gen. nov. and *Hercolithus* gen. nov. have not been found above the Berriasian. It is anticipated that future work will permit further stratigraphical subdivision and, thus, potentially increase their biostratigraphic application. It is recommended that the geochemical composition of spicules should be examined, for the purpose of further confirming their origin and taxonomic affinity.

The terminology used in this study is presented in Figure 2. The following four types of spicule have been identified: (a) **fusiform type** - spicules made up of a single, or several, rays, with or without appendices, as in *Velasquezia* gen. nov. and *Paleodidemnum* gen. nov.; (b) **petaloid type** - brick-like rays forming a petal-like circular or elliptical wall, as in *Hercolithus* gen. nov.; (c) **spherical type** - spicules composed of rays radiating from the centre of the spicule, and characteristic of *Fusellinus*; and (d) **asteroid type** - star-shaped spicules made up of numerous rays, and peculiar to *Didemnoides*. Sketches of the ascidian taxa are shown in Figure 3.

Acinodidemnum gen. nov.

Type species: *Acinodidemnum lineola* sp. nov. **Derivation of name**: From *acino*, Latin for 'thorn', or 'appendix', referring to its appendices. **Diagnosis**: Didemnid ascidian spicules having a fusiform, or modified fusiform, ray with single bilateral appendices. **Description**: The rays are fusiform in shape, but may be curved. The spicule has two appendices, one on each side of the ray. These appendices are believed to help join spicules to each other. The species of this genus are distinguished by the position of the appendices and the shape of the ray. **Remarks**: *Acinodidemnum* is distinguished from *Didemnotribaculus* gen. nov. by having a single appendix on each side of the ray. The latter has two appendices on one side and a single appendix on the other side of the ray.

Acinodidemnum arcuatus sp. nov.

Pl.1, figs 26-28. **Derivation of name**: From *arcus*, Latin for 'bow-like', referring to the concave sides of the ray. **Diagnosis**: Spicule with a bow-like ray, having a short appendix on one side and a large appendix on the other side. **Remarks**: The ray is modified fusiform. It appears bow-like due to the different sizes of the depressions at the bases of the appendices on the ray. There are different sizes of single appendices on each side of the ray. The small appendix may or may not be central. The base of the large appendix extends almost along the entire side of the ray. *A. arcuatus* is distinguished from other species of *Acinodidemnum* by having a bow-shaped ray and two distinctly different sizes of appendix. **Holotype**: Pl.1, figs 26, 27 (same specimen). **Dimensions of holotype**: Length of ray = 6.0μm; maximum width of ray = 3.0μm; length of appendix = 4.5μm, maximum width of appendix = 3.5μm. **Type level**: Sulaiy Formation (Berriasian). **Type locality**: Well MRJN-39, 7981.20' (core), Marjan Field, offshore eastern Saudi Arabia. **Occurrence**: Upper Jurassic-Valanginian.

Acinodidemnum ecpalesis sp. nov.

Pl.1, figs 20, 25, 30. **Derivation of name**: From *ecpalesis*, Greek for 'dislocation', referring to the misalignment of the appendices. **Diagnosis**: A species of *Acinodidemnum* in which the appendices are offset along the ray. **Remarks**: The ray is fusiform but usually strongly curved. Appendices are short and offset along the ray. *A. ecpalesis* differs from *A. lineola* sp. nov. by having these dislocated/offset appendices. In the latter, the appendices are aligned. Moreover, the ray in *A. ecpalesis* is usually curved, whereas in *A. lineola* sp. nov. the ray is always plain fusiform. **Holotype**: Pl.1, figs 25, 30 (same specimen). **Dimensions of holotype**: Length of ray = 6.5μm; maximum width of ray = 3.0μm. **Type level**: Sulaiy Formation (Berriasian). **Type locality**: Well LWHH-17, 8656.20' (core), Marjan Field, offshore eastern Saudi Arabia. **Occurrence**: Upper Jurassic-Pleistocene.

Acinodidemnum lineola sp. nov.

Pl.1, figs 16-19.

1971 *Didemnoides minutum* Bonet & Benveniste-Velasquez, pp.11-13, pl.1, figs 4, 19; non pl.1, figs 1-3, 5-18.

2002 *Uniplanarius* sp. Herrle, p.78, pl.6, fig.24.

Derivation of name: From *lineola,* Latin for 'aligned', referring to the alignment of the appendices. **Diagnosis**: A species of *Acinodidemnum* in which the appendices are aligned. **Remarks**: The ray is always fusiform. The short appendices are situated in a median or submedian location, but are always aligned. This species is distinguished from *A. ecpalesis* in having aligned appendices. It differs from *A. arcuatus* in having almost equal-sized appendices. In *A. arcuatus*, one of the appendices is large and the spicule ray is bow-tie-shaped. **Holotype**: Pl.1, fig.16. **Dimensions of holotype**: Length of ray = 14.5μm; maximum width of ray = 5.5μm. **Type level**: Arab D Formation (Kimmeridgian). **Type locality**: Well Qatif-48,

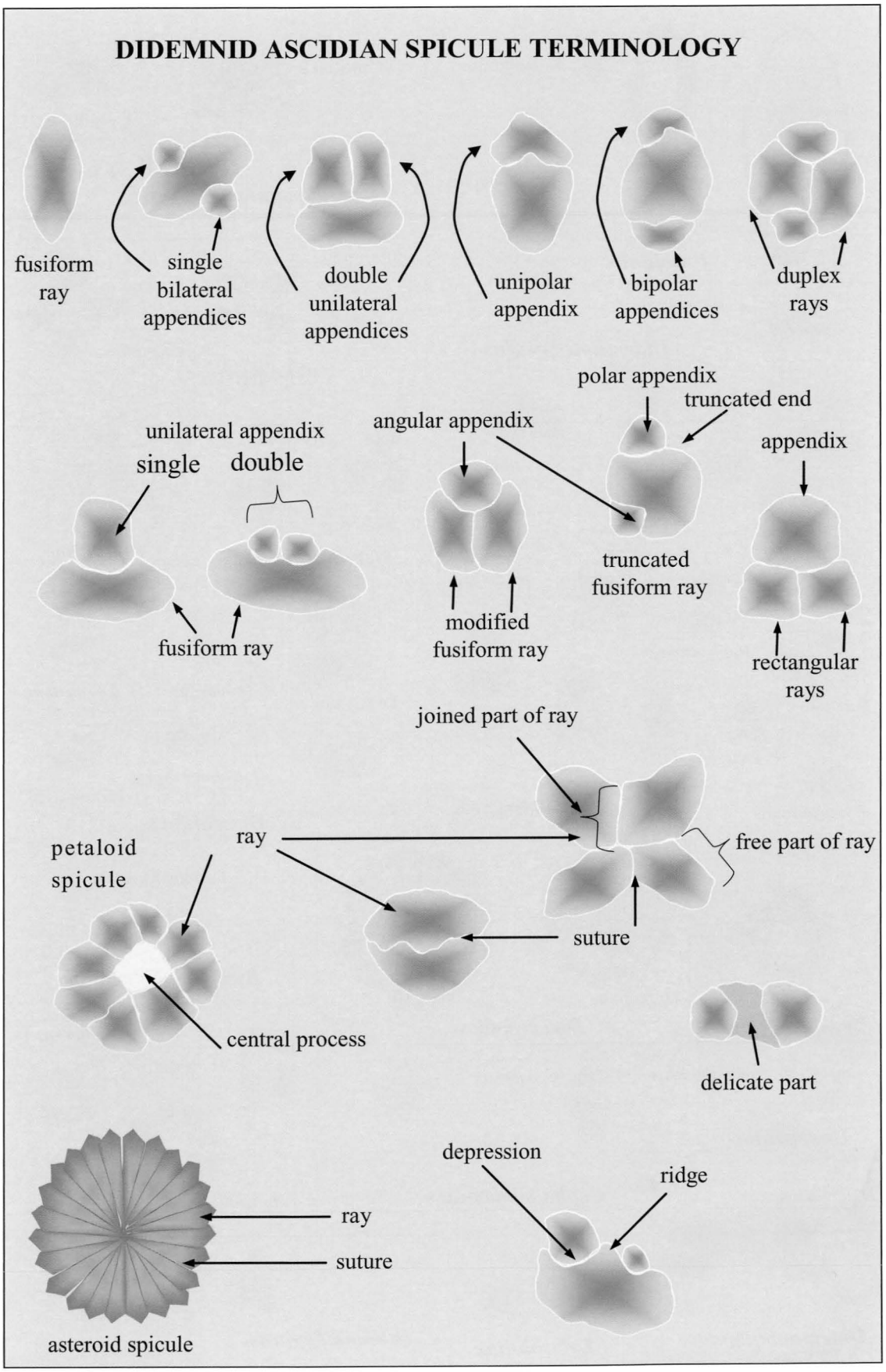

Figure 2: Didemnid ascidian spicule terminology and identifying features

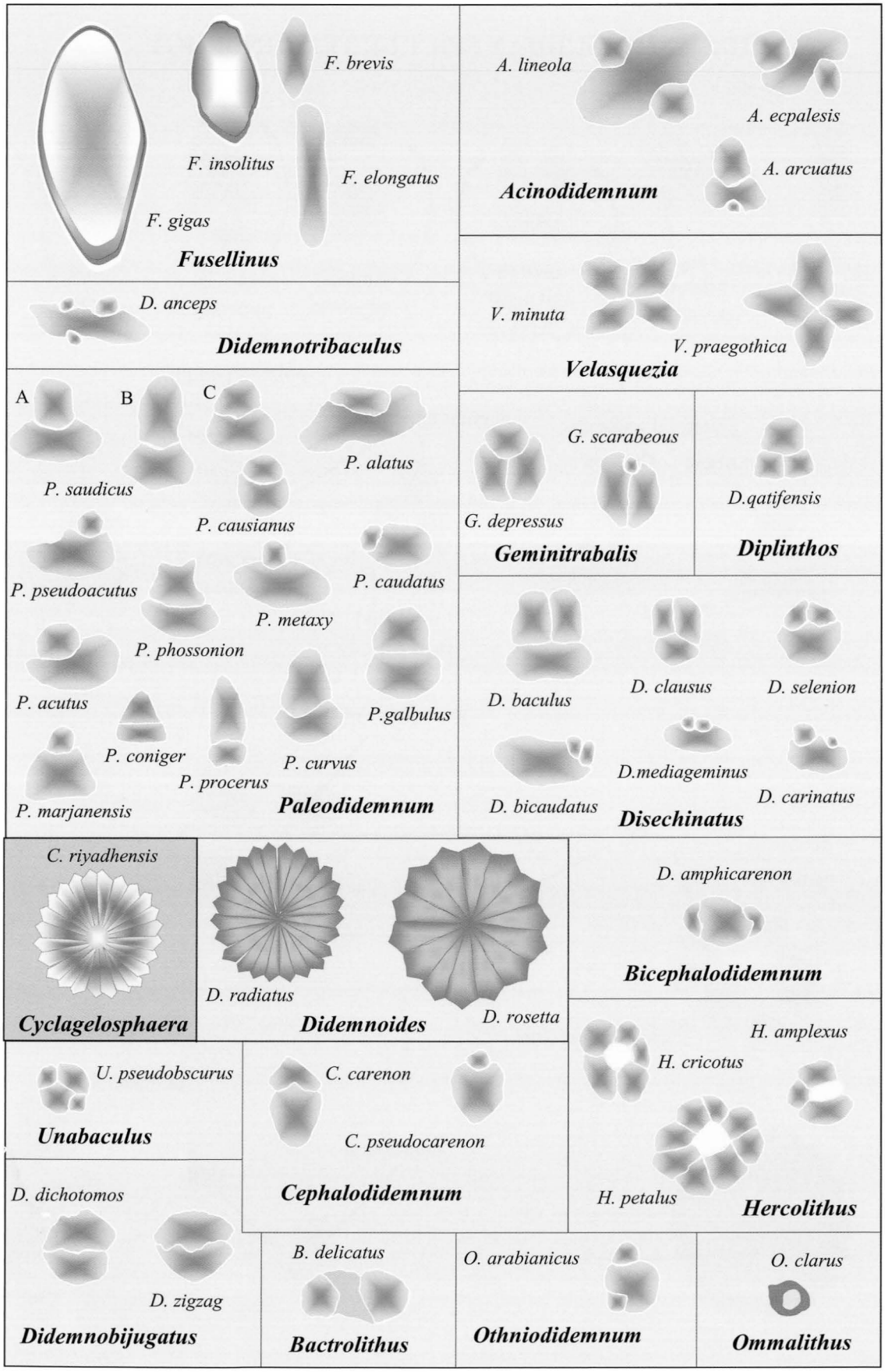

Figure 3: Sketches of the didemnid ascidian spicules, and the coccolith Cyclagelosphaera, described herein, highlighting differentiation between the taxa

7946.00' (core), Qatif Field, eastern Saudi Arabia. **Occurrence**: Upper Jurassic-Pleistocene.

Bactrolithus gen. nov.

Type species: *Bactrolithus delicatus* sp. nov. **Derivation of name**: From *bactro*, Greek for 'rod', or 'stick', referring to its shape. **Diagnosis**: Didemnid ascidian spicule having fusiform rays without appendices. The rays are compressed in the middle, where two rays join each other to form a complete spicule. **Remarks**: The angle between the two rays varies but is never at a right-angle. The rays of *Bactrolithus* are distinguished from the rays of *Fusellinus* by having a thinned part in the middle of the ray.

Bactrolithus delicatus sp. nov.

Pl.4, figs 1-4. **Derivation of name**: From *delicatus*, Greek for 'delicate', referring to the delicate middle part of the ray. **Diagnosis**: The spicule ray is fusiform and thinned in the middle, where two rays are joined to form an asymmetric cross. **Remarks**: The complete spicule is formed by two rays which are fusiform in shape. The rays are joined to each other at their thinned parts. The opposite angles between the rays are usually equal. No appendices are present. The rays of *B. delicatus* are distinguished from the rays of *Fusellinus* by being compressed in the middle. In *B. delicatus*, each ray is joined by its thinned part to form a complete spicule that is an asymmetrical cross, whereas in *Fusellinus* the rays join each other to form a spherical spicule. **Holotype**: Pl.4, fig.1. **Dimensions of holotype**: Length of ray = 17.5μm; maximum width of ray = 7.5μm; length of thinned part = 7.5μm. **Type level**: Arab D Formation (Kimmeridgian). **Type locality**: Well Qatif-48, 7496.00' (core), Qatif Field, eastern Saudi Arabia. **Occurrence**: Upper Jurassic-Lower Valanginian.

Bicephalodidemnum gen. nov.

Type species: *Bicephalodidemnum amphicarenon* sp. nov. **Derivation of name**: From *bi*, Latin for 'two', and *cephalo*, Greek for 'head', referring to its head-like appendices at each pole of the ray. **Diagnosis**: Didemnid ascidian spicule having a ray with an appendix at each pole. **Remarks**: The ray, together with appendices, is fusiform in shape. The sutures between the appendices and the ray are zigzag-shaped. *Bicephalodidemnum* is distinguished from *Cephalodidemnum* gen. nov. by having an appendix at each pole of the ray. *Cephalodidemnum* has a single appendix at one pole of the ray. *Bicephalodidemnum* differs from *Disechinatus* gen. nov. in the position of the appendices. The appendices are bipolar in *Bicephalodidemnum*, whereas appendices are unilateral in *Disechinatus*.

Bicephalodidemnum amphicarenon sp. nov.

Pl.4, figs 15, 16. **Derivation of name**: From *amphi*, Greek for 'on both sides', and *careno*, Greek for 'head', referring to its cap-like appendices at the poles of the ray. **Diagnosis**: Species of *Bicephalodidemnum* having cap-like appendices at both poles of the ray. **Remarks**: Zigzag sutures separate the appendices from the ray. *B. amphicarenon* is distinguished from *Cephalodidemnum carenon* gen. et sp. nov. by having bipolar appendices, whereas the latter has a monopolar appendix. The species of *Disechinatus* gen. nov. are distinguished from *B. amphicarenon* in having two unilateral appendices. **Holotype**: Pl.4, figs 15, 16 (same specimen). **Dimensions of holotype**: Length of ray with appendices = 7.5μm; maximum width = 4.5μm. **Type level**: Sulaiy Formation (Berriasian). **Type locality**: Well Marjan-39, 8372.70' (core), Marjan Field, offshore eastern Saudi Arabia. **Occurrence**: Berriasian-Lower Valanginian.

Cephalodidemnum gen. nov.

Type species: *Cephalodidemnum carenon* sp. nov. **Derivation of name**: From *cephalo*, Greek for 'head', referring to its head-like appendix. **Diagnosis**: Didemnid ascidian spicule having a fusiform ray with an appendix at one pole. **Remarks**: The ray with appendix is fusiform in shape. *Cephalodidemnum* is distinguished from *Paleodidemnum* gen. nov. by having a polar appendix, whereas in the latter the appendix is unilateral.

Cephalodidemnum carenon sp. nov.

Pl.4, figs 17, 18. **Derivation of name**: From *careno*,, Greek for 'head', referring to its single, head-like appendix. **Diagnosis**: Spicule having a fusiform ray with an appendix at one of the poles. The suture between the ray and the appendix is zigzag-shaped. **Remarks**: The appendix looks like a cap situated at one of the poles of the ray. A zigzag suture joins the ray to the appendix, which appears as a continuation of the ray. *C. carenon* is distinguished from *C. pseudocarenon* sp. nov. by the shape of the appendix. The appendix is cap-like and joins the spicule ray with a zigzag suture in *C. carenon,* whereas in *C. pseudocarenon*, the small appendix is partially inserted into to the depression at one pole of the ray. **Holotype**: Pl.4, figs 17, 18. (same specimen). **Dimensions of holotype**: Length of ray and appendix = 8.5μm; length of ray = 5.5μm; maximum width = 5.0μm. **Type level**: Sulaiy Formation (Berriasian). **Type locality**: Well Marjan-39, 8269.20' (core), Marjan Field, offshore eastern Saudi Arabia. **Occurrence**: Lower Valanginian-Berriasian.

Cephalodidemnum pseudocarenon sp. nov.

Pl.4, figs 12-14, 19. **Derivation of name**: From *pseudo*, Greek for 'false', referring to its false similarity to *C. carenon*. **Diagnosis**: Species of *Cephalodidemnum* with a small appendix, partially inserted into a depression at one pole of the ray. **Remarks**: *C. pseudocarenon* is distinguished from *Paleodidemnum caudatus* gen. et sp. nov. in the position of the appendix. The appendix is located at one pole of the ray in *C. pseudocarenon,* whereas the appendix is unilateral, but in an angular position, in *P.*

caudatus. **Holotype**: Pl.4, figs 14, 19 (same specimen). **Dimensions of holotype**: Length of ray = 5.0μm; maximum width of ray = 5.0μm. **Type level**: Sulaiy Formation (Berriasian). **Type locality**: Well Marjan-64 , 8225.20' (core), Marjan Field, offshore eastern Saudi Arabia. **Occurrence**: Lower Valanginian-Berriasian.

Didemnobijugatus gen. nov.

Type species: *Didemnobijugatus dichotomus* sp. nov. **Derivation of name**: From *jugum*, Latin for 'yoked together', or 'double', referring to the double rays. **Diagnosis**: Didemnid ascidian spicule made up of two rays without an appendix. **Remarks**: The spicule is a modified semicircular or modified fusiform form. The rays are joined along their lengths on their relatively flatter sides. Each ray in the spicule is not identical. The suture between the spicule rays is straight or zigzagged.

Didemnobijugatus dichotomus sp. nov.

Pl.4, figs 30-33. **Derivation of name**: From *dicho*, Greek for 'two', and *tomos*, Greek for 'part', referring to the two rays. **Diagnosis**: Spicule having two semicircular rays joined along their relatively flat sides. The suture between the rays is straight, or slightly kinked in the middle. **Remarks**: One of the rays is usually slightly larger and has a shallow depression at its periphery. *D. dichotomus* is distinguished from *D. zigzag* sp. nov. by having an almost straight suture between the rays and a shallow depression on one of the rays. **Holotype**: Pl.4, figs 30, 31 (same specimen). **Dimensions of holotype**: Length = 6.5μm; width = 6.0μm. **Type level**: Sulaiy Formation (Berriasian). **Type locality**: Well LWHH-17, 8683.20' (core), Marjan Field, offshore eastern Saudi Arabia. **Occurrence**: Upper Jurassic-Lower Valanginian.

Didemnobijugatus zigzag sp. nov.

Pl.4, figs 27, 28. **Derivation of name**: From *zigzag*, Latin for 'alternately changing direction by sharp angles', referring to the suture between the spicule rays. **Diagnosis**: Spicule having two modified fusiform spicules joined along their relatively flat sides. The suture between the rays is zigzagged. **Remarks**: This species is distinguished from *D. dichotomus* by having a zigzag suture between the rays. Moreover, in *D. zigzag*, the rays are modified fusiform in shape and lack a peripheral depression. **Holotype**: Pl.4, figs 27, 28 (same specimen). **Dimensions of holotype**: Length = 7.0μm; width = 6.5μm. **Type level**: Sulaiy Formation (Berriasian). **Type locality**: Well MRJN-64, 8511.20' (core), Marjan Field, offshore eastern Saudi Arabia. **Occurrence**: Berriasian-Lower Valanginian.

Didemnoides Bonet & Benveniste-Velasquez, 1971

Type species: *Didemnoides rosetta* Bonet & Benveniste-Velasquez, 1971. **Remarks**: Asteroid didemnid ascidian spicule made up of 10 to 24 rays. The tips of the rays are usually triangular. The species of this genus are distinguished by the width of their rays.

Didemnoides radiatus sp. nov.

Pl.3, figs 31, 32. **Derivation of name**: From *radiatus*, Latin for 'rayed', referring to its multiple rays. **Diagnosis**: Species of *Didemnoides* having 10 to 24 slender rays. The maximum width of the rays is <2.5μm. **Remarks**: The spicule appears brownish-blue under XPL. The tips of the rays are triangular. This form is distinguished from *D. rosetta* by having narrower rays (<2.5μm). **Holotype**: Pl.3, fig.31. **Dimensions of holotype**: Diameter = 16.0μm. **Type level**: Jubaila Formation (Kimmeridgian). **Type locality**: Wadi Laban Well, Sample 40', Riyadh-Mecca highway, central Saudi Arabia. **Occurrence**: Upper Jurassic. The last occurrence of this form was noted in the upper part of the Jubaila Formation.

Didemnoides rosetta Bonet & Benveniste-Velasquez, 1971

Pl.3, figs 33, 34.

1971 *Didemnoides rosetta* Bonet & Benveniste-Velasquez, pp.10-11, pl.2, figs 1-6; pl.3, figs 1-6.

Remarks: The maximum width of the rays is always >2.5μm. The tips of the spicule rays are triangular. *D. rosetta* is distinguished from *D. radiatus* by having wider rays. **Occurrence**: Upper Jurassic. The last occurrence of *D. rosetta* was noted in the upper part of the Arab D Formation.

Didemnotribaculus gen. nov.

Type species: *Didemnotribaculus anceps* sp. nov. **Derivation of name**: From *tri*, Latin for 'three', and *baculum*, Latin for 'rod', referring to the number of its appendices. **Diagnosis**: Didemnid ascidian spicule having a fusiform ray with three bilateral appendices, two on one side and one on the other. **Remarks**: The position of the appendices on each side of the ray can vary, but always there are two on one side and one on the other. *Didemnotribaculus* differs from *Acinodidemnum* in having three bilateral appendices, whereas the latter has only two.

Didemnotribaculus anceps sp. nov.

Pl.1, figs 8-10. **Derivation of name**: From *anceps*, Latin for 'two-sided', referring to the appendices on both sides of the ray. **Diagnosis**: Spicule having a fusiform ray with two appendices on one side and a single appendix on the other side. The position of the appendices varies. **Remarks**: The appendices may be confined to the middle part of the ray, or to one of the poles of the ray. **Holotype**: Pl.1, fig.9. **Dimensions of holotype**: Length = 11.5μm; maximum width = 3.5μm. **Type level**: Arab D Formation (Kimmeridgian). **Type locality**: Well HRDH-87, 7074.10' (core), Ghawar Field, eastern Saudi Arabia. **Occurrence**: Upper Jurassic-Lower Valanginian.

Diplinthos gen. nov.

Type species: *Diplinthos qatifensis* sp. nov. **Derivation of name**: From *dis*, Greek for 'double', and *plinthos*, Greek for 'brick', referring to its two brick-like rays. **Diagnosis**: Spicule made up of two subrectangular rays and one appendix. **Remarks**: The rectangular rays are joined together along their short sides. A single appendix extends from these rays. The width of the appendix base is almost equal to the combined lengths of the two joined rays. *Diplinthos* is distinguished from *Geminitrabalis* nov. gen. in having two rectangular rays joined along their shorter sides and without a depression. In *Geminitrabalis*, the two elongated rays are joined along their length. The rays of *Geminitrabalis* have depressions along the suture near the poles, where an appendix sits.

Diplinthos qatifensis sp. nov.

Pl.3, figs 16-19. **Derivation of name**: From the type locality, the Qatif Field, eastern Saudi Arabia. **Diagnosis**: This spicule has two subrectangular rays joined along their short sides. The large appendix extends from their combined longer sides. **Remarks**: The rays are equal in dimension in well-preserved specimens, but one of the edges is slightly angled. The large appendix extends from the concavity formed where the two rays are joined. The maximum width of the appendix is slightly shorter than, or equal in length to, the joined rays. **Holotype**: Pl.3, figs 16, 17 (same specimen). **Dimensions of holotype**: Length of rays = 5.5μm; width of rays = 2.5μm; height of appendix = 3.5μm. **Type level**: Arab D Formation (Kimmeridgian). **Type locality**: Well Qatif-40, 7485.80' (core), Qatif Field, eastern Saudi Arabia. **Occurrence**: Upper Jurassic.

Disechinatus gen nov.

Type species: *Disechinatus clausus* sp. nov. **Derivation of name**: From *dis*, Greek for 'double', and *echinos*, Greek for 'spine', referring to its two appendices. **Diagnosis**: Didemnid ascidian spicule having a ray with two unilateral appendices. The shape of the ray varies from fusiform to half-moon-shaped. **Remarks**: Two appendices extend from one side of the ray. The species of this genus are distinguished by the size and position of the appendices and the shape of the ray. *Disechinatus* is distinguished from *Paleodidemnum* gen. nov. in having two unilateral appendices, whereas the latter has only one unilateral appendix.

Disechinatus baculus sp. nov.

Pl.5, figs 16-20. **Derivation of name**: From *baculum*, Latin for 'rod', referring to its large appendices. **Diagnosis**: Species of *Disechinatus* having a fusiform ray and double unilateral appendices. The combined length of the bases of the appendices is approximately equal to the length of the ray. The bases of the large appendices (compared to the ray) do not form a distinct depression on the ray. **Remarks**: The appendices are usually joined to each other along their long sides. The ray may form a low ridge between the appendices. This form artificially resembles the Paleocene nannofossil species *Fasciculithus pileatus*. *D. baculus* is distinguished from *D. clausus* sp. nov. by the shape of its ray, as the ray in *D. baculus* is elongated fusiform whereas the ray is rhomboidal in *D. clausus*. **Holotype**: Pl.5, fig.18. **Dimensions of holotype**: Length of ray = 7.5μm; width of ray = 3.5μm; maximum width of appendix = 3.5μm; length of appendices = 5.0μm. **Type level**: Arab D Formation (Kimmeridgian). **Type locality**: Well Qatif-46, 7441.20'(core), Marjan Field, offshore eastern Saudi Arabia. **Occurrence**: Upper Jurassic-Lower Valanginian.

Disechinatus bicaudatus sp. nov.

Pl.5, figs 26-29. **Derivation of name**: From *bi*, Latin for 'two', and *cauda*, Latin for 'appendix', or 'tail', referring to the two appendices near one of the poles of the ray. **Diagnosis**: Spicule having a fusiform ray with two appendices located in a depression near one of the poles. There is usually no gap between appendices.

Remarks: *D. bicaudatus* is distinguished from *D. mediageminus* sp. nov. by the position of the appendices. In *D. bicaudatus*, the appendices are located near one pole of the ray, whereas in *D. mediageminus*, the appendices are confined to the middle of the ray. **Holotype**: Pl.5, fig.26. **Dimensions of holotype**: Length = 9.5μm; maximum width = 5.0μm. **Type level**: Sulaiy Formation (Berriasian). **Type locality**: Well MRJN-64 , 8323.20' (core), Marjan Field, offshore eastern Saudi Arabia. **Occurrence**: Upper Jurassic-Lower Valanginian.

Disechinatus carinatus sp. nov.

Pl.5, figs 21-23. **Derivation of name**: From *carina*, Latin for 'ridge', referring to the ridge formed by the ray between the appendices. **Diagnosis**: Species of *Disechinatus* having a truncated fusiform ray with double unilateral appendices located in depressions on the ray. The ray forms a distinct ridge between the appendices. **Remarks**: The truncated fusiform ray resembles a shoe shape, due to the marked depressions and the ridge to one side. The appendices are different sizes and never touch each other. The appendix near the truncated end is larger and located in a more pronounced depression. **Holotype**: Pl.5, fig.21. **Dimensions of holotype**: Length of ray = 6.0μm; maximum width of ray (at the ridge) = 3.5μm. **Type level**: Arab D Formation (Kimmeridgian). **Type locality**: Well Qatif-58, 8091.20' (core), Qatif Field, eastern Saudi Arabia. **Occurrence**: Upper Jurassic-Lower Valanginian.

Disechinatus clausus sp. nov.

Pl.5, figs 11-14. **Derivation of name**: From *clausus*, Latin for 'closed', referring to the closed, 'V'-shaped suture formed by the bases of the appendices where they join the ray. **Diagnosis**: Species of *Disechinatus* having a diamond-shaped fusiform ray with large (relative to ray)

double unilateral appendices. The bases of the appendices form a 'V'-shaped suture where they join the ray. **Remarks**: Two unilateral appendices dominate the species. The lengths of the appendices are almost equal to their width. *D. clausus* is distinguished from *D. baculus* by the shape of its ray; *D. clausus* has a diamond-shaped ray, whereas *D. baculus* has an elongated fusiform ray. Moreover, the suture between the ray and appendices is 'V'-shaped in *D. clausus*, whereas it is straight in *D. baculus*. **Holotype**: Pl.5, fig.13. **Dimensions of holotype**: Length of ray = 4.5μm; maximum width of ray = 3.0μm; maximum length of appendix = 4.5μm; maximum width of appendix = 4.5μm. **Type level**: Arab D Formation (Kimmeridgian). **Type locality**: Well Qatif-58, 7475.00' (core), Qatif Field, eastern Saudi Arabia. **Occurrence**: Upper Jurassic-Lower Valanginian.

Disechinatus mediageminus sp. nov.

Pl.5, figs 24, 25, 30. **Derivation of name**: From *medius*, Latin for 'middle', and *geminus*, Latin for 'twin', referring to the median location of appendices on the ray. **Diagnosis**: Spicule having a fusiform ray with median double unilateral appendices. The appendices are very small in comparison to the size of the ray. **Remarks**: *D. mediageminus* is distinguished from *D. bicaudatus* by the position of the appendices; these are at the middle of the ray in *D. mediageminus*, but near to one pole of the ray in *D. bicaudatus*. **Holotype**: Pl.5, figs 24, 25 (same specimen). **Dimensions of holotype**: Length = 7.0μm; width = 2.5μm. **Type level**: Sulaiy Formation (Berriasian). **Type locality**: Well MRJN-64, 8600.70' (core), Marjan Field, offshore eastern Saudi Arabia. **Occurrence**: Upper Jurassic-Lower Valanginian.

Disechinatus selenion sp. nov.

Pl.5, figs 9, 10, 15. **Derivation of name**: From *selene*, Greek for 'small moon', referring to its half-moon-shaped ray. **Diagnosis**: Species of *Disechinatus* having a fusiform ray with a half-moon shape and bearing double unilateral appendices along the flat side. The appendices are usually joined to each other, and their combined bases almost extend along the entire flat side of the ray. **Remarks**: The flat side of the ray may form a slight ridge between the appendices. *D. selenion* is distinguished from all other species of *Disechinatus* by its half-moon-shaped ray. **Holotype**: Pl.5, figs 9, 10 (same specimen). **Dimensions of holotype**: Length of ray = 6.0μm; maximum width of ray = 4.0μm. **Type level**: Arab D Formation (Kimmeridgian). **Type locality**: Well Qatif-48, 7598.30' (core), Qatif Field, eastern Saudi Arabia. **Occurrence**: Upper Jurassic.

Fusellinus Noël, 1956

Type species: *Fusellinus insolitus* Noël, 1965. **Synonym**: *Ascidites* Bonet & Benveniste-Velasquez, 1971. **Remarks**: Didemnid ascidian spicule composed of fusiform rays without appendices. The rays are joined to each other along their lengths to form a spherical complete spicule. The ratio between the length of the joined part of the rays and the free part of the rays varies. No difference in diameter is noted between the free and joined parts of the ray.

Fusellinus brevis sp. nov.

Pl.1, figs 11-13.

1971 *Didemnoides minutum* Bonet & Benveniste-Velasquez, pp.10-11, pl.1, figs 6, 14; non pl.1, figs 1-5, 7-13, 15-19.

Derivation of name: From *brevis*, Latin for 'short', referring to its length, relative to other species of the genus. **Diagnosis**: A short species of *Fusellinus* having a fusiform ray. The length of the rays are <10μm. Mainly isolated rays have been observed. Rarely, complete spherical spicules have been observed. **Remarks**: The rays are a yellowish-brownish colour in XPL. The length of the joined part of each ray is equal to, or greater than, the free part of the ray. The rays of *F. brevis* are distinguished from those of *F. insolitus* in being shorter, and by their colour. **Holotype**: Pl.1, fig.13. **Dimensions of holotype**: Length of ray = 7.0μm; maximum width of ray = 4.0μm. **Type level**: Arab D Formation (Kimmeridgian). **Type locality**: Well Qatif-67, 7124.50' (core), Qatif Field, eastern Saudi Arabia. **Occurrence**: Permian-Pleistocene.

Fusellinus elongatus sp. nov.

Pl.1, figs 14, 15. **Derivation of name**: From *elongatus*, Latin for 'elongated', referring to the elongated shape of the rays. **Diagnosis**: A species of *Fusellinus* having relatively long, elongated rays. **Remarks**: The colour of the rays is yellowish-brown in XPL. This form is distinguished from *F. brevis* by its elongated shape. **Holotype**: Pl.1, fig.15. **Dimensions of holotype**: Length of ray = 13.5μm; maximum width of ray = 3.0μm. **Type level**: Arab D Formation (Kimmeridgian). **Type locality**: Well Qatif-58, 7438.70' (core), Qatif Field, eastern Saudi Arabia. **Occurrence**: Upper Jurassic-Pleistocene.

Fusellinus gigas sp. nov.

Pl.1, figs 1-5. **Derivation of name**: From *gigas*, Greek for 'giant', referring to its relatively large size. **Diagnosis**: A species of *Fusellinus* having relatively large fusiform rays. The length of the rays is >20μm. **Remarks**: The dominant colour of the rays is greenish-blue in the outer part and reddish in the central part in XPL. The length of the joined parts of the rays greatly varies. **Holotype**: Pl.1, fig.4. **Dimensions of holotype**: Length of ray = 21.0μm; maximum width of ray = 9.0μm. **Type level**: Arab D Formation (Kimmeridgian). **Type locality**: Well Qatif-46, 7409.00' (core), Qatif Field, eastern Saudi Arabia. **Occurrence**: Upper Jurassic-Lower Valanginian.

Fusellinus insolitus Noël, 1965

Pl.1, figs 6, 7.

1965 *Fusellinus insolitus* Noël, p.172, pl.27, figs 9, 10,

text-fig.73.

1971 *Ascidites dubius* Bonet & Benveniste-Velasquez, p.10, figs 1A-1O.

1971 *Didemnoides minutum* Bonet & Benveniste-Velasquez, p.10, text-fig.1.

1971 *Didemnoides minutum* Bonet & Benveniste-Velasquez, pp.10-11, pl.1, figs 2, 15, 16; non pl.1, figs 1, 3-14, 17-19.

Remarks: Species of *Fusellinus* having rays >10μm and <20μm in length. The dominant colour of the rays is usually greenish-blue in XPL, although, rarely, the central part of the rays is reddish. The rays of this form resemble those of *Micrascidites vulgaris* Deflandre & Deflandre-Rigaud (1956), but differ from it by having smooth surfaces, whereas the latter has fibrous surfaces. The rays form a stellate spicule in *M. vulgaris,* whereas they are believed to form spherical spicules in *F. insolitus*. **Occurrence**: Permian-Pleistocene.

Geminitrabalis gen nov.

Type species: *Geminitrabalis depressus* sp. nov. **Derivation of name**: From *geminus*, Latin for 'twin', and *trabalis*, Latin for 'twin beam', referring to the two rays forming the spicule. **Diagnosis**: Didemnid ascidian spicule having two fusiform rays joined along their short lengths. The rays share one appendix, inserted between them at the suture, located towards one pole.

Geminitrabalis depressus sp. nov.

Pl.5, figs 1-6. **Derivation of name**: From *depressus*, Latin for 'low', or 'pressed down', referring to the way in which the appendix is inserted between the rays. **Diagnosis**: Species of *Geminitrabalis* having two subrectangular rays, joined along their shorter lengths, and thus forming a marked depression near one pole, along the suture. A relatively large appendix is inserted in this depression. **Remarks**: The width of the spicule rays is equal to, or greater than, the length of the spicule rays. *G. depressus* is distinguished from *G. scarabaeus* sp. nov. by having a deep depression and a larger appendix. Moreover, in *G. depressus*, the combined width of the rays is greater than their length, whereas in *G. scarabaeus,* the length of the individual rays is always greater than their combined width. **Holotype**: Pl.5, figs 1, 2 (same specimen). **Dimensions of holotype**: Length of ray = 6.0μm; width of ray = 3.0μm. **Type level**: Sulaiy Formation (Berriasian). **Type locality**: Well MRJN-64, 8563.20' (core), Marjan Field, offshore eastern Saudi Arabia. **Occurrence**: Upper Jurassic-Lower Valanginian.

Geminitrabalis scarabaeus sp. nov.

Pl.5, figs 7, 8. **Derivation of name**: From *scarabaeus*, Latin for a kind of beetle, referring to its resemblance to a beetle. **Diagnosis**: Species of *Geminitrabalis* having two fusiform rays, joined along their length, but forming a relatively small, shallow depression near one pole, along the suture, in which a relatively small appendix is situated. **Remarks**: The length of the rays is always greater than their combined width. Differs from *G. depressus* in the length of the individual rays always being greater than their combined width. **Holotype**: Pl.5, fig.8. **Dimensions of holotype**: Length of ray = 7.0μm; width of ray = 5.5μm. **Type level**: Arab D Formation (Kimmeridgian). **Type locality**: Well Qatif-58, 8096.30' (core), Qatif Field, eastern Saudi Arabia.**Occurrence**: Upper Jurassic.

Hercolithus gen. nov.

Type species: *Hercolithus cricotus* sp. nov. **Derivation of name**: From *herkos*, Greek for 'wall', referring to its wall-like appearance. **Diagnosis**: Petaloid spicule having a circular or elliptical wall made up of five to 10 brick-shaped rays. The central opening is filled with a variously-shaped process. **Remarks**: The shape of the rays is variable. An elongated, pentagonal or square process fills the central opening. *Hercolithus* is superficially similar to genera of the calcareous nannoplankton Family Polycyclolithaceae, but differs in having a single cycle of rays/elements. Moreover, these spicules, under XPL with the gypsum plate inserted, display an opposite colour distribution to genera of the Polycyclolithaceae.

Hercolithus amplexus sp. nov.

Pl.4., figs 23-26. **Derivation of name**: From *amplector*, Latin for 'encircling', referring to the encircling of the central process by rays. **Diagnosis**: An elliptical species of *Hercolithus* made up of five to six rays and an elongated central process. **Remarks**: A complete specimen was not photographed. Incomplete specimens photographed here contain only two or three rays. The complete spicule has five or six rays. The central process is elongated, but its shape varies with the ellipticity of specimens. **Holotype**: Pl.4, figs 25, 26 (same specimen). **Dimensions of holotype**: Width of spicule = 5.5μm; length of spicule = 5.5μm (broken). **Type level**: Sulaiy Formation (Valanginian). **Type locality**: Well MRJN-64, 8247.20' (core), Marjan Field, offshore eastern Saudi Arabia. **Occurrence**: Berriasian-Lower Valanginian.

Hercolithus cricotus sp. nov.

Pl.4, figs 20-22. **Derivation of name**: From *crico*, Greek for 'ring', referring to the ring-shaped spicule. **Diagnosis**: Circular to subcircular petaloid spicule made up of five irregularly-sized rays and enclosing a pentagonal central process. **Remarks**: The central process is pentagonal in well-preserved specimens. *H. cricotus* is distinguished from *H. amplexus* by being circular and possessing a pentagonal process. It differs from *H. petalus* sp. nov. in having fewer rays. **Holotype**: Pl.4, fig.20. **Dimensions of holotype**: Maximum diameter = 7.5μm; diameter of central opening = 2.5μm. **Type level**: Arab D Formation (Kimmeridgian). **Type locality**: Well Qatif-68, 7221.00' (core), Qatif Field, eastern Saudi Arabia. **Occurrence**: Lower Valanginian-Upper Jurassic.

Hercolithus petalus sp. nov.

Pl.4. figs 29, 34. **Derivation of name**: From *petalon*, Latin for 'leaf', referring to the appearance of the rays. **Diagnosis**: Circular to subcircular species of *Hercolithus*, comprising eight to 10 irregular, variably-sized rays. The central opening is filled by a rectangular process. **Remarks**: *H. petalus* is distinguished from *H. cricotus* in having eight to 10 rays, whereas the latter has only five rays. **Holotype**: Pl.4, figs 29, 34 (same specimen). **Dimensions of holotype**: Diameter of spicule = 10.0μm; diameter of central opening = 3.5μm. **Type level**: Arab D Formation (Kimmeridgian). **Type locality**: Well Qatif-40, 7481.60' (core), Qatif Field, eastern Saudi Arabia. **Occurrence**: Upper Jurassic.

Ommalithus gen. nov.

Type species: *Ommalithus clarus* sp. nov. **Derivation of name**: From *omma*, Greek for 'eye', referring to its shape. **Diagnosis**: This eye-shaped spicule appears dim (low-order grey) in XPL, unlike other spicules. The central process is bright in XPL.

Ommalithus clarus sp. nov.

Pl.5, figs 31-34. **Derivation of name**: From *clarus*, Latin for 'bright', referring to its bright process. **Diagnosis**: Relatively small, eye-shaped spicule with a central process. The ray is dim in XPL (low-order grey) and the appendix/process is bright. **Holotype**: Pl.5, figs 31, 32 (same specimen). **Dimensions of holotype**: Length = 4.0μm; width = 3.0μm. **Type level**: Sulaiy Formation (Berriasian). **Type locality**: Well MRJN-64, 8062.70' (core), Marjan Field, offshore eastern Saudi Arabia. **Occurrence**: Berriasian-Lower Valanginian.

Othniodidemnum gen. nov.

Type species: *Othniodidemnum arabianicus* sp. nov. **Derivation of name**: From *othneios*, Greek for 'strange', referring to the unusual arrangement of the appendices. **Diagnosis**: Didemnid ascidian spicule comprising a fusiform ray with two appendices, one situated at one pole of the ray, the other unilateral but in proximity to the other pole. **Remarks**: *Othniodidemnum* is distinguished from *Disechinatus* in having one of the appendices at its pole. It is distinguished from *Bicephalodidemnum* in having one lateral and one polar appendix. The latter has bipolar appendices.

Othniodidemnum arabianicus sp. nov.

Pl.3, figs 20, 25. **Derivation of name**: After the Arabian Peninsula, from which it is described. **Diagnosis**: Spicule comprising a squarish truncated fusiform ray and bearing two appendices. The appendices are situated, respectively, at one pole and on one side close to the other pole. **Remarks**: *O. arabianicus* is distinguished from species of the genus *Disechinatus* in having one of the appendices situated at one pole. It is distinguished from *Bicephalodidemnum amphicarenon* in having one lateral and one polar appendix. The latter has bipolar appendices. **Holotype**: Pl.3, figs 20, 25 (same specimen). **Dimensions of holotype**: Length and width of ray = 5.0μm. **Type level**: Sulaiy Formation (Berriasian). **Type locality**: Well MRJN-39, 8200.20' (core), Marjan Field, offshore eastern Saudi Arabia. **Occurrence**: Berriasian-Lower Valanginian.

Paleodidemnum gen. nov.

Type species: *Paleodidemnum saudicus* sp. nov. **Derivation of name**: From *paleo*, Latin for 'old', referring to the older stratigraphic range of this genus, compared to other didemnid ascidian spicules. **Diagnosis**: Spicule having a fusiform, or modified fusiform, ray with a single unilateral appendix. **Remarks**: *Paleodidemnum* is distinguished from *Cephalodidemnum* by the position of the appendix; in *Paleodidemnum* the appendix is single and unilateral, whereas in *Cephalodidemnum,* the appendix is polar.

Paleodidemnum acutus sp. nov.

Pl.2, figs 22, 23. **Derivation of name**: From *acutus*, Latin for 'pointed', referring to the pointed end of the ray. **Diagnosis**: Species of *Paleodidemnum* having a concavo-convex fusiform ray, which tapers towards one pole. The single unilateral appendix is located towards the tapered end of the ray, and situated on the concave side of the ray. **Remarks**: *P. acutus* is distinguished from *P. pseudoacutus* sp. nov. in the position of its appendix; in the latter species, this is located away from the tapered end. **Holotype**: Pl.2, figs 22, 23 (same specimen). **Dimensions of holotype**: Length of ray = 8.5μm; maximum width of ray = 5.0μm. **Type level**: Sulaiy Formation (Berriasian). **Type locality**: Well MRJN-39, 8225.70' (core), Marjan Field, offshore eastern Saudi Arabia. **Occurrence**: Upper Jurassic-Lower Valanginian.

Paleodidemnum alatus sp. nov.

Pl.2, figs 34-36. **Derivation of name**: From *alatus*, Latin for 'wing', referring to the wing-like extension of the ray. **Diagnosis**: Species of *Paleodidemnum* having an elongated fusiform ray with a wing-like extension at one pole. A relatively large single unilateral appendix is situated in a relatively broad depression. **Holotype**: Pl.2, figs 34, 35 (same specimen). **Dimensions of holotype**: Length of ray = 11.5μm; maximum width of ray = 5.0μm. **Type level**: Sulaiy Formation (Berriasian). **Type locality**: Well Marjan-64, 8632.20' (core), Marjan Field, offshore eastern Saudi Arabia. **Occurrence**: Berriasian-Lower Valanginian.

Paleodidemnum caudatus sp. nov.

Pl.2, figs 12-19; Pl.3, fig.5. **Derivation of name**: From *cauda*, Latin for 'appendage', or 'tail', referring to the position of the appendix adjacent to the pole of the ray. **Diagnosis**: Species of *Paleodidemnum* having a fusiform ray with a single unilateral appendix placed adjacent to

one of the poles. **Remarks**: *P. caudatus* is distinguished from *P. saudicus* sp. nov. and *P. metaxy* sp. nov. in having an appendix adjacent to one pole, whereas in *P. saudicus*, the appendix is at the mid-point of the ray, and in *P. metaxy*, the appendix lies between the mid-point and pole of the ray. **Holotype**: Pl.2, fig.17. **Dimensions of holotype**: Length of ray = 6.0μm; maximum width of ray = 4.0μm. **Type level**: Arab D Formation (Kimmeridgian). **Type locality**: Well Qatif-46, 7411.40' (core), Marjan Field, offshore eastern Saudi Arabia. **Occurrence**: Upper Jurassic-Lower Valanginian.

Paleodidemnum causianus sp. nov.

Pl.3, figs 3, 4. **Derivation of name**: From *causia*, Latin for 'hat', referring to the location of the appendix. **Diagnosis**: Species of *Paleodidemnum* having a cylindrical fusiform ray with an appendix lying in a relatively broad depression along one side. **Remarks**: The base of the appendix is almost equal in length to the length of the ray. *P. causianus* is distinguished from *P. marjanensis* sp. nov. in having a cylindrical ray with a broad depression along one side, whereas in the latter the ray is trapezoid. **Holotype**: Pl.3, figs 3, 4 (same specimen). **Dimensions of holotype**: Length of ray = 4.5μm; maximum width of ray = 3.5μm. **Type level**: Sulaiy Formation (Berriasian). **Type locality**: Well Marjan-64, 8237.10' (core), Marjan Field, offshore eastern Saudi Arabia. **Occurrence**: Upper Jurassic-Lower Valanginian.

Paleodidemnum coniger sp. nov.

Pl.3, figs 21-24. **Derivation of name**: From *coniger*, Latin for 'cone', referring to its conical shape. **Diagnosis**: Species of *Paleodidemnum* having a slightly concavo-convex, rectangular fusiform ray and a conical unilateral appendix. The base of the appendix extends along the entire concave length of the ray. **Remarks**: *P. coniger* is distinguished from *P. procerus* sp. nov. in having a conical appendix, whereas the latter has a more slender and larger appendix. **Holotype**: Pl.3, figs 22, 23 (same specimen). **Dimensions of holotype**: Length of ray = 5.0μm; maximum width of ray = 2.5μm. **Type level**: Sulaiy Formation (Berriasian). **Type locality**: Well MRJN-39, 8231.70' (core), Marjan Field, offshore eastern Saudi Arabia. **Occurrence**: Upper Jurassic-Lower Valanginian.

Paleodidemnum curvus sp. nov.

Pl.3, figs 6-10. **Derivation of name**: From *curvus*, Latin for 'bent', referring to the bent appearance of the ray. **Diagnosis**: Species of *Paleodidemnum* having a strongly concavo-convex fusiform ray with a relatively large unilateral appendix. **Remarks**: *P. curvus* is distinguished from other species of *Paleodidemnum* in having a strongly concavo-convex ray. **Holotype**: Pl.3, fig.8. **Dimensions of holotype**: Length of ray = 6.5μm; maximum width of ray = 2.5μm; length of appendix = 6.0μm. **Type level**: Arab D Formation (Kimmeridgian). **Type locality**: Well Qatif-58, 7483.70' (core), Qatif Field, eastern Saudi Arabia. **Occurrence**: Upper Jurassic-Lower Valanginian.

Paleodidemnum galbulus sp. nov.

Pl.3, figs 11-15. **Derivation of name**: From *galbulus*, Latin for 'cone of the cypress', referring to its appearance. **Diagnosis**: Species of *Paleodidemnum* having a slightly concavo-convex modified fusiform ray with a relatively large appendix attached along almost the entire length of the flatter side. The suture is straight. **Remarks**: The straight suture distinguishes this species from other species of *Paleodidemnum*. **Holotype**: Pl.3, figs 14, 15 (same specimen). **Dimensions of holotype**: Length of ray = 7.0μm; maximum width of ray = 4.0μm; length of appendix = 4.5μm; maximum width of appendix = 6.0μm. **Type level**: Sulaiy Formation (Berriasian). **Type locality**: Well MRJN-64, 8623.20' (core), Marjan Field, offshore eastern Saudi Arabia. **Occurrence**: Upper Jurassic-Lower Valanginian.

Paleodidemnum marjanensis sp. nov.

Pl.3, figs 26-30. **Derivation of name**: After the Marjan Field in Saudi Arabia, where this species has been recorded. **Diagnosis**: Species of *Paleodidemnum* having a trapezoid fusiform ray, with an appendix located along the shorter length. The appendix lies in a shallow depression, the base of the appendix being equal to the length of the ray. **Remarks**: The trapezoid ray distinguishes this form from other species of *Paleodidemnum*. **Holotype**: Pl.3, fig.30. **Dimensions of holotype**: Length of ray = 8.5μm; maximum width of ray = 7.0μm. **Type level**: Arab D Formation (Kimmeridgian). **Type locality**: Well Qatif-48, 7444.80' (core), Qatif Field, eastern Saudi Arabia. **Occurrence**: Upper Jurassic-Lower Valanginian.

Paleodidemnum metaxy sp. nov.

Pl.2, figs 4-11. **Derivation of name**: From *metaxy*, Greek for 'between', referring to the position of the appendix between the positions seen in *P. saudicus* sp. nov. and *P. caudatus*. **Diagnosis**: Species of *Paleodidemnum* having a fusiform ray with an appendix positioned between the mid-point and one pole of the ray. **Remarks**: This species has its appendix mid-way between the mid-point and one pole. It is thus distinct from *P. saudicus* sp. nov. (appendix at mid-point of ray) and *P. caudatus* (appendix adjacent to pole). **Holotype**: Pl.2, fig.6a. **Dimensions of holotype**: Length of ray = 10.0μm; maximum width of ray = 4.5μm. **Type level**: Sulaiy Formation (Berriasian). **Type locality**: Well MRJN-64, 8623.20' (core), Marjan Field, offshore eastern Saudi Arabia. **Occurrence**: Upper Jurassic-Lower Valanginian.

Paleodidemnum phossonion sp. nov.

Pl.2, figs 32, 33. **Derivation of name**: From *phosson*, Greek for 'sail', referring to the appearance of its appendix. **Diagnosis**: Species of *Paleodidemnum* having a slightly concavo-convex fusiform ray with a sail-shaped

appendix. The base of the appendix extends along the entire length of the concave side of the ray. **Remarks**: *P. phossonion* is distinguished from *P. saudicus* sp. nov. and *P. procerus* sp. nov. in having a sail-shaped appendix. **Holotype**: Pl.2, figs 32, 33 (same specimen). **Dimensions of holotype**: Length of ray = 7.0μm; maximum width of ray = 3.0μm; length of appendix = 4.0μm; width of appendix = 5.0μm. **Type level**: Sulaiy Formation (Berriasian). **Type locality**: Well MRJN-64, 8546.20' (core), Marjan Field, offshore eastern Saudi Arabia. **Occurrence**: Berriasian-LowerValanginian.

Paleodidemnum procerus sp. nov.

Pl.3, figs 1, 2. **Derivation of name**: From *procerus*, Latin for 'tall', or 'slender', referring to its appendix. **Diagnosis**: Species of *Paleodidemnum* having a relatively small, slightly concavo-convex, rectangular fusiform ray with a relatively long, slender appendix. The appendix is attached to the convex side of the ray, its base extending for almost the entire length of the ray. **Remarks**: The appendix dominates the species. In *P. coniger*, the ray is slightly concave where the appendix is attached, unlike in this species. **Holotype**: Pl.3, figs 1, 2 (same specimen). **Dimensions of holotype**: Length of ray = 3.5μm; width of ray = 2.5μm; length of appendix = 6.0μm. **Type level**: Sulaiy Formation (Berriasian). **Type locality**: Well MRJN-64, 8557.20' (core), Marjan Field, offshore eastern Saudi Arabia. **Occurrence**: Upper Jurassic-Lower Valanginian.

Paleodidemnum pseudoacutus sp. nov.

Pl.2, figs 20, 21. **Derivation of name**: From *pseudo*, Greek for 'false', referring to its false similarity to *Paleodidemnum acutus*. **Diagnosis**: Species of *Paleodidemnum* having a ray which tapers towards one pole. A single unilateral appendix is attached towards the untapered end of the ray. **Remarks**: *P. pseudoacutus* is distinguished from *P. acutus* in the position of the appendix. **Holotype**: Pl.2, figs 20, 21 (same specimen). **Dimensions of holotype**: Length of ray = 8.5μm; maximum width of ray = 5.0μm. **Type level**: Sulaiy Formation (Berriasian). **Type locality**: Well MRJN-39, 8225.70' (core), Marjan Field, offshore eastern Saudi Arabia. **Occurrence**: Upper Jurassic-Lower Valanginian.

Paleodidemnum saudicus sp. nov.

Pl.2, figs 24-31.

1971 *Didemnoides minutum* Bonet & Benveniste-Velasquez, pp.10-11, pl.1, figs 8, 10, 17, 18; non pl.1, figs 1-7, 9, 11-16, 19.

1994 *Didemnoides minutum* Bonet & Benveniste-Velasquez: Varol & Girgis, Fig.10(20).

Derivation of name: After Saudi Arabia, from where this species is described. **Diagnosis**: Species of *Paleodidemnum* having a fusiform ray with a single unilateral appendix at its mid-point. **Remarks**: *P. saudicus* is distinguished from *P. caudatus* and *P. metaxy* in having an appendix at the mid-point of the ray. This is adjacent to one pole in *P. caudatus* and between the mid-point and one pole in *P. metaxy*. **Holotype**: Pl.2, figs 27, 28 (same specimen). **Dimensions of holotype**: Length of ray = 8.5μm; maximum width of ray = 3.5μm. **Type level**: Sulaiy Formation (Berriasian). **Type locality**: Well MRJN-64, 8515.20' (core), Marjan Field, offshore eastern Saudi Arabia. **Occurrence**: Upper Jurassic-Lower Valanginian.

Unabaculus gen. nov.

Type species: *Unabaculus pseudobscurus* sp. nov. **Derivation of name**: From *unio*, Latin for 'jointed', and *baculus*, Latin for 'rod', referring to its two joined rays. **Diagnosis**: Spicule made up of subtrapezoid duplex fusiform rays, joined along the short length of the subtrapezoid, with bipolar appendices located in depressions formed at the poles of the joined rays. **Remarks**: *Unabaculus* is distinguished from *Didemnobijugatus* by having appendices.

Unabaculus pseudobscurus sp. nov.

Pl.4, figs 5-11. **Derivation of name**: From *pseudo*, Latin for 'false', referring to its superficial similarity to the calcareous nannofossil *Calculites obscurus*. **Diagnosis**: The spicule is made up of subtrapezoid duplex fusiform rays, joined along their short lengths. Two bipolar appendices sit in the depressions formed at the ends of the suture between the rays. **Remarks**: This form differs from the nannofossil species *Calculites obscurus* by lacking a rim. The latter is also flatter and larger. **Holotype**: Pl.4, figs 7, 8 (same specimen). **Dimensions of holotype**: Length of spicule = 6.0μm; width of spicule = 5.0μm. **Type level**: Sulaiy Formation (Berriasian). **Type locality**: Well Marjan-64, 8538.70' (core), Marjan Field, offshore eastern Saudi Arabia. **Occurrence**: Upper Jurassic-Lower Ryazanian.

Velasquezia gen. nov.

Type species: *Velasquezia praegothica* (Herrle) nov. comb. **Derivation of name**: In honour of N. Benveniste-Velasquez (Instituto Mexicano Del Petroleo, Mexico), didemnid ascidian specialist. **Diagnosis**: Spicules made up of four joined fusiform rays. **Remarks**: The joined part of the rays is usually shorter than the free part of the rays. The rays are identical in size in well-preserved specimens. *Velasquezia* differs from *Acinodidemnum* in having four rays, whereas the latter has a single ray and two bilateral appendices. *Velasquezia* is superficially similar in appearance to species of the calcareous nannofossil genus *Uniplanarius* but differs in having a single cycle. Species of *Velasquezia,* in XPL with a gypsum plate inserted, display an opposite colour distribution to that of species of *Uniplanarius*.

Velasquezia minuta (Bonet & Benveniste-Velasquez) comb. nov.

Pl.1, fig.29. **Basionym**: *Didemnoides minutum* Bonet & Beneviste-Velasquez, 1971, pp.11-13, pl.1, figs 3, 4, 7, 11; non pl.1, figs 1, 2, 5, 6, 8-10, 12-19. *Revista del Instituto Mexicano del Petroleo*, **3**: 8-35. **Remarks**: In this spicule, four fusiform rays are joined to form an asymmetrical cross. The opposite angles of the cross are equal. The free parts of the rays are usually longer than the joined lengths. **Occurrence**: Upper Jurassic-Pleistocene.

Velasquezia praegothica (Herrle) comb. nov.

Pl.1, figs 21-24. **Basionym**: *Uniplanarius praegothica* Herrle, 2002, p.78, pl.6, fig.23. *Institut und Museum für Geologie und Paläontologie der Universität Tubingen,* **27**: 1-114.

1971 *Didemnoides minutum* Bonet & Benveniste-Velasquez, pp.11-13, pl.1, figs 9, 12; non pl.1, figs 1-8, 10, 11, 13-19.

Remarks: The spicule is made up of four fusiform rays. The spicule rays are joined to each other at right-angles. *V. praegothica* is distinguished from *V. minuta* by the arrangement of the rays. In *V. praegothica*, the rays join each other at right-angles to form a symmetrical cross, whilst in *V. minuta*, the rays make an asymmetrical cross, in which opposite angles are equal. **Occurrence**: Upper Jurassic-Pleistocene.

4.2 Calcareous nannofossils

Cyclagelosphaera Noël, 1965

Cyclagelosphaera riyadhensis sp. nov.

Pl.2, figs 1-3. **Derivation of name**: After Riyadh, capital of Saudi Arabia, from where this form has been recorded. **Diagnosis**: A large species of *Cyclagelosphaera* (10-13μm) with 24 to 36 elements in the distal shield. **Remarks**: This species of *Cyclagelosphaera* is relatively large, with a small, closed central-area, enclosed by a narrow tube-cycle. The placolith shields are monocyclic and birefringent in XPL. *C. riyadhensis* is distinguished from *Cyclagelosphaera deflandrei* by its smaller size. The latter has a minimum size >13μm and is not recorded above the Lower Oxfordian Hanifa Formation in the Arabian Peninsula. Poorly-preserved specimens of *C. riyadhensis* may be confused with the ascidian spicule *Didemnoides radiatus*, however, *C. riyadhensis* always appears brownish to yellowish in XPL, whereas *D. radiatus* appears brownish-blue. Moreover, *C. riyadhensis* has distinct black gyres/extinction lines, a defined central-area and a tube-cycle, whereas *D. radiatus* lacks these features. **Holotype**: Pl.2, fig.1. **Dimensions of holotype**: Diameter = 12.0μm. **Type level**: Jubaila Formation (Kimmeridgian). **Type locality**: Diplomat outcrop, Sample D-68, near Riyadh, Riyadh-Mecca highway, central Saudi Arabia. **Occurrence**: Upper Jurassic. The last occurrence of this form was noted at the top of the Jubaila Formation.

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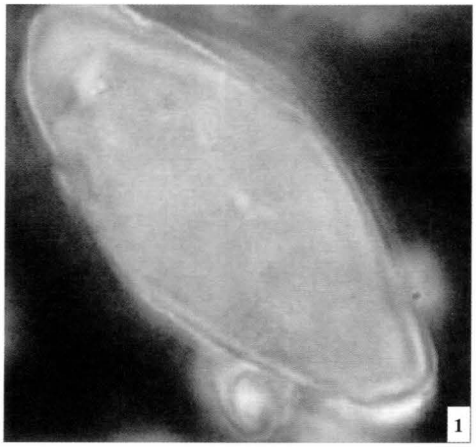
Plate 1

Fusellinus, Didemnotribaculus, Acinodidemnum, Velasquezia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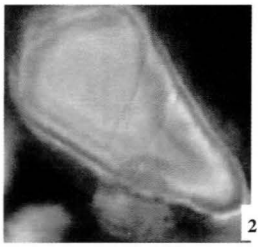
Fusellinus gigas (Qatif-46, 7403')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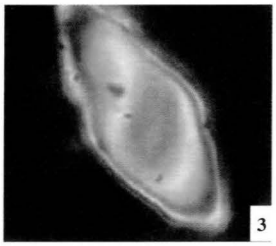
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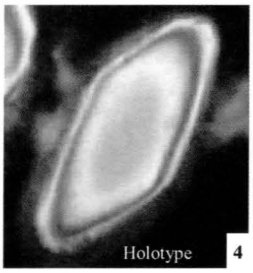

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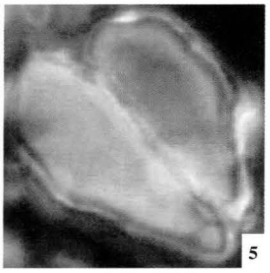
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F. gigas (Qatif-48, 7496')


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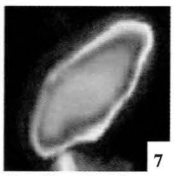
Fusellinus insolitus (MRJN-39, 8169.2')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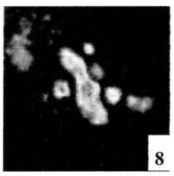
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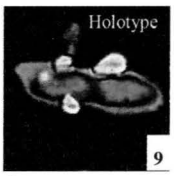
Didemnotribaculus anceps (HRDH-87, 7074.1')



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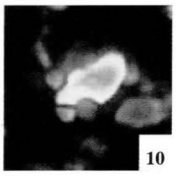
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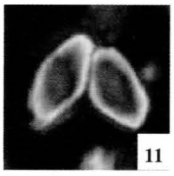
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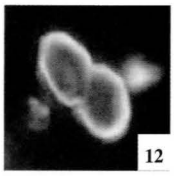
Fusellinus brevis (MRJN-39, 8103.7')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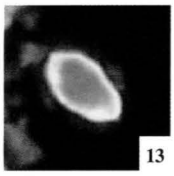
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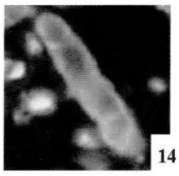
F. brevis (Qatif-67, 7124.5')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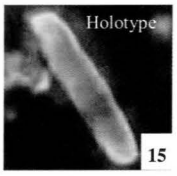
Fusellinus elongatus (Qatif-58, 7438.7')



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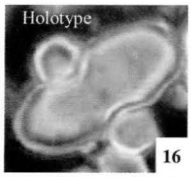

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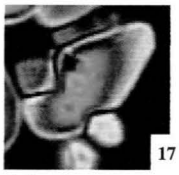
Acinodidemnum lineola (Qatif-48, 7946')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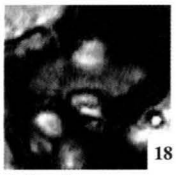
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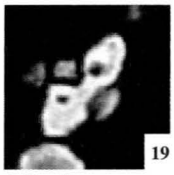
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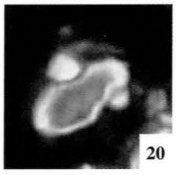
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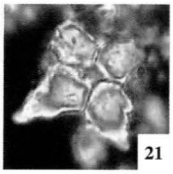
A. ecpalesis (MRJN-64, 8107')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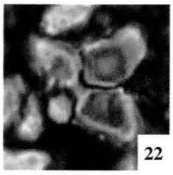
Velasquezia praegothica (MRJN-64, 8240.2')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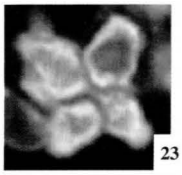
V. praegothica (MRJN-64, 8240.2')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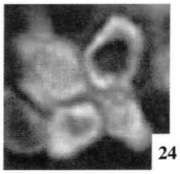
Velasquezia praegothica (LWHH-17, 8191.2')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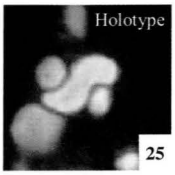

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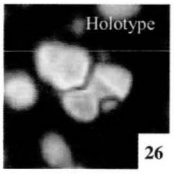

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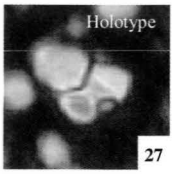
Acinodidemnum arcuatus (MRJN-39, 7981.2')



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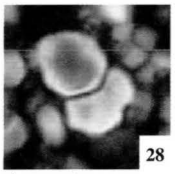
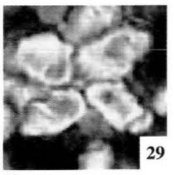
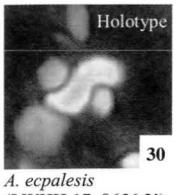

28

A. arcuatus (LWHH-17, 7996.7')


29

V. minuta (LWHH-17, 8191.2')



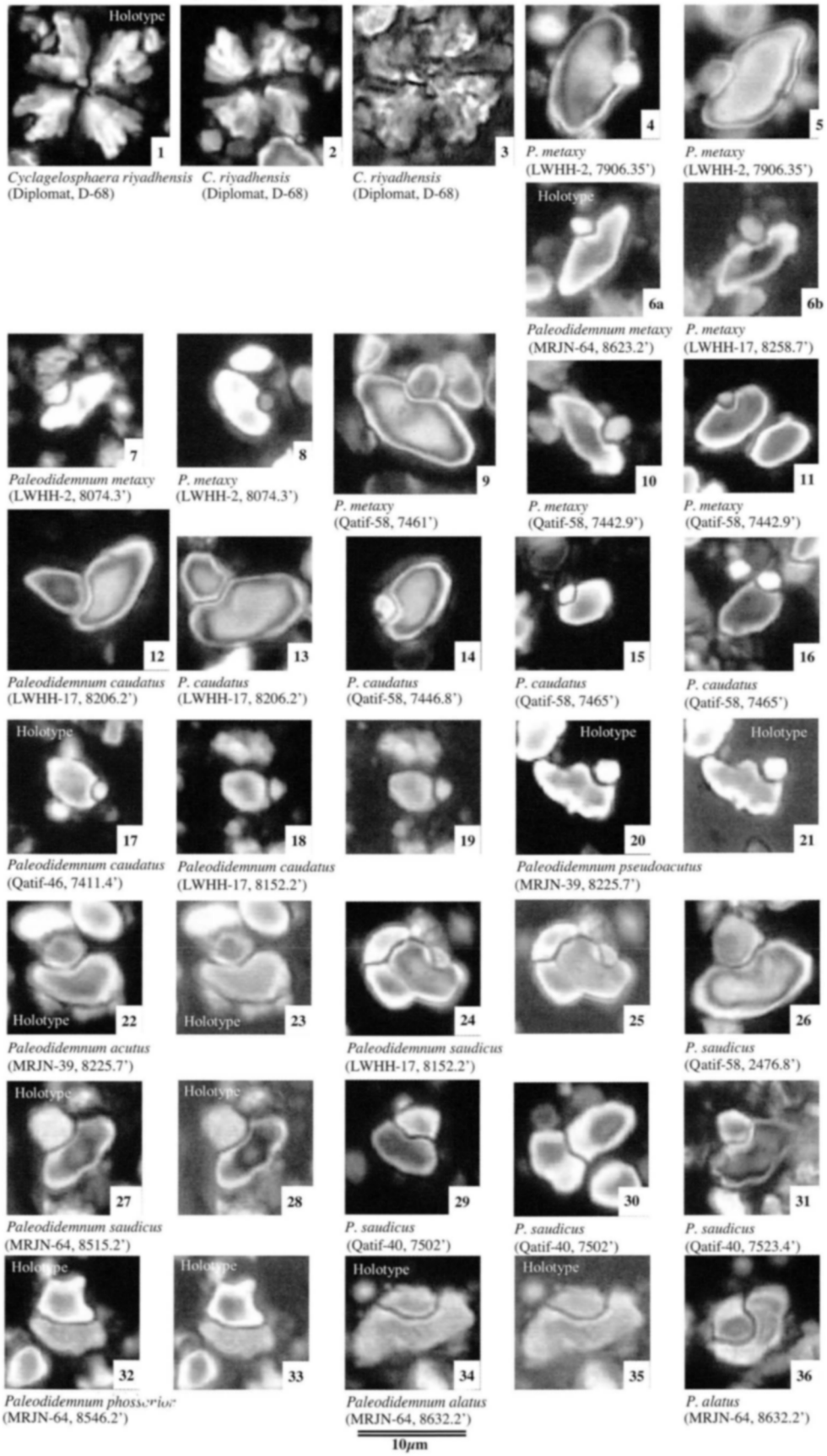
30

A. ecpalesis (LWHH-17, 8656.2')

10μm

Plate 2

Cyclagelosphaera, Paleodidemnum



Cyclagelosphaera riyadhensis (Diplomat, D-68)

C. riyadhensis (Diplomat, D-68)

C. riyadhensis (Diplomat, D-68)

P. metaxy (LWHH-2, 7906.35')

P. metaxy (LWHH-2, 7906.35')

Paleodidemnum metaxy (MRJN-64, 8623.2')

P. metaxy (LWHH-17, 8258.7')

Paleodidemnum metaxy (LWHH-2, 8074.3')

P. metaxy (LWHH-2, 8074.3')

P. metaxy (Qatif-58, 7461')

P. metaxy (Qatif-58, 7442.9')

P. metaxy (Qatif-58, 7442.9')

Paleodidemnum caudatus (LWHH-17, 8206.2')

P. caudatus (LWHH-17, 8206.2')

P. caudatus (Qatif-58, 7446.8')

P. caudatus (Qatif-58, 7465')

P. caudatus (Qatif-58, 7465')

Paleodidemnum caudatus (Qatif-46, 7411.4')

Paleodidemnum caudatus (LWHH-17, 8152.2')

Paleodidemnum pseudoacutus (MRJN-39, 8225.7')

Paleodidemnum acutus (MRJN-39, 8225.7')

Paleodidemnum saudicus (LWHH-17, 8152.2')

P. saudicus (Qatif-58, 2476.8')

Paleodidemnum saudicus (MRJN-64, 8515.2')

P. saudicus (Qatif-40, 7502')

P. saudicus (Qatif-40, 7502')

P. saudicus (Qatif-40, 7523.4')

Paleodidemnum phoscriae (MRJN-64, 8546.2')

Paleodidemnum alatus (MRJN-64, 8632.2')

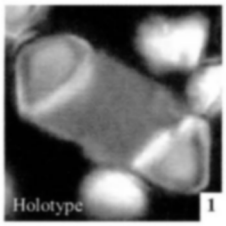
P. alatus (MRJN-64, 8632.2')

Plate 3

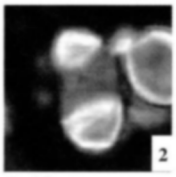
Paleodidemnum, Diplinthos, Othniodidemnum, Didemnoides

Plate 4

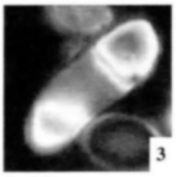
Bactrol., Unabacul., Cephalodid., Bicephalodid., Hercol., Didemnobijug.



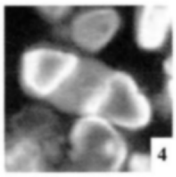
Bactrolithus delicatus
(Qatif-48, 7496')



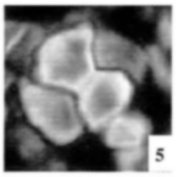
B. delicatus
(LWHH-17, 8511.2')

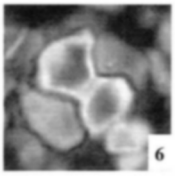


B. delicatus
(MRJN-39, 8366.7')

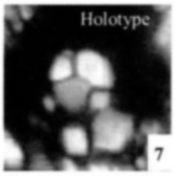


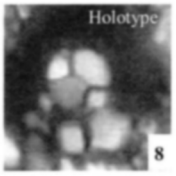
B. delicatus
(LWHH-17, 8511.2')



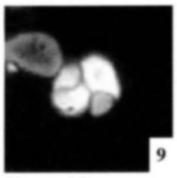


Unabaculus pseudobscurus
(MRJN-39, 8261.7')

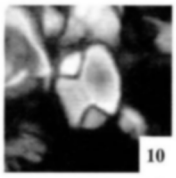


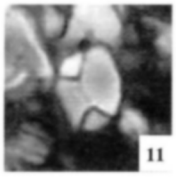


Unabaculus pseudobscurus
(MRJN-64, 8538.7')

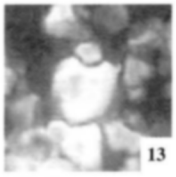


U. pseudobscurus
(LWHH-17, 8397.2')

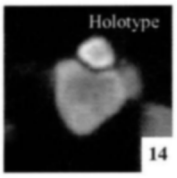




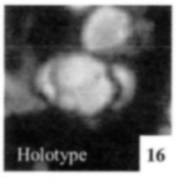
Unabaculus pseudobscurus
(MRJN-64, 8151.2')



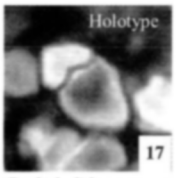
Cephalodidemnum pseudocarenon
(MRJN-64, 8225.2')

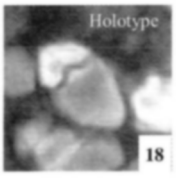


C. pseudocarenon
(MRJN-64, 8225.2')

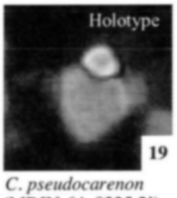


Bicephalodidemnum amphicarenon
(MRJN-39, 8372.7')

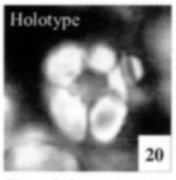




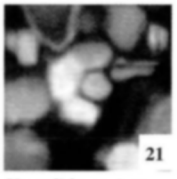
Cephalodidemnum carenon
(MRJN-39, 8269.2')



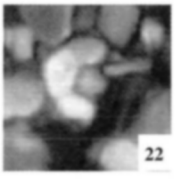
C. pseudocarenon
(MRJN-64, 8225.2')

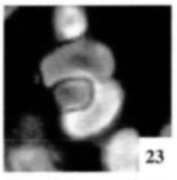


Hercolithus cricotus
(Qatif-68, 7221')

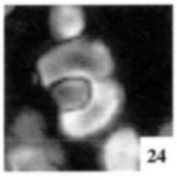


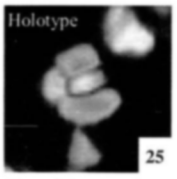
Hercolithus cricotus
(MRJN-64, 8030.2')



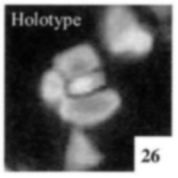


Hercolithus amplexus
(LWHH-17, 8058.7')

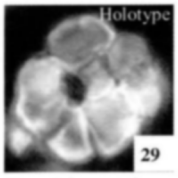




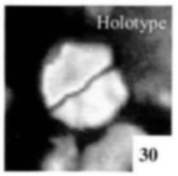
Hercolithus amplexus
(MRJN-64, 8247.2')

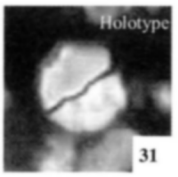


Didemnobijugatus zigzag
(MRJN-64, 8511.2')

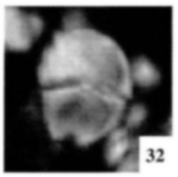


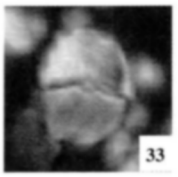
Hercolithus petalus
(Qatif-40, 7481.6')





Didemnobijugatus dichotomus
(LWHH-17, 8683.2')





Didemnobijugatus dichotomus
(LWHH-17, 8683.2')

Hercolithus petalus
(Qatif-40, 7481.6')

10μm

Plate 5

Geminitrabalis, Disechinatus, Ommalithus