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Cenomanian echinoids, larger foraminifera and calcareous algae from the Natih Formation, central Oman Mountains

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Within the Natih Formation (late Albian–early Turonian) of the Oman Mountains, there occurs a distinctive, correlatable horizon with an abundant and moderately diverse echinoderm fauna. This horizon occurs within Member c of the Natih Formation and can be assigned a latest middle Cenomanian age based on the associated microfossil assemblage which is dominated by alveolinids and gymnocodiacian algae. The depositional environment of this echinoderm-rich bed was probably back barrier, close to radiolitid rudist biostromes and bioclastic shoals which fringed the upper Natih shelf edge. Nine species of echinoid are described, most of which are new records for the Arabian Peninsula. One new species, *Pedinopsis sphaerica*, is erected. *Coenholectypus larteti* dominates the assemblage and occurs together with *Stereocidaris sarracenarum*, *Tetragramma variolare*, *Heterodiadema lybica*, *Pedinopsis humei*, *P. desori*, *P. sphaerica*, *Hemiaster syriacus* and *H. cubicus*. The composition of the genus *Pedinopsis* is critically reviewed and a new subgenus, *Sinaiopsis*, erected. Many of the species have previously been reported from Egypt, the Sinai Peninsula and Israel.

KEY WORDS: Oman; Cenomanian; echinoids; foraminifera; algae; carbonate shelf.

1. Introduction

The Sultanate of Oman occupies the easternmost corner of the Arabian Peninsula. The Oman Mountains form a prominent arcuate range in the northern part of the country. The mountains largely comprise a sequence of thrust sheets, mainly of Mesozoic Tethyan marine sediments and volcanics (the Hawasina and Haybi complexes and the Sumeini Group), overlain by the Semail Ophiolite slab. These were emplaced during the Campanian onto an autochthonous sequence consisting of Precambrian to Cambrian basement overlain by Permian to Late Cretaceous sediments largely of shelf origin (the Hajar Super-group). Unconformably overlying the thrust sequence are marine Maastrichtian and Palaeogene sediments which today crop out mainly around the mountain flanks. The regional geology is further detailed in Glennie *et al.* (1974), Glennie (1977) and Hughes-Clarke (1988). Figure 1 presents a simplified geological map for the Oman Mountains region.

The autochthonous Cretaceous shelf sequence forming part of the Hajar Super-group, from which the studied fauna and flora were collected, crops out in four main areas (Figure 1); the Musandam Peninsula, the tectonic windows of Jebel Akhdar and Saih Hatat, and the isolated jebels to the south of the main mountain belt (i.e. Jebel Nahdah, Jebel Salak, Jebel Madamar and Jebel Madar). This paper describes a moderately diverse and well-preserved Cenomanian echinoid fauna from a distinctive bed within the Natih Formation (the uppermost part of this autochthonous Cretaceous shelf sequence) which is known to occur on the southern side of Jebel Akhdar and at the jebels to the south of the main mountain belt. The majority of the macrofauna was collected from outcrops at the western end of Jebel Madamar (see Figures 2, 3).

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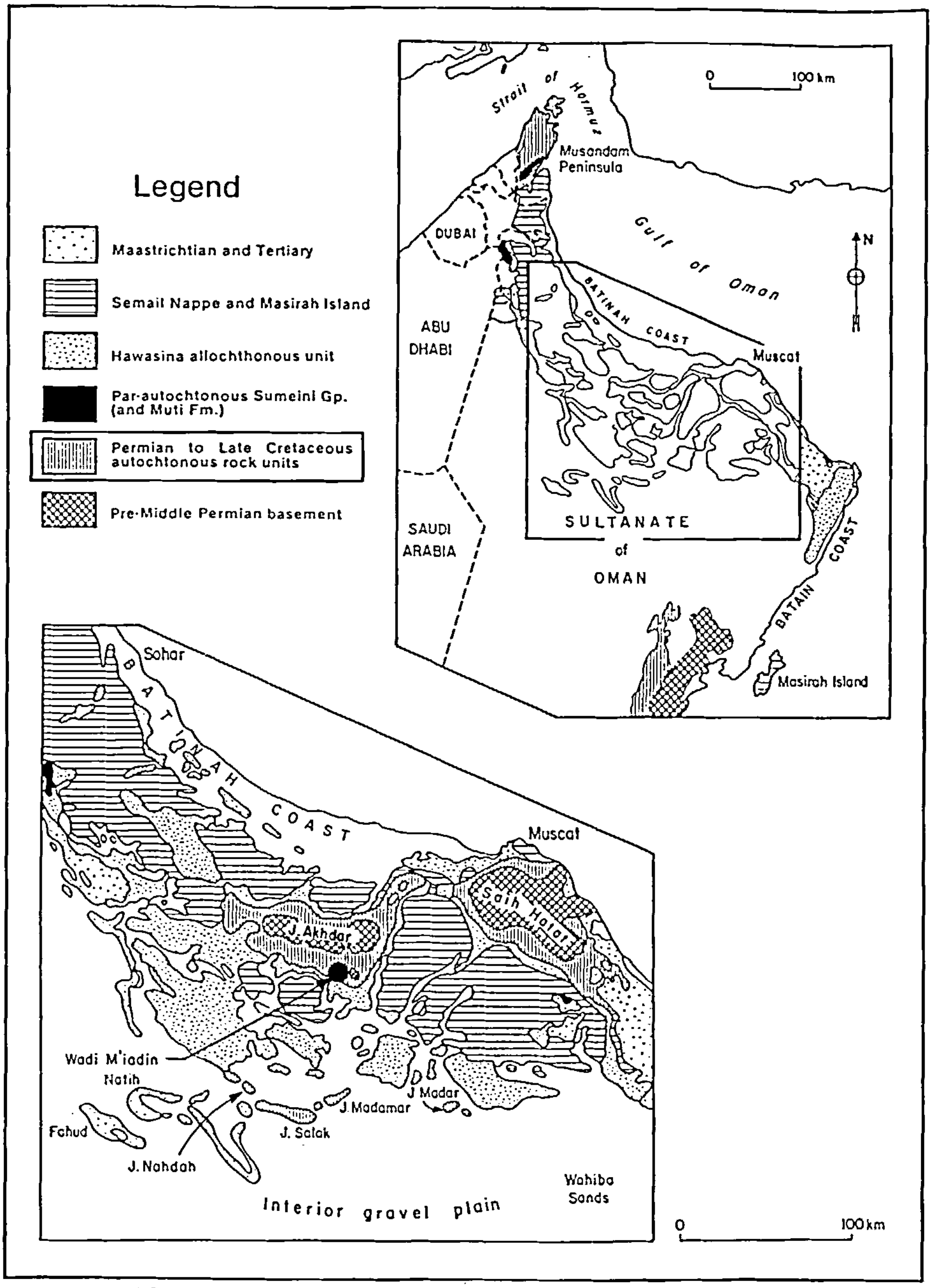


Figure 1. Simplified geological map of the Oman Mountains. The echinoid-rich horizon described in this paper occurs within the Permian to Late Cretaceous authochthonous sediments. The localities mentioned in the text are indicated. Figure modified from Simmons & Hart (1987).

Little has been published on the echinoid faunas of the Oman Mountains region and adjacent areas. Carter (1852) described Late Cretaceous sediments outcropping in the Hadramaut region of south-east Oman. Duncan (1865) described the echinoid fauna from these sediments which are largely of Cenomanian age. Duncan's determinations are in need of revision, but the fauna that he documented, now housed in the British Museum (Natural History), shares no species in common with

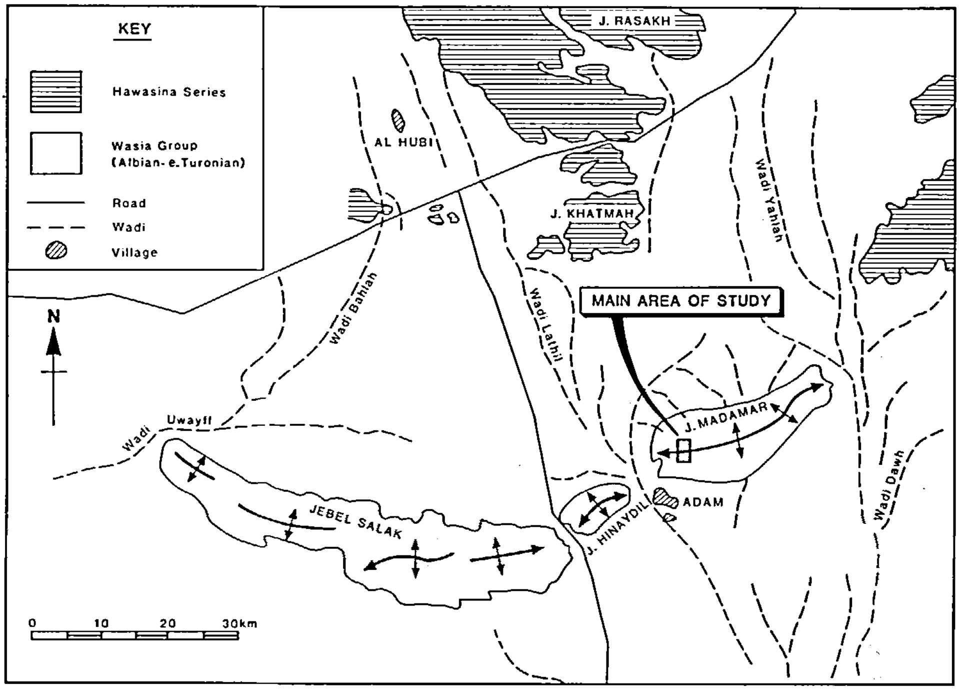


Figure 2. Map showing the location of the Jebel Salak and Jebel Madamar anticlines. The main source of the material described herein is from the western end of Jebel Madamar.

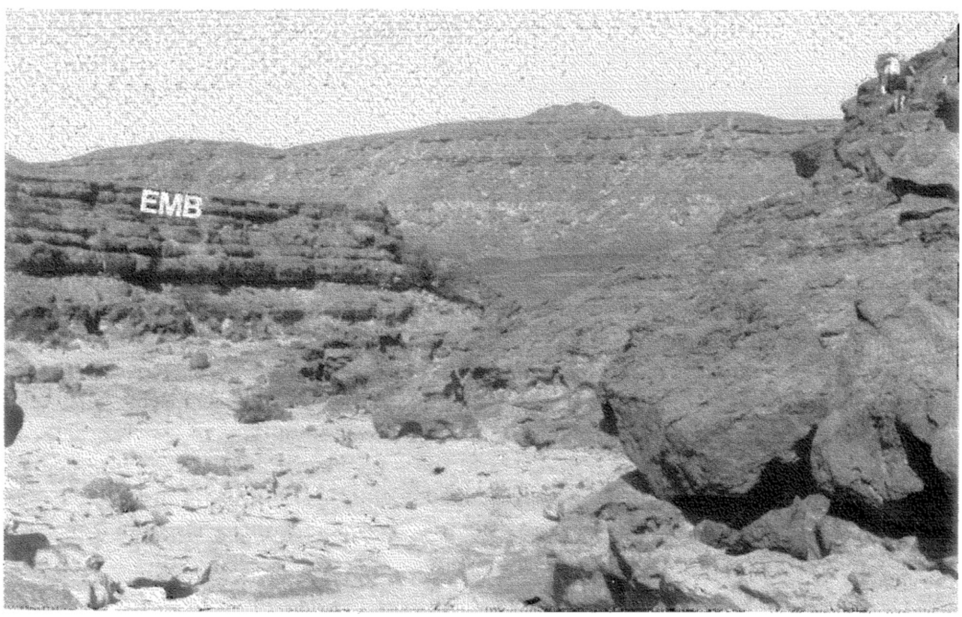


Figure 3. View of the Natih Formation at the western end of Jebel Madamar. The Echinoid Marker Bed is indicated by the letters 'EMB'.

the fauna described here and appears to be somewhat older. Lees (1928) described a few Campanian/Maastrichtian species from northern Oman and also listed *Salenia scutigera* Gray as present in Cenomanian beds in Dhofar. He also described a few Early Cretaceous species from northern Oman, including a new species, *Heteraster musandamensis*, from Aptian limestones of the Musandam Peninsula. Kuhn (1929), in his description of the palaeontology and stratigraphy of Oman, only listed the echinoid species described by Duncan (1865) from the Cenomanian of Hadramaut and mentioned a few other species from the Campanian/Maastrichtian. Clegg (1933) described echinoderms from the Cretaceous and Tertiary of the Persian Gulf (including Oman) collected by the Geological Survey of India. He described two species from unspecified levels in the Late? Cretaceous (almost certainly Campanian/Maastrichtian): *Holectypus khamirensis* from Khamir in Iran and *Pyrina arabica* from near Khalhat in Oman. A diverse Late Cretaceous echinoid fauna was described from southern Iran by Cotteau & Gauthier (1895) but this was almost entirely Campanian/Maastrichtian in age and only two possible Cenomanian species were recorded by them. Similarly, Kier (1972) described the Cretaceous echinoids from the Riyadh district of Saudi Arabia which consisted of a diverse Campanian/Maastrichtian echinoid fauna but no Cenomanian species. Ali (1989) has described an echinoid fauna of similar age from the United Arab Emirates. Roman *et al.* (1989) have recently published faunal lists of Cretaceous and Tertiary echinoids from the Dhofar region of southern Oman and discussed their biogeographical relationships. This includes fifteen Albian/Cenomanian species, but only three are common to the fauna described here.

There are few publications on the Cenomanian micropalaeontology of Oman. Glennie *et al.* (1974) outlined the microfauna present in the partly Cenomanian Wasia Group, but did not go into any detail. Simmons & Hart (1987) have produced one of the more detailed studies to date, describing the biostratigraphy and microfacies of the Early–Middle Cretaceous carbonates exposed at Wadi Mi'aidin, whilst Scott (in press) has described the chronostratigraphic setting for the entire Cretaceous of the Oman Mountains. There are more publications concerning the Cenomanian micropalaeontology of other regions of the Middle East. Those of importance to this study include Sampo (1969), Kalantari (1986; Iran), and Saint-Marc (1974, 1981; Lebanon).

2. Stratigraphic setting

The echinoid-bearing horizon that is the focus of this study occurs within the Natih Formation, which forms the upper part of the Wasia Group (Owen & Nasr, 1958) in the Oman Mountains region. This group is widely recognized throughout the Gulf region and represents the second major depositional cycle recognized by Harris *et al.* (1984) in the Cretaceous of the Arabian Peninsula. The Wasia Group contains numerous cycles of varying orders of magnitude, some at least being driven by eustatic sea-level changes (Scott, in press). The lower boundary of the Wasia Group (Figure 4) is marked by a major disconformity between limestones of the Shuaiba Formation (Kahmah Group), which in the Central Oman Mountains are early Aptian (Simmons & Hart, 1987; Scott, in press), and the shales and marls of the Nahr Umr Formation (Wasia Group), which are Albian (Simmons & Hart, 1987; Hughes-Clarke, 1988). The upper boundary of the Wasia Group (Figure 4) is marked by a hiatus between the mainly carbonate Natih Formation, which locally may be as young as earliest Turonian (Simmons & Hart, 1987; Scott,

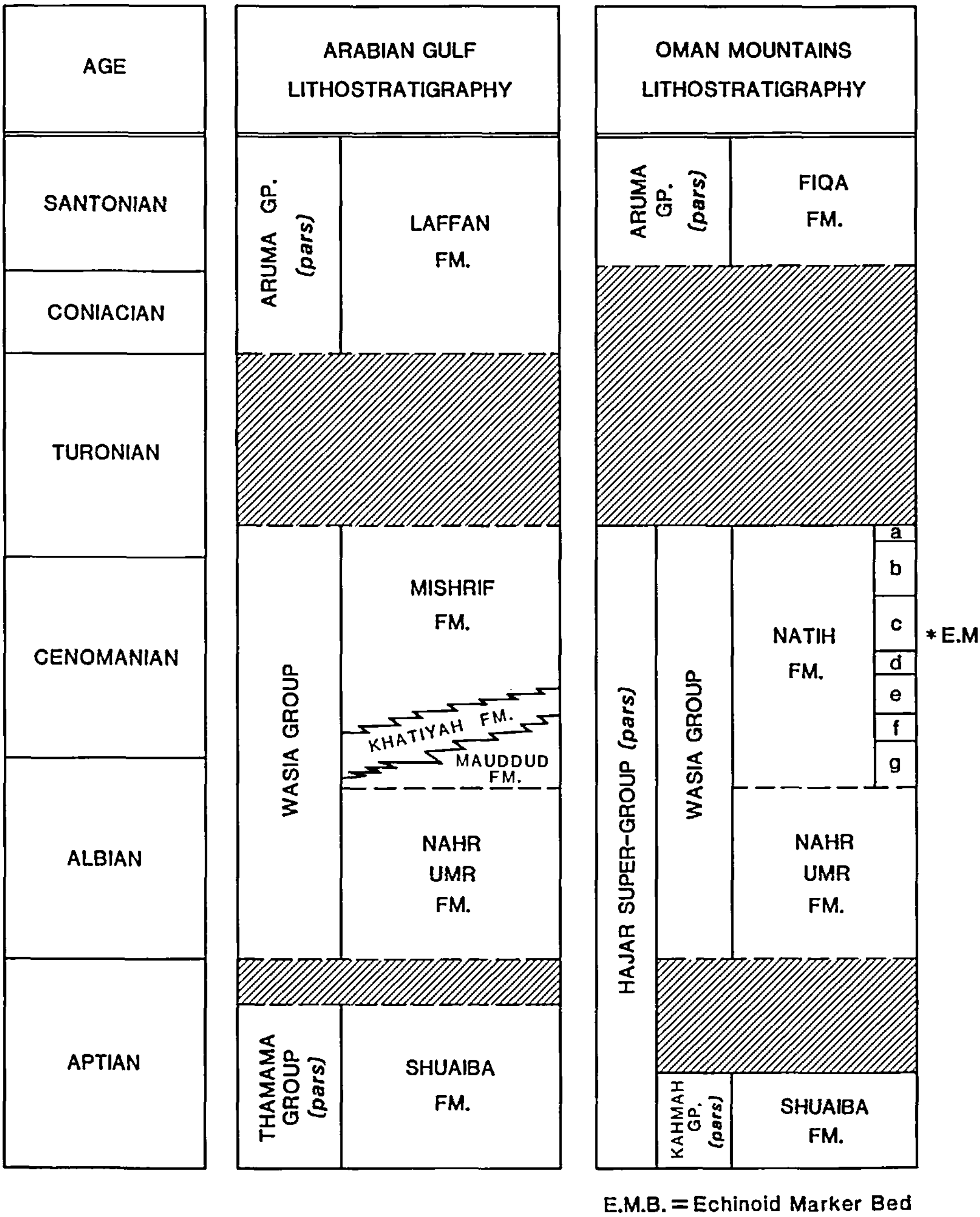


Figure 4. Lithostratigraphy of Aptian to Santonian sediments in the Arabian Gulf and Oman Mountains region.

in press; Kennedy & Simmons, in prep.) and the overlying shaley Fiqa Formation (Aruma Group), which is Santonian to Campanian in age (Hughes-Clarke, 1988). In Oman, the Wasia Group is thus divided into a lower argillaceous unit, the Nahr Umr Formation, and an upper carbonate unit, the Natih Formation. The contact between these two formations is transitional (Hughes-Clarke, 1988).

Type and reference sections of the Natih Formation were described by Hughes-Clarke (1988). The surface reference section at Wadi Mi'aidin on the southern side of Jebel Akhdar (see Figure 1) was the subject of a biostratigraphic and microfacies study by Simmons & Hart (1987). They concluded that at this locality the formation was ?late Albian/early Cenomanian–late Cenomanian. To the south of this locality the formation may be as young as earliest Turonian (Simmons & Hart, 1987; Scott, in press; Kennedy & Simmons, in prep.), although this is disputed by Hughes-Clarke (1988) and others.

Tschopp (1967), in his original description of the Wasia Limestone Formation (= Natih Formation) in the subsurface of the Fahud oilfield, recognized seven members within the formation which he termed a to g. Some authors (e.g. Harris & Frost, 1984) have suggested that these members are not recognizable in the surface outcrop sections because of facies variations. However, Scott (in press) has shown that the seven-fold subdivision of the Natih Formation into members can be applied to the outcrop sections, and has redescribed the members in terms of the facies seen in the outcrops around and to the south of Jebel Akhdar. It would appear that the echinoderm-rich horizon forming the subject of this study occurs within Member c (Figure 4).

The Natih Formation is equivalent to the Mauddud, Khatiyah (or Shilaif) and Mishrif Formations identified in the Arabian Gulf region. However, precise correlation to these formations is problematic (Harris & Frost, 1984; Brennan, 1985, 1986; O'Connor & Patton, 1986, Hughes-Clarke, 1988; Alsharhan & Nairn, 1988) because of apparently diachronous and localized intrashelf basin deposits that accumulated during the Cenomanian–Turonian period in this region. The preferred correlation used in this study is shown on Figure 4. This shows that the Mauddud Formation correlates with Members g, f and e of the Natih Formation, whilst the Mishrif Formation correlates with Members d, c, b and a (see also Harris & Frost, 1984; Alsharhan & Nairn, 1988). A hardground surface is located at the top of Member e at several localities in the Oman Mountains which probably correlates with a regional disconformity between the Mishrif and Mauddud Formations, the boundary between two regionally recognized cycles of deposition; the Nahr Umr–Mauddud cycle and the Wara–Mishrif cycle (Alsharhan & Nairn, 1988). This disconformity can also be recognized in Oman by a marked break in isotopic signatures (Wagner, in press). The basinal Khatiyah Formation of Abu Dhabi is less easily correlated with the Oman Mountains sections. Scott (in press) has suggested correlation with a bituminous horizon in the lower part of Member e of the Natih Formation. There is some biostratigraphic support for this in that both the Khatiyah Formation of Abu Dhabi and Member e of the Natih Formation contain the planktonic foraminifera *Favusella washitensis* Carsey, which ranges no higher stratigraphically than middle Cenomanian (Caron, 1985). Basinal sediments occurring higher in the Natih Formation (e.g. Member b) have no direct correlative to the formations seen in Abu Dhabi. Member b of the Natih Formation contains a late Cenomanian–earliest Turonian planktonic foraminiferal assemblage (Simmons & Hart, 1987; Scott, in press; Kennedy & Simmons, in prep.) suggesting that it cannot be biostratigraphically correlated with the Khatiyah Formation of Abu Dhabi.

The Natih Formation thus consists of two separate cycles of deposition separated by a disconformity surface corresponding to the Mishrif–Mauddud boundary. The echinoderm-rich horizon lies within Member c of the Natih Formation which corresponds to a level within the Mishrif Formation of the Arabian Gulf region.

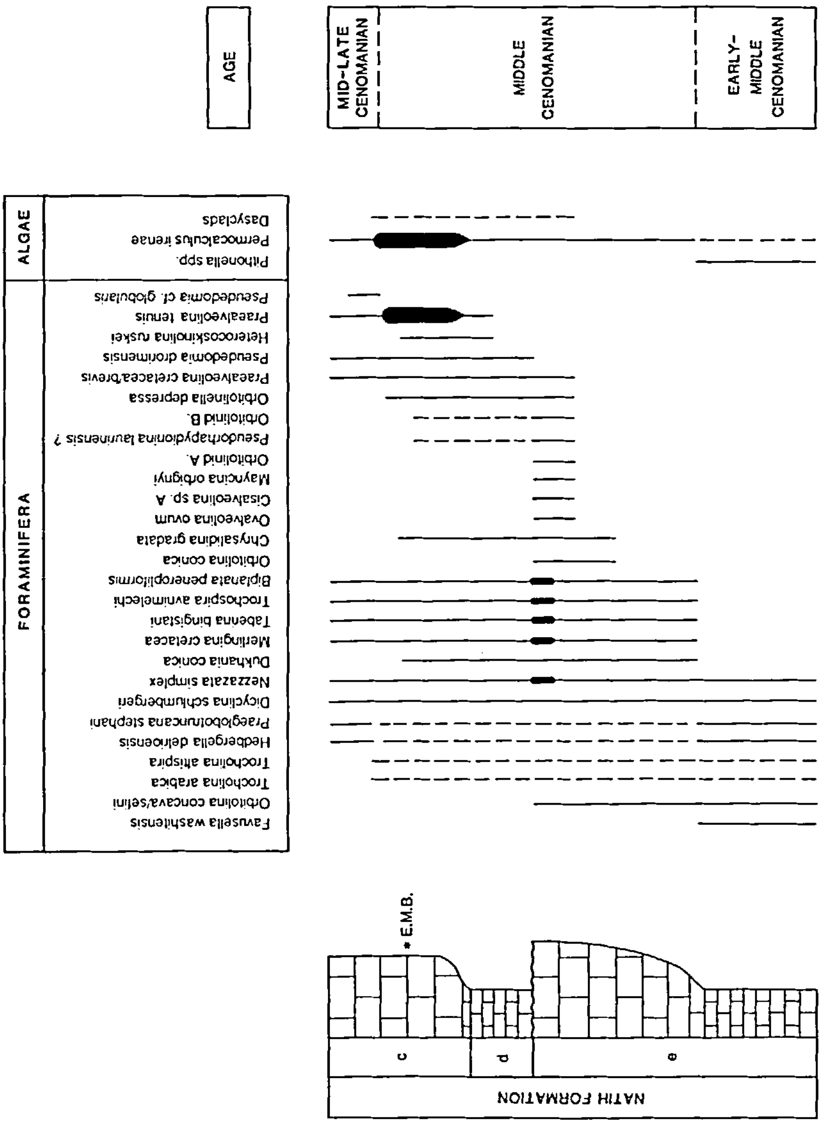
3. Microfossil assemblages and biostratigraphy

The echinoid-rich bed within Member c of the Natih Formation forms a distinctive horizon which can be correlated across much of the Central Oman Mountains. Field geologists operating in the region have termed it the "Echinoid Marker Bed". The lithofacies adjacent to this marker bed appear to be constant, and biostratigraphic studies demonstrate that the microfauna and flora associated with the horizon are similar at all localities where it was examined. Within the limits of biostratigraphic resolution the bed appears to be synchronous.

The Echinoid Marker Bed was noted at five localities during the course of this study: Wadi Mi'aidin, Jebel Nahdah, Jebel Salak, Jebel Madamar and Jebel Madar (see Figure 1). It probably occurs at other localities on the south side of Jebel Akhdar, but on the northern side of Jebel Akhdar, the upper part of the Natih Formation is absent, presumably a result of differential pre-Aruma Group erosion and the effects of local faulting, so the Echinoid Marker Bed does not occur. The majority of the echinoderm fauna described in the subsequent section of this paper is from Jebel Madamar, where the echinoids are most abundant and easily collected, whilst the microfossil assemblages were studied from all the localities mentioned above. There are only minor differences between the microfossil assemblages associated with the Echinoid Marker Bed recorded at all these localities. For the sake of brevity, the microfossil assemblages are considered as being from one composite section, a range chart for which is given as Figure 5.

The lower part of the Natih e Member occurs in two distinct lithofacies across the Central Oman Mountains. At some localities (e.g. Jebel Madamar) it occurs as a bituminous thinly bedded limestone, which in thin-section contains abundant planktonic foraminifera (*Favusella washitensis, Hedbergella delrioensis* (Carsey) and *Praeglobotruncana stephani* (Gandolfi)) and calcispheres (*Pithonella* spp.), together with locally reworked benthonic microfaunas. This indicates deposition in deep outer shelf conditions, corresponding to an arm of the Khatiyah intrashelf basin. At other localities (e.g. Wadi Mi'aidin) the lower part of Member e is a platform bioclastic limestone dominated by benthonic foraminifera, notably species of *Orbitolina*. In both facies, microfauna from the lower part of Member e suggests an early–middle Cenomanian age.

The upper part of Member e is developed in platform limestone facies across all the Central Oman Mountains. A fairly diverse microfauna is present together with the gymnocodiacian alga *Permocalculus irenae* Elliott (Figure 6 l,m). Benthonic foraminifera present in this part of the succession include *Orbitolina conica* (d'Archiac), forms from the *Orbitolina sefini-concava* plexus, rare *Trocholina arabica* Henson and *Trocholina altispira* Henson, *Dicyclina schlumbergeri* Munier-Chalmas, *Dukhania conica* Henson (Figure 6d), *Chrysalidina gradata* d'Orbigny, *Mayncina orbignyi* (Cuvillier & Szakall), two distinctive new species of orbitolinid here referred to as Orbitolinid A (Figure 6i) and B (Figure 6j), and *Orbitolinella depressa* Henson (Figure 6h). *Nezzazata simplex* Omara (Figure 6f), *Merlingina cretacea* Hamaoui (Figure 6g), *Taberina bingistani* Hamaoui & Saint-Marc, *Trochospira avnimelechi* Hamaoui and *Biplanata peneropliformis* Hamaoui & Saint-Marc are present and occur in abundance together near the top of the member. Alveolinids also occur at the top of Member e: *Ovalveolina ovum* d'Orbigny, forms from the *Praealveolina cretacea-brevis* plexus, and a distinctive and often abundant new species of *Cisalveolina*, here referred to as *Cisalveolina* sp. A (Figure 6a). Questionable



E.M.B. Echinoid Marker Bed

Figure 5. Composite total range of foraminifera and calcareous algae within Members c to e of the Natih Formation, central Oman Mountains.

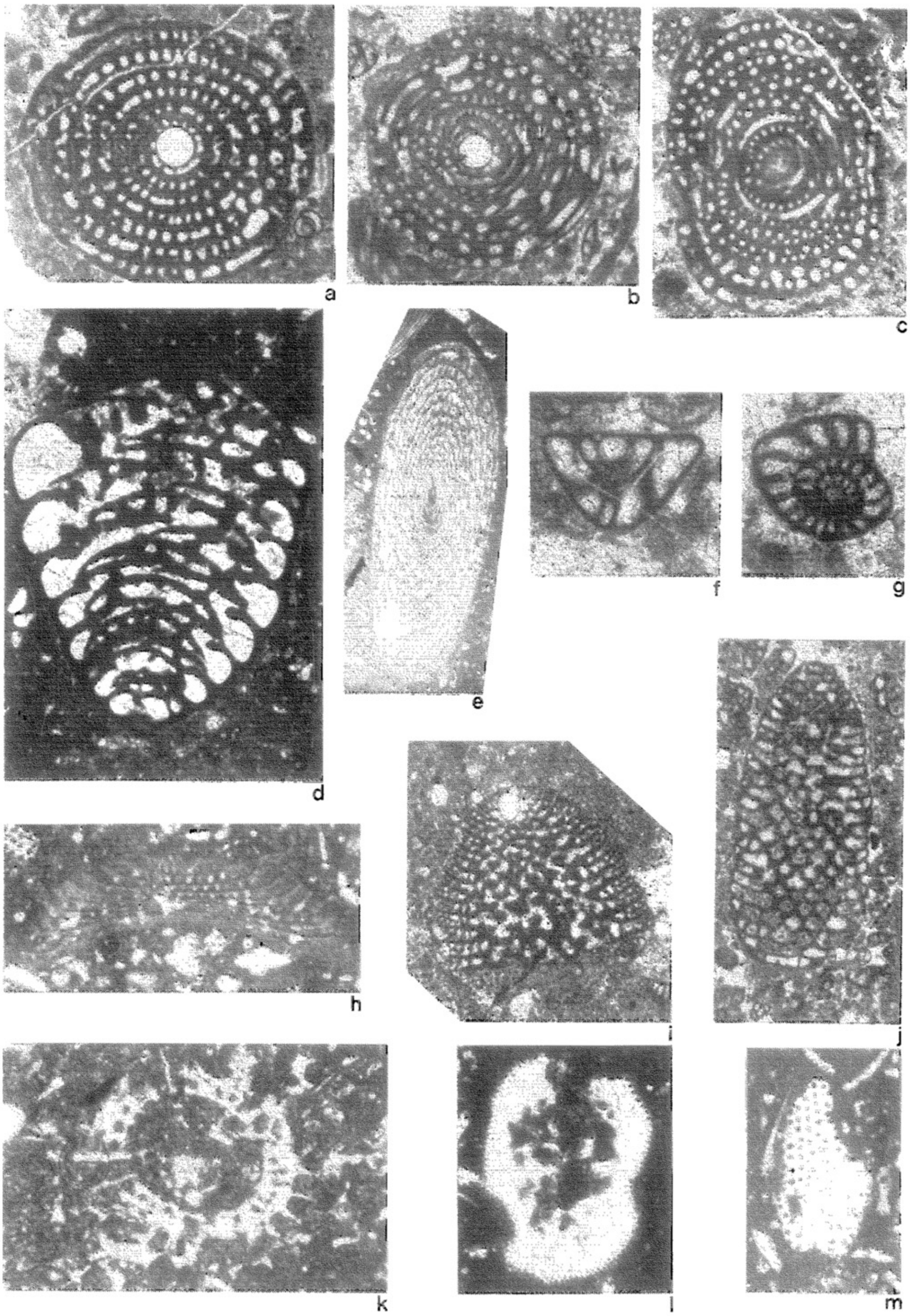


Figure 6. Foraminifera (a–j) and calcareous algae (k–m) from the Natih Formation, central Oman Mountains. a, *Cisalveolina* sp. A, ×20. b, c, *Pseudedomia* cf. *globularis* Smout, ×20. d, *Dukhania conica* Henson, ×20 (possibly a transitional form to *Chrysalidina gradata*). e, *Praealveolina tenuis* Reichel, ×5. f, *Nezzazata simplex* Omara, ×20. g, *Merlingina cretacea* Hamaoui, ×20. h, *Orbitolinella depressa* Henson, ×20. i, Orbitolinid A, ×20. j, Orbitolinid B, ×20. k, unidentified dasycladacean alga, ×20. l, m, *Permocalculus irenae* Elliott, ×20.

specimens of *Pseudorhapydionina laurinensis* (De Castro) are also present. Unidentified dasycladacean algae (Figure 6k) occur in this part of the succession, but are rare.

The overlap of orbitolinids and alveolinids in the upper part of Member e forms a distinctive, correlatable horizon, which, considering the species involved, is indicative of middle Cenomanian age (Schroeder & Neumann, 1985). This is supported by the abundance of nezzazatid species, similar to the middle Cenomanian of Lebanon (Saint-Marc, 1981). The base of this clearly middle Cenomanian interval is taken at the first local inception of *Merlingina cretacea* which is known to range no older than middle Cenomanian (Schroeder & Neumann, 1985). The following species occurring within the upper part of Member e also have supposedly pan-Tethyan inceptions in the middle Cenomanian: *Ovalveolina ovum, Chrysalidina gradata, Praealveolina brevis/cretacea* and *Pseudorhapydionina laurinensis*, the latter species being virtually restricted to this substage (Schroeder & Neuman, 1985). *Trocholina arabica, Trocholina altispira, Orbitolina sefini/concava* and *Orbitolina conica* range no higher than middle Cenomanian.

Although a major disconformity surface occurs at the top of Member e, there is no major change in the microfossil assemblages across this boundary, and the overlying unit (Member d) is also considered to be middle Cenomanian. Thus this non-deposition event was short-lived and probably corresponds to the so-called 'Mid-Cenomanian non-sequence' (Carter & Hart, 1977), which can be correlated across much of Tethys (Hart & Simmons, in prep.). This in turn may relate to the major intra-Cenomanian sea-level fluctuation and sequence boundary recognized by Haq *et al.* (1987).

The microfauna from Member d is broadly similar to that described from the upper part of Member e. With the exception of the new taxon Orbitolinid B, no orbitolinids range up into Member d. Similarly *Ovalveolina ovum* and *Cisalveolina* sp. A do not range above the hardground at the top of Member e. However, *Praealveolina cretacea/brevis* is present as are *Chrysalidina gradata, Dukhania conica, Orbitolinella depressa, Permocalculus irenae* and rare unidentified dasycladacean algae. Trocholinids are present, but are rare, whilst *Nezzazata simplex, Merlingina cretacea, Trochospira avnimelechi* and *Biplanata peneropliformis* are present, but are less common than in Member e. *Pseudedomia drorimensis* Reiss, Hamaoui & Ecker, *Heterocoskinolina ruskei* Saint-Marc and *Praealveolina tenuis* Reichel (Figure 6e) all have their local inceptions within Member d. At some localities *Hedbergella delrioensis* and *Praeglobotruncana stephani* are sporadically present.

The lower part of Member c, which contains the Echinoid Marker Bed, has a microfossil assemblage very similar to Member d. However, *Praealveolina tenuis* and *Permocalculus irenae* (and possibly some new species of *Permocalculus*) become extremely abundant, particularly within, and directly adjacent to, the Echinoid Marker Bed. Most of the taxa described from Member d range up to and occur within, and just above, the Echinoid Marker Bed, although they may be somewhat scarce. The presence of *Trocholina arabica, Trocholina altispira, Heterocoskinolina ruskei* and questionable specimens of *Pseudorhapydionina laurinensis* all indicate an age no younger than middle Cenomanian (Saint-Marc, 1978; Schroeder & Neumann, 1985). The overlap with *Praealveolina tenuis* indicates more specifically a latest middle Cenomanian age (Schroeder & Neumann, 1985). This is supported by the nature of the overall microfossil assemblage which is comparable to the middle Cenomanian of other parts of the Middle East (Sampo 1969; Saint-Marc, 1978, 1981; Kalantari, 1986). Additionally the echinoid fauna itself is indicative of a middle Cenomanian age (see subsequent section), whilst at Jebel Salak, middle Cenomanian ammonites have been found some distance above the Echinoid Marker Bed (Kennedy & Simmons, in prep.). A latest middle Cenomanian age for the Echinoid Marker Bed is in agreement with the work of Scott (in press), who, by graphic correlation to European and Gulf Coast sections, places the middle–late Cenomanian boundary within Natih Member b.

Above the Echinoid Marker Bed, in the upper part of Member c, the microfossil assemblage decreases in abundance and diversity. *Hedbergella delrioensis* and *Praeglobotruncana stephani* are present, whilst *Dicyclina schlumbergeri*, *Nezzazata simplex*, *Merlingina cretacea*, *Taberina bingistani*, *Trochospira avnimelechi* and *Biplanata peneropliformis* occur but are not common. *Permocalculus* is present as are alveolinids; *Praealveolina tenuis*, *Praealveolina cretacea/brevis* together with *Pseudedomia drorimensis*. Of note is the presence of *Pseudedomia* cf. *globularis* Smout (Figure 6b, c). *Pseudedomia globularis* was originally described by Smout (1963) from the Campanian of Iraq. However, Hottinger (pers. comm., 1989) has evidence that *Pseudedomia globularis* was originally considered to be a Cenomanian species when first discovered by Iraq Petroleum Company biostratigraphers. The specimens noted here are very similar to the types, suggesting that further research is required to determine the true age range of this species. Overall the fauna from this part of the succession indicates a middle–late Cenomanian age (Saint-Marc, 1981; Schroeder & Neumann, 1985). No clearly middle Cenomanian species are present.

4. Depositional environment

The Wasia Group was deposited on a carbonate ramp (*sensu* Read, 1985). The lower part, the Nahr Umr Formation, is believed to represent slow sedimentation on a shallow platform, with clastic input from the Arabo-Nubian shield (Harris *et al.*, 1984). The overlying Cenomanian Natih Formation represents deposition on a carbonate platform rimmed by coarse bioclastic shoals or radiolitid rudist biostromes (Simmons & Hart, 1987; Skelton & Simmons, in prep.). Landwards from these barriers there was a platform lagoon with benthonic foraminiferal mudstones, whilst oceanwards the shoals passed into bioclastic slope deposits and then into planktonic foraminiferal intrashelf, basinal wackestones (Glennie *et al.*, 1974; Harris *et al.*, 1984; Simmons & Hart, 1987).

The upper part of the Natih Formation (containing the echinoid bed) comprises alveolinid-molluscan-algal debris wackestones which are overlain by packstones and wackestones with varying abundances of algae, alveolinids, and molluscan and echinoderm debris. Rudist biostromes associated with bioclastic shoals are also locally developed. In the upper part of the formation at localities to the south of the main mountain belt, pelagic wackestones and packstones are developed with abundant calcispheres and planktonic foraminifera. Simmons & Hart (1987) noted that such microfacies are similar to the Mishrif Formation in Abu Dhabi as described by Burchette & Britton (1985), and represent deposition in a shallow, quiet-water, platform lagoon environment, passing into shelf-edge barrier facies, and further seawards, into deeper water, intra-shelf basin conditions. At all localities where it was seen, the echinoid bed is associated with biostromal radiolitid rudist beds and thinly bedded bioclastic packstones containing abundant rudist and/or oyster fragments. The latter facies may represent periods of extension of back-barrier skeletal sands and the development of intra-lagoonal biostromes.

As noted above, the upper part of the Natih Formation containing the Echinoid

Marker Bed correlates with the Mishrif Formation of the Arabian Gulf. The depositional environment of this formation has been described by a number of authors, notably Burchette & Britton (1985), Jordan *et al.* (1985) and Reulet (1982). Harris & Frost (1984) described upper Natih Formation in the region of the Fahud oilfield in terms of Mishrif depositional environments. All of these authors have described the same basic depositional model for the Mishrif Formation (and hence the upper Natih Formation of the Oman Mountains). It can be summarized as a carbonate shelf with a marked barrier (rudist biostromes and/or bioclastic shoals) prograding into a deeper intrashelf basin.

Reulet (1982) recognized several distinct facies within the Mishrif Formation of Iraq: (i) open outer shelf–basin mudstones–packstones with planktonic foraminifera and calcispheres, (ii) outer peri-reefal wackestones–grainstones with echinoderms, alveolinids and algae, (iii) barrier deposits including packstones–grainstones of rudist debris forming shoals, and more rarely, true rudist bioherms, (iv) inner peri-reefal wackestones–packstones of rudist debris and other bioclasts, (v) inner shelf subtidal, lagoon mudstones and wackestones with a diverse microfauna and (vi) intertidal peloidal–bioclastic wackestones and packstones with miliolids and gastropods. Similar lithofacies associations were recognized by Burchette & Britton (1985) in the Mishrif Formation of Abu Dhabi.

According to the model of Reulet (1982) a biofacies of common *Permocalculus*, *Praealveolina*, nezzazatids, coarse rudist and coral debris, and echinoids, as found in the Echinoid Marker Bed, is likely to represent deposition in 'peri-reefal' conditions either directly behind or in front of a barrier (facies ii and iv above). We favour a depositional position directly behind the barrier rimming the Mishrif (= upper Natih) shelf. This is because the Echinoid Marker Bed lies within a progradational shelf sequence, where below it are coarse rudist biostromes representing the barrier, and above it are *Exogyra*-rich lagoonal wackestones, with a moderately diverse microfauna. It is unlikely that true reefal barriers developed to rim the upper Natih shelf. Instead bioclastic shoals developed which were stabilized by radiolitid rudists, and were capped by caprinid rudists. Although not bioherms, these shoals/biostromes formed an effective hydrodynamic barrier to the upper Natih shelf. This type of barrier may have also been prevalent in the Mishrif shelf of Abu Dhabi (Burchette & Britton, 1985) and Iraq (Reulet, 1982). Jordan *et al.* (1985, p. 431), whilst referring to 'reefs' in the Mishrif of Dubai, also stated that "The reefs are discontinuous and may be more a series of near-reef shoals than ecologic reefs".

The dominance of alveolinids also points to a back-barrier depositional environment (Henson, 1950; Hottinger, 1973; Saint-Marc, 1982; Pautal, 1987; Racey, in prep.), whilst the abundance of gymnocodiacian algae (*Permocalculus*) suggests deposition in outer shelf conditions of moderate water depth (5–20 m?), either in front of, or behind a barrier. The echinoid assemblage, which is dominated by holectypoids, also suggests deposition in conditions close to a barrier. Modern-day holectypoids occupy niches directly behind reefs in areas of coarse reef talus (Rose, 1976). The predominance of epifaunal regular echinoids and scarcity of burrowing spatangoids suggests that the sediment was consolidated, perhaps algal bound.

5. The echinoid fauna

Nine species of echinoid were collected from the Echinoid Marker Bed at Jebel Madamar, *Temnocidaris* (*Stereocidaris*) *sarracenarum* Fourtau, *Tetragramma variolare* (Brongniart), *Pedinopsis humilis* Fourtau, *P. sinaica* (Agassiz & Desor), *Pedinopsis* *sphaerica* sp. nov., *Heterodiadema lybica* (Agassiz & Desor), *Hemiaster syriacus* (Conrad), *Hemiaster cubicus* Cotteau and *Coenholectypus larteti* (Cotteau), most of which have not previously been reported from the Arabian Peninsula. *Pedinopsis sphaerica, H. lybica* and *C. larteti* were also collected from Jebel Madar, while *H. lybica, C. larteti, H. syriacus* and *T. variolare* were collected from Jebel Salak. In terms of specimens, *C. larteti* greatly outnumbers other species at Jebel Madamar, *H. lybica* being the only other species present in any abundance. At Jebel Madar the faunal composition is similar, but at Jebel Salak *H. lybica* and *C. larteti* occur in equal abundance, with subsidiary *T. variolare.*

Faunas of similar age are known from North Africa (Algeria; Cotteau *et al.*, 1878: Egypt (Sinai Peninsula; Fourtau, 1914, 1921), the Middle East (Israel, Jordan; Blanckenhorn, 1925; Bandel & Geys, 1985), and India (Chiplonkar & Badve, 1972) as well as from Europe. Interestingly none of the species described here is known to occur in India, but most are recorded from Sinai. Of the nine species, eight are definitely known from Sinai and the ninth may be present. Six of these species are also known from Jordan/Israel and five from Algeria (Figure 7). Only two of the Omani species are found in Portugal and southern France. Clearly then there can have been little barrier to dispersal between Oman and Sinai during the middle Cenomanian but much less interchange between Oman and south-western Europe. Roman *et al.* (1989, p. 282) suggested that during the Albian–Cenomanian there existed an eastern Mediterranean sub-province comprising the area circumscribed by Egypt, Iran and Somalia. Our results are consistent with this view and demonstrate that the Cenomanian faunas of Oman, Egypt and the Middle East are very similar.

6. Systematic descriptions

Class Echinoidea Leske, 1778
Subclass Cidaroidea Claus, 1880
Order Cidaroida Claus, 1880
Family Cidaridae Gray, 1825
Genus *Temnocidaris* Cotteau, 1863
Temnocidaris (*Stereocidaris*) *sarracenarum* (Fourtau, 1921)
Figure 8a.

1921 *Stereocidaris sarracenarum* Fourtau, p. 6, pl. 3, fig. 10.

Diagnosis. A *Stereocidaris* with five interambulacral plates in a column, the top bearing only a rudimentary tubercle. Ambital and adapical plates about as tall as broad with large circular areoles occupying most of the plate. Scrobicular circles tangential at the ambitus, separated adapically. Extra-scrobicular tuberculation absent except adapically where a single row of miliary tubercles may occur along the interradial margin.

Material. One specimen, BMNH E83119, from the Echinoid Marker Bed at Jebel Madamar.

Description. The single specimen is 24.5 mm in diameter and 14.5 mm in height (60% of the test diameter). It is incomplete and rather badly weathered in places.

The apical disc is not seen. Ambulacra are sinuous and about 13% of the test diameter in width. The central tuberculate zone forms about 60% of the width of an ambulacrum. Ambulacral pores are non-conjugate and the two pores are separated

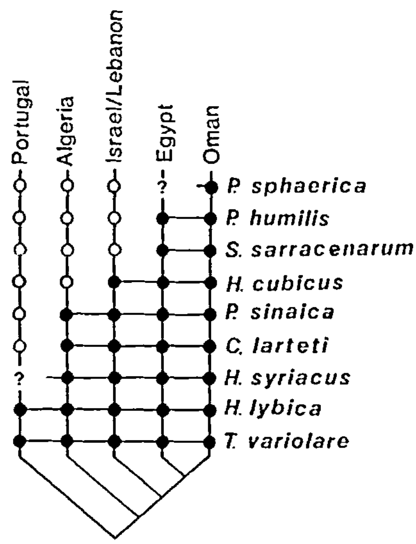


Figure 7. Geographical distribution of Oman echinoid species given in the form of an area cladogram. Filled circles = taxon present; open circles = taxon not recorded; ? = taxon may be present but material inadequate.

by a raised partition that is slightly narrower than the diameter of a single pore. Each ambulacral plate has a large mamelonate primary tubercle adjacent to the pore-pair and two smaller secondary tubercles placed one above the other per-radially.

There are five interambulacral plates in a column, the most adapical of which bears a small rudimentary tubercle surrounded by numerous equal-sized miliaries. The other plates each have a perforate, non-crenulate primary tubercle surrounded by a large circular areole that occupies most of the plate. Scrobicular circles on adoral plates are tangential or confluent and leave no room for extrascrobicular tuberculation. Adapically a single row of secondary tubercles and miliaries is present along the interradial and adapical margins of plates outside the scrobicular circle. Plate sutures are clearly marked and slightly incised. There are small angular pits at interradial triple suture junctions.

The peristome is small and subpentagonal, measuring 42% of the test diameter.

Remarks. This species was established by Fourtau (1921) on the basis of two 18 mm diameter specimens from the Cenomanian of the northern Sinai (Egypt). It is clearly differentiated from other species of *Temnocidaris* (*Stereocidaris*) on account of the large size of its primary interambulacral tubercles and virtual absence of secondary tuberculation outside the scrobicular circles. This is a juvenile feature in cidarid development, but, by the equivalent size, other *T.* (*Stereocidaris*) species have extensive zones of miliary granulation on interambulacral plates (Smith & Wright, 1989). The specimen described here differs slightly from the types in having only two secondary tubercles on ambulacral plates, whereas Fourtau described four irregular rows developed at the widest part of the ambulacrum. Possibly in his specimen the two tubercles that are positioned one above the other in the Oman specimen are offset slightly in the types. However, the differences seem slight and in other cidarid species considerable variation may be encountered in the precise arrangement of secondary tubercles on ambulacral plates (Smith & Wright, 1989).

Subclass Euechinoidea Bronn, 1860
Cohort Echinacea Claus, 1876
Family Pseudodiadematidae Pomel, 1883
Genus *Tetragramma* Agassiz, 1840
Tetragramma variolare (Brongniart, 1822)
Figure 8b.

1822 *Cidarites variolaris* Brongniart, p. 84, 390 (*partim*); pl. 5, fig. 9.
1985 *Tetragramma variolare* (Brongniart); Geys, p. 135 [see for full prior synonymy].

Diagnosis. A *Tetragramma* with ambulacral compounding of four elements at the ambitus and above but only three elements adorally. There are two equal-sized primary tubercles on ambital plates from about 15–40 mm test diameter.

Material. BMNH E83120, a single, incomplete specimen from the Echinoid Marker Bed at Jebel Madamar: BMNH E83279-82, four specimens from Jebel Salak.

Description. This species is very well known and needs little description. The Oman specimens reach almost 40 mm in diameter and approximately 17 mm in height (40% of the diameter). Ambulacral pores, which are arranged in weak arcs of four at the ambitus and immediately subambitally, become biserial adapically. The four most adoral plates are trigeminate, but all other plates are quadrigeminate. In quadrigeminate plates the upper of the two middle elements is a demi-plate. At the ambitus there are two equal-sized interambulacral tubercles which occupy virtually the entire width of the plate.

Remarks. This species is widespread, being reported from the Cenomanian of North Africa (Algeria, Tunisia and Egypt), the Middle East (Syria, Lebanon, Israel and Jordan) as well as Europe (see Geys, 1985). It has also recently been reported from the Albian/Cenomanian of Dhofar, southern Oman by Roman *et al.* (1989). There are subtle differences in test shape between the populations found in Britain and France and those of North Africa and the Middle East. In comparison with populations from Wilmington, England for example (Smith *et al.*, 1988), the Oman specimen has slightly coarser interambulacral tuberculation and the ambitus lies at mid-height. In the Wilmington population and in most of the French material examined the ambitus lies above mid-height so that in profile the test has a broad, flat top and a slightly narrower base. However, these differences are not consistently developed.

Genus *Heterodiadema* Cotteau, 1864
Heterodiadema lybica (Agassiz & Desor, 1846)
Figures 8c–g, 9, 10.

1846 *Hemicidaris lybica* Agassiz & Desor, p. 338.
1980 *Heterodiadema lybica* (Agassiz & Desor); Geys, p. 449, pl. 8 [includes a full synonymy].

Diagnosis. A depressed *Heterodiadema* (height about 50% of diameter) in which both ambulacral and interambulacral primary tubercles decrease abruptly and markedly in size at the ambitus.

Age and distribution. A widespread species known from the Cenomanian and Turonian of southern Europe, North Africa and the Middle East; possibly also from the Campanian of Belgium (Geys, 1980). The type comes from the Cenomanian of Egypt.

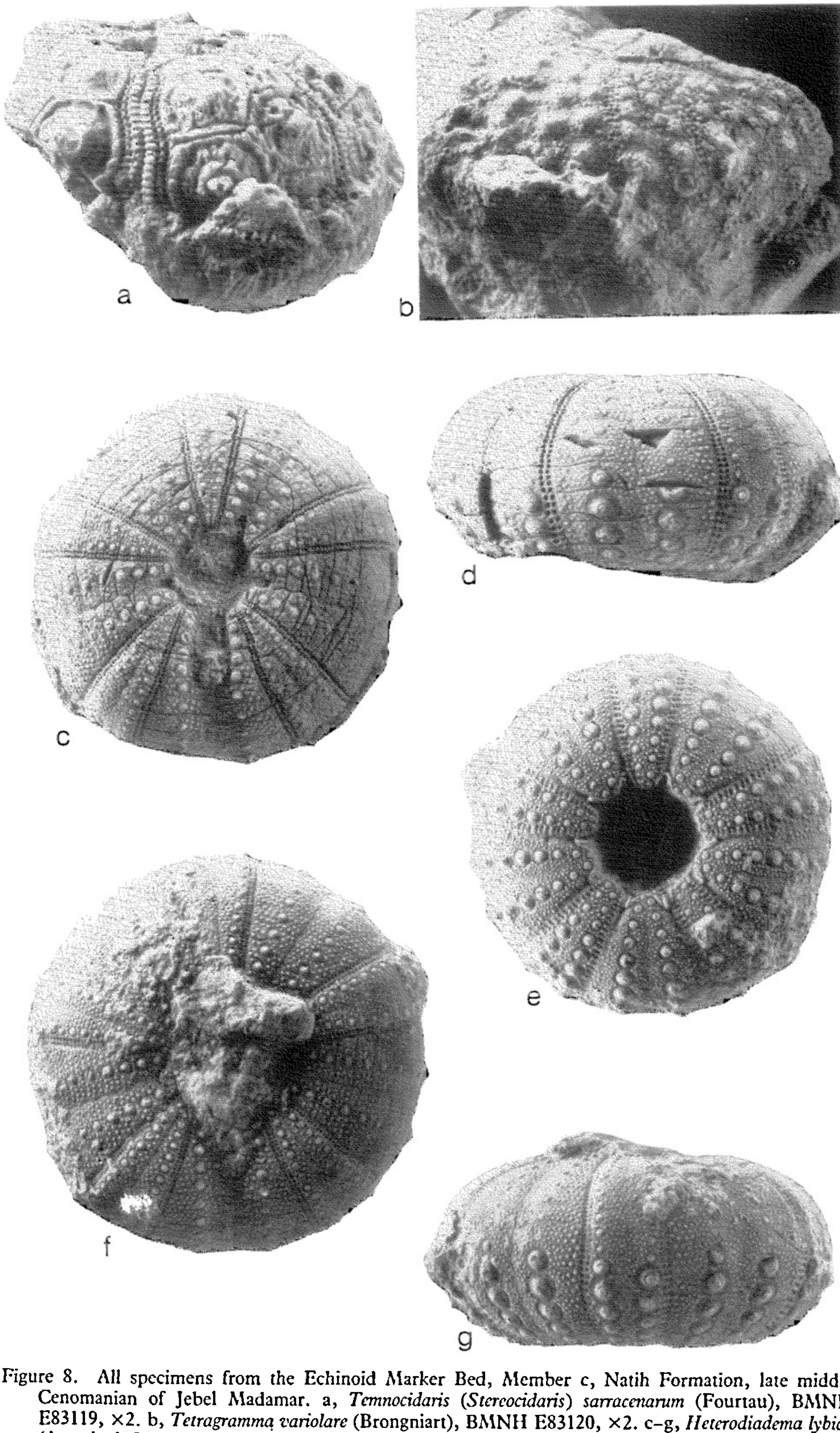


Figure 8. All specimens from the Echinoid Marker Bed, Member c, Natih Formation, late middle Cenomanian of Jebel Madamar. a, *Temnocidaris* (*Stereocidaris*) *sarracenarum* (Fourtau), BMNH E83119, ×2. b, *Tetragramma variolare* (Brongniart), BMNH E83120, ×2. c–g, *Heterodiadema lybica* (Agassiz & Desor): c, d, adapical and lateral views of BMNH E83121, ×1.5; e, f, g, oral, adapical and lateral views of BMNH E83122, ×1.5.

Material. Nine well-preserved specimens, BMNH E83121-5, E83290-3, from the Echinoid Marker Bed at Jebel Madamar form the basis for the following description. A number of other specimens were collected from here and from Jebel Salak and Jebel Madar.

Description. Tests are 15.3–36.3 mm in diameter and are subpentagonal in outline, the angles of the pentagon being radial. Test height is 40–53% of the test diameter (mean = 46%, SD = 3.8%, N = 9; Figure 9). In profile the sides are strongly inflated and the ambitus is at mid-height. Both the apex and the peristome are slightly invaginated.

No specimen retains plating of the apical disc. The outline of the disc is highly distinctive, resembling a key-hole with four small interradial notches in interambulacra 1–4 and a deep, narrow cleft penetrating well into the posterior interambulacrum (Figure 8c). The width of the apical disc is 22–32% of the test diameter. In large individuals, 30–35 mm in test diameter, the top two plates of interambulacra 1–4 are separated by a sharp, clearly defined notch created by the genital plates. In the posterior interambulacrum, however, up to five adapical plates are separated and the notch is slightly pinched adapically. The notches increase in size

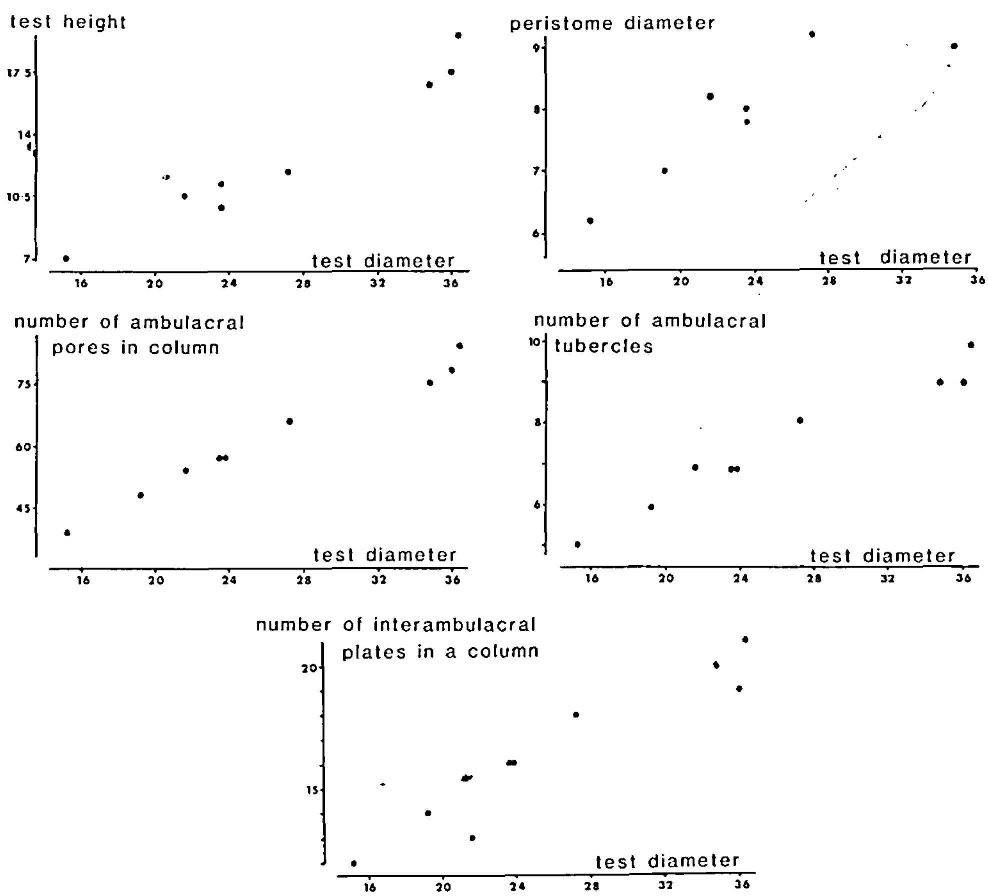


Figure 9. Biometric data on *Heterodiadema lybica* (Agassiz & Desor) from the Echinoid Marker Bed, Member c, Natih Formation, late middle Cenomanian of Jebel Madamar. All measurements in millimetres.

during growth. In a 15-mm diameter individual, genital plates 1–4 hardly notch the interradii while the posterior notch is broad, open and only separates the most adapical two interambulacral plates. By 21 mm test diameter genital plates 1–4 form distinctive notches at the interradial sutures and the posterior notch is more clearly differentiated, slightly pinched adapically and separates the three most adapical interambulacral plates in each column. The length of the apical disc also grows relative to the test diameter. In a 15-mm individual, the length of the apical disc is only 11% of the test diameter whereas, by 35 mm, it is 18–20% of the test diameter.

Ambulacral width is 21–23% of the test diameter at the ambitus. There are 40 ambulacral pores in a column at 15 mm test diameter rising to 78–83 at about 35-mm test diameter (Figure 9). Pores are uniserial throughout, with a tendency to become weakly arcuate in triads towards the peristome. All plates are compound triads in which the three elements reach the perradial suture. The central of the three plates in each triad is distinctly pinched towards the centre (Figure 10), particularly on ambital plates. Primary tubercles are perforate and crenulate adorally but imperforate and with either little or no crenulation adapically. There is a single large primary tubercle on each oral compound plate up to the ambitus. Those on the lowest three of four plates have non-contiguous areoles but above this, areoles are contiguous and elliptical rather than circular in outline. A narrow band of perradial miliaries occupies the centre of the ambulacrum. At the ambitus there is an abrupt decrease in the size of primary tubercles, which suddenly become less than half the diameter of adoral tubercles (Figures 8d, g, 10). Tubercles remain small to the apex. Primary tubercles are situated on the adradial margin of the plate adjacent to the pore zone and there is a broad perradial band of equal-sized miliary tubercles some 6–10 abreast. Adapically the primary tubercles are non-contiguous and are separated by a band of miliary tubercles. There are five large oral tubercles at 15 mm test diameter, 7 at 22 mm diameter and 9 or 10 at 35–36 mm test diameter (Figure 9). Four to five ambulacral pore-pairs lie opposite at ambital interambulacral plate.

Interambulacral plates are wide and low. There are 12 plates in a column at 15 mm test diameter, rising to 19–21 at about 35 mm test diameter (Figure 9).

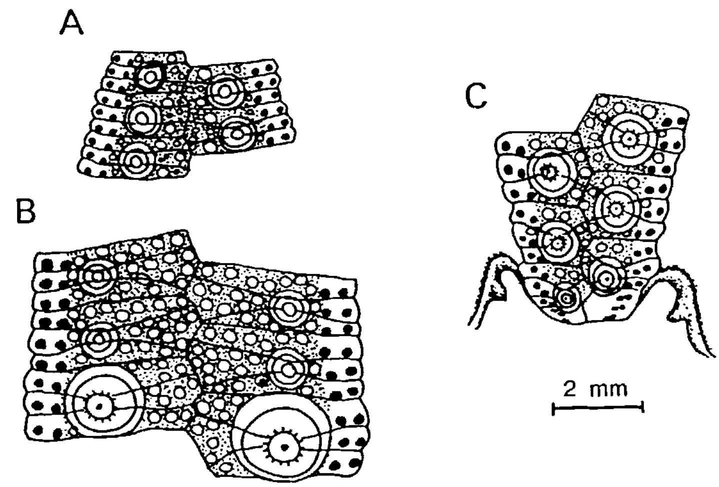


Figure 10. Camera lucida drawings of ambulacral plating in *Heterodiadema lybica* (Agassiz & Desor), BMNH E83122, from the Echinoid Marker Bed, Member c, Natih Formation, late middle Cenomanian of Jebel Madamar. A, adapical plating; B, ambital plating; C, adoral plating (note shape of buccal notches).

Adoral primary tubercles are large, perforate and crenulate, adapical ones are much smaller, imperforate and hardly crenulate. Primary tubercles lie at the centre of interambulacral plates and there are well-developed bands of miliaries both adradially and interradially. On an ambital plate of larger specimens there are approximately five miliaries abreast interradially and three or four abreast adradially. Close to the peristome the primary tubercles are non-confluent, with narrow bands of miliaries separating adjacent areoles. But over most of the oral surface, up to the ambitus, areoles are confluent. At the ambitus there is an abrupt decrease in the size of primary tubercles and adapical tubercles are less than half the diameter of ambital tubercles (Figure 8d, g). Adapically, tubercles are all non-confluent and miliaries are arranged in semi-regular horizontal rows. In the most adapical five or so plates the primary tubercles may enlarge slightly. There is a narrow granule-free interradial 'naked zone' developed toward the apex. At the ambitus, ambulacral primary tubercles are only slightly smaller than interambulacral primary tubercles.

The peristome forms about 40% of the test diameter in 15-mm-sized individuals but becomes proportionally smaller during growth (Figure 9), reducing to only 26% of the test diameter at about 35 mm. It is circular in outline but incised by very deep buccal notches that penetrate as far as the fifth ambulacral pore-pair. The notch is partitioned (Figure 10c) and has a well-developed rim. Buccal notches are poorly developed at 15 mm test diameter but become deeper and sharper as test size increases. In large specimens a naked channel extends from the tip of the buccal notch adambitally for a further three interambulacral plates (Figure 8e), indicating that in *H. lybica* the coelomic expansion sacs were large and recumbent.

Remarks. This species has been described and figured on several occasions but its growth has not previously been documented biometrically. The abruptness with which primary tubercle size decreases at the ambitus varies from population to population. In the Oman sample the change is extremely abrupt whereas in other populations, such as those from Batna, Algeria, the change tends to be less abrupt and tubercle size decreases gradually adapically. There is, however, no sharp distinction between the two and all intermediates can be found. The imperforate nature of aboral primary tubercles has not previously been noted.

The species differs from *H. ouremense* Loriol, from the Cenomanian of Portugal, in shape, *H. ouremense* having an almost globular test. *H. bigranulatum* Gregory, from the Cenomanian of the Sinai Peninsula, Egypt, appears to be a poorly preserved juvenile of *H. lybica*. *H. lybica* is known from the Cenomanian of southern Europe, north Africa and the Middle East, and has been reported as far afield as the Karakorum Mountains and Niger (Geys, 1980).

Genus *Pedinopsis* Cotteau, 1863

Diagnosis. Regular echinoid with perforate, feebly crenulate tubercles. Both ambulacral and interambulacral tubercles small, with primary tubercles not much differentiated from secondary tubercles; these arranged in horizontal rows. Ambulacral plates compound; trigeminate adorally, quadrigeminate or polygeminate at ambitus and above with only the principal element in each compound plate reaching the perradial suture. Pore-pairs arranged biserially adapically but uniserial adorally. Apical disc much smaller than peristome.

Type species. Pedinopsis meridianensis Cotteau, 1863 by original designation.

Range. Neocomian to Coniacian/Santonian unspecified.

Remarks. *Pedinopsis* is readily recognized by its very complex ambulacral compounding in which all but the principal element are demi-plates. It resembles *Tetragramma* in having ambulacral pores arranged biserially adapically, but in *Tetragramma* ambulacral compounding never includes more than four elements and all elements reach the perradial suture. Furthermore, *Tetragramma* is a very much more coarsely tuberculate and has a very much larger apical disc that is similar in size to the peristome.

Several species of *Pedinopsis* have been described and these can be separated into three discrete groups based on their style of ambulacral compounding. In members of the first group, characterized by *P. desori* (Coquand, 1862), only the four or so most adoral ambulacral plates are trigeminate; the other adoral plates are quadrigeminate and the adapical plates are composed of six elements. Biserial pore arrangement extends from the apex to well below the ambitus. The type species, *P. meridianensis* Cotteau, belongs here and is based on a large specimen with a row of up to eight interambulacral tubercles on ambital interambulacral plates. Its compound plates comprise six elements and the biserial arrangement of ambulacral pores extends virtually to the peristome. It is stated to come from Neocomian beds in France. Also included are the Cenomanian *P. humilis* Fourtau and *P. sphaerica* nov., differentiated from *P. desori* on general shape and on the size and degree of invagination of the peristome. *P. texana* Cook, from the Upper Albian of Texas, also belongs here but appears virtually indistinguishable from *P. desori* in morphology and is probably best treated as synonymous. The same is true of the Lower Cenomanian *P. weisti* Wright from England. *P. pondi* Clark from the Coniacian/Santonian Austin Chalk of Texas is the youngest member known (Cooke, 1953).

In the second group, which contains only *P. sinaica* (Agassiz & Desor), ambulacra are trigeminate adorally and quadrigeminate adapically, while pores are arranged uniserially adorally and become biserial adapically. Complex polygeminate compounding is not developed.

A closely related species is *Dumblea symmetrica* Cragin, from the Upper Albian of Texas and Mexico (Cooke, 1955). This species resembles *Pedinopsis* in having rows of small equal-sized tubercles on ambulacral and interambulacral plates and in having biserially arranged pores from the apex to subambitally. Only the primary element in each compound plate reaches the perradial suture. *Dumblea* differs from *Pedinopsis* in having compound plating of triads throughout. Two species, *P. yarboroughi* and *P. engerrandi*, both from the Fredericksburg Group (Albian) of Texas, also belong here and were described by Iken (1940, p. 14). Cooke (1946, p. 212) treated these as synonymous and noted that they were 'very similar' to *P. symmetrica* [= *Dumblea symmetrica*] but were tentatively maintained as valid species because they were found at a different stratigraphical level. In addition, the Egyptian species *P. torrendi* Cotteau may belong here although it is poorly known. It was redescribed by Fourtau (1921, p. 34) and differentiated from other species of *Pedinopsis* by having three adradial and three interradial columns of tubercles.

These species are clearly closely related on account of their biserial pore arrangement, similarity of demiplating and style of tuberculation, but they differ in the detailed construction of compound plates. This allows the recognition of three subgenera within *Pedinopsis*, *P.* (*Pedinopsis*) [type species *P. meridianensis* Cotteau] for species with compound ambulacral plates constructed of six elements adapically and four adorally; *P.* (*Dumblea*) Cragin [type species *Dumblea symmetrica* Cargin] for species with trigeminate compound plating throughout; and *P.* (*Sinaiopsis*) nov.

[type species *Pedina sinaica* Agassiz & Desor] for species with trigeminate compound plating adorally and quadrigeminate compound plating adapically.

Subgenus *Pedinopsis* (*Pedinopsis*) Cotteau, 1863

Type species. Pedinopsis meridianensis Cotteau, 1863.

Diagnosis. Pedinopsis with polygeminate ambulacral plate compounding ambitally and adapically comprising six elements. Quadrigeminate plate compounding usually developed adorally and trigeminate plating confined to the most adoral two to four compound plates.

Range. Neocomian to Coniacian/Santonian, Europe, U.S.A., North Africa, Middle East.

Pedinopsis (*Pedinopsis*) *humilis* Fourtau, 1921
Figures 11, 14a–c.

1921 *Pedinopsis humilis* Fourtau, p. 33, pl. 5, fig. 2.

Diagnosis. A large, wheel-shaped *Pedinopsis* with pores arranged biserially except in the adoral half of the lower surface. Adapical and ambital plates include occluded elements. One large primary ambulacral tubercle on each plate. Ambital interambulacral plates broad, with a row of four equal-sized tubercles occupying most of the plate height.

Material. One specimen, BMNH E83282, from the Echinoid Marker Bed at Jebel Madamar.

Age and distribution. The two syntypes come from the Lower Cenomanian of Jebel el Helal, Egypt. The Oman specimen is late middle Cenomanian in age. No other material has been reported.

Description. The unique specimen is rather badly weathered removing much surface detail. The test is flat and wheel-shaped (Figure 14c), being 38 mm in diameter and 14 mm in height (37% of test diameter). It is slightly pentagonal in outline and has a rounded margin, with the ambitus at about mid-height. The apical disc is small and approximately circular in outline, being 6 mm in diameter (16% of the test diameter). No apical disc plates remain in position.

Ambulacra are 8.5 mm in width at the ambitus (22% of the test diameter). Pores are arranged biserially from the apex to half-way towards the peristome on the oral surface, where they become arranged into arcs of four. The pore-pairs are very closely packed together and elements in compound plates often become occluded from one or other of the sutures, or indeed from both (Figure 11a–b). The pore zone is broad adapically and, at the ambitus, occupies about half of the plate width. Plate compounding is illustrated in Figure 11. One large primary tubercle lies centrally on each compound plate; details of any finer tuberculation have been lost through weathering. There are more than 80 pore-pairs in a column (adoral part of ambulacrum not seen).

Interambulacra have a width about 40% that of the test diameter. Ambital plates are wide and short with a row of four equal-sized tubercles on each plate which occupy much of the plate height (Figure 14c) Miliary granules occur along the upper and lower plate edge.

The peristome is not exposed.

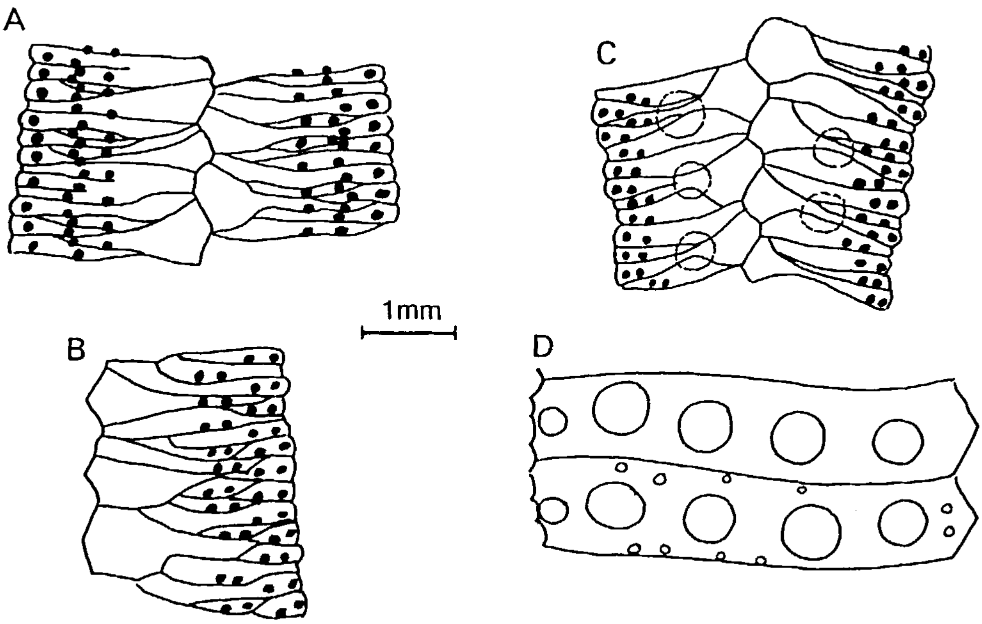


Figure 11. Camera lucida drawings of plating and tuberculation in *Pedinopsis* (*Pedinopsis*) *humilis* Fourtau: BMNH E83283, from the Echinoid Marker Bed, Member c, Natih Formation, late middle Cenomanian of Jebel Madamar. A, adapical ambulacral plating; B, ambital ambulacral plating; C, adoral ambulacral plating. D, ambital interambulacral plates (interradial suture to the right) showing the position and size of the principal tubercles. All to same scale.

Remarks. The Oman specimen is identical to the types described and figured by Fourtau (1921) from the Lower Cenomanian of Egypt. It resembles *P. desori* and *P. sphaericus* in having six elements in aboral and ambital ambulacral compound plates and four adorally, but differs in having much wider and shorter interambulacral plates each with a row of four equal-sized tubercles at the ambitus; the primary tubercle is not obviously differentiated from the rest. Furthermore, in ambital and adapical compound plates some elements are occluded from both the adradial and perradial suture, a feature not seen in other species. Finally, its wheel-like shape is also characteristic.

Pedinopsis (*Pedinopsis*) *sphaerica* sp. nov.
Figures 12a–e, 13.

?1921 *Pedinopsis desori* Coquand; Fourtau, p. 32.

Diagnosis. A globular species of *Pedinopsis*, almost as tall as wide, with pores arranged biserially from subambitally to the apex. Peristome small and not at all invaginated.

Types. Holotype BMNH E83127, paratype BMNH E83128, designated here.

Origin of name. In allusion to the highly distinctive test shape.

Age and distribution. The types come from the Echinoid Marker Bed at Jebel Madamar, of late middle Cenomanian age. A third, poorly preserved specimen comes from a similar horizon at Jebel Madar. Possibly also known from the Cenomanian of Egypt (see discussion).

Description. The types are 23 and 27 mm in diameter and circular in outline. Test height is 20 and 23 mm (85–87%) of test diameter. In profile the test is almost perfectly circular, with a small flat base and apex (Figure 12c, e). The ambitus is at mid-height. Plates of the apical disc are missing in both specimens and must have been rather loosely attached to the corona. The apical disc is circular in outline and 16–17% of the test diameter in diameter.

Ambulacra are broad and straight, tapering gradually adorally and rather abruptly adapically. At the ambitus they are 19–22% of the test diameter in width. The pore zones are relatively narrow, leaving a broad perradial zone of tubercles forming about 67% of the ambulacral width. Pores are undifferentiated and are biserially arranged from the apex to a little below the ambitus. Towards the peristome pore-pairs are arranged in arcs of three. The change in pore arrangement occurs about 8 or 9 compound plates away from the peristome. There are about 140–150 pore-pairs in a column and 29–31 compound plates. Plate compounding is highly complex (Figure 13). At the apex the very first few plates are simple and all reach the perradial suture. However, there rapidly develops a compounding style involving six elements, only one of which reaches the perradius (Figure 13b). This coincides with the development of a clear biserial arrangement of pore-pairs. Below the ambitus, where the biserial pore arrangement starts to disappear, only four elements are included in a compound plate, three of which are occluded from the perradial suture (Figure 13c). In the most adoral few plates compounding involves just three elements, only the lowest of which is occluded from the perradial suture (Figure 13d). Here pores become offset into strong arcs forming a phyllode. On the lower surface each compound plate has a moderately large primary tubercle situated close to the pore zone. This is situated on the largest of the three plates but also overlaps one of the smaller elements. Towards the ambitus this primary tubercle decreases in size and comes to lie almost entirely on the largest of the elements in each compound plate, though still encroaching over one of the smaller elements (Figure 13e). On ambital plates two horizontal rows of two or three smaller secondary tubercles and scattered miliaries occur perradial to the primary tubercle (Figure 13e). Primary tubercles continue to the apex, but are small and confined entirely to the largest of the elements in the compound plate. They are hardly differentiated from other small tubercles on ambulacral plates from the ambitus adapically. Ambulacral and interambulacral plates are similar in height at the ambitus and are arranged opposite rather than alternately.

Interambulacral plates are wide and low, more than four times as wide as tall at the ambitus. There are 27 plates in a column at 23 mm test diameter and 28 at 27 mm. Adorally each plate carries three large perforate, crenulate tubercles which occupy most of the plate (Figure 13h). The largest of these is the central tubercle. Away from the peristome, first the adradial and later the interradial tubercle diminish in size rapidly, leaving only a single larger tubercle situated on the centre of the plate. This primary tubercle also diminishes in size away from the peristome so that by the ambitus it occupies only a small part of the plate height and is only slightly larger than the numerous other small tubercles and miliaries that cover the surface (Figure 13f). This continues to the apex where the primary tubercle is barely distinguishable.

The peristome is circular and not invaginated. Its diameter is 36% of the test diameter and there are small, but sharply incised, buccal notches with a thickened rim.

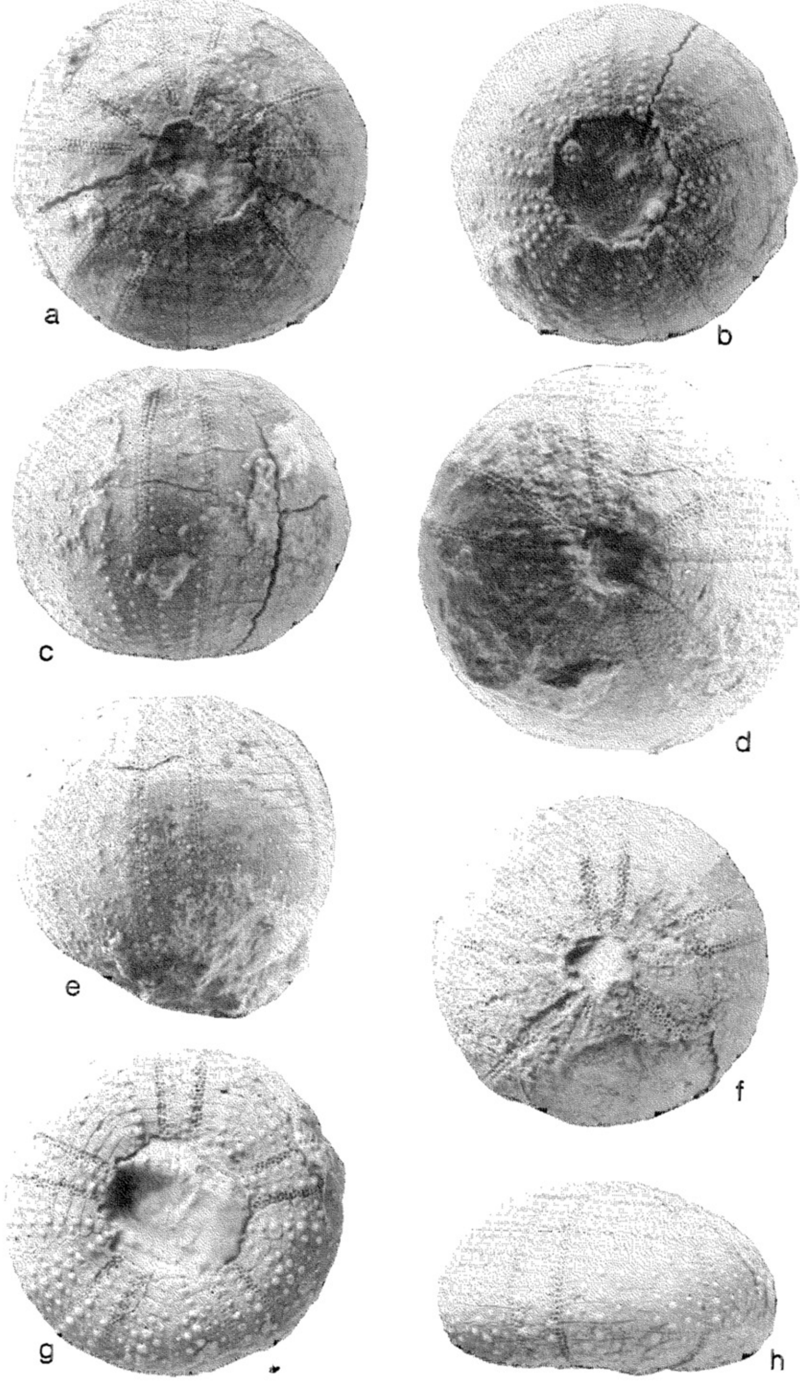


Figure 12. All specimens from the Echinoid Marker Bed, Member c, Natih Formation, late middle Cenomanian of Jebel Madamar. a–e, *Pedinopsis (Pedinopsis) sphaerica* sp. nov.; a–c, apical, oral and lateral views of BMNH E83127, ×2; d, e, apical (×2) and lateral (×1.5) views of BMNH E83128. f–h, *Pedinopsis (Sinaiopsis) sinaica* (Agassiz & Desor), BMNH E83289, apical, oral and lateral views, ×2.

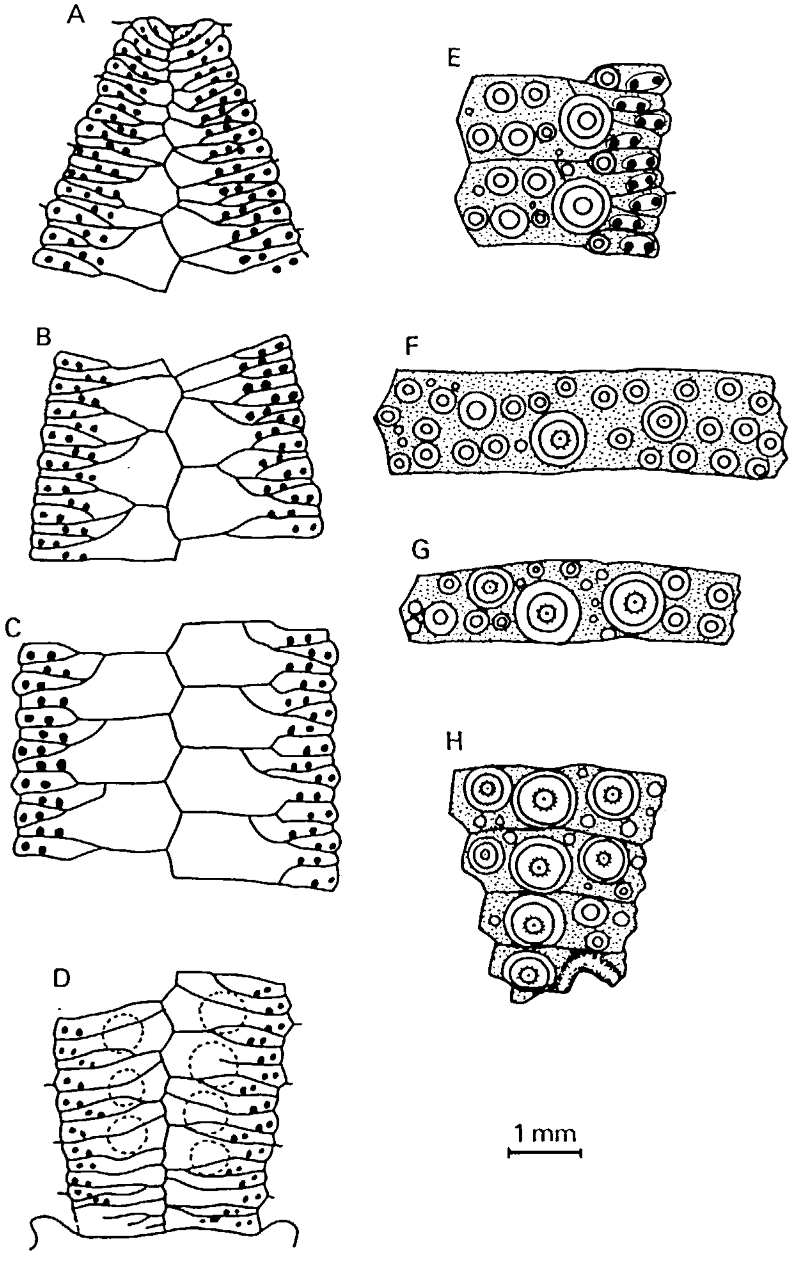


Figure 13. Camera lucida drawings of plating and tuberculation of *Pedinopsis* (*Pedinopsis*) *sphaerica* sp. nov. A, adapical ambulacral plating, apex at top; B, supra-ambital ambulacral plating; C, sub-ambital plating; D, adoral plating, peristomial margin at bottom; E, ambital ambulacral tuberculation; F, ambital interambulacral plate, interradius to the left; G, adoral interambulacral plate, interradius to the left; H, adoral interambulacral plates, peristomial margin at bottom. A–C & E–G, BMNH E83128; D, H, BMNH E83127: all to same scale.

Remarks. P. desori comes closest to this species but differs in having a subconical profile and a larger and noticeably invaginated peristome. Test height in *P. desori* is no more than about 60% of the test diameter. The type of *P. desori* comes from north east Algeria, and additional specimens were illustrated by Cotteau (1865) (though these are inaccurately illustrated in depicting an unnaturally large peristome) and by Blanckenhorn (1925). The small, globular, badly preserved specimen described by Fourtau (1921) as *P. desori,* from the Cenomanian of Egypt, is probably the same as our Oman species but no illustration was given and the type has not been seen. *P. sinaica* (Agassiz & Desor, 1847) is easily distinguished both on test shape and on style of ambulacral compounding. *P. humilis* Fourtau, which is also found at this horizon, is easily distinguished by its wheel-shaped test and has more complex ambulacral compounding in which occluded elements are present.

Subgenus *Pedinopsis* (*Sinaiopsis*) nov.

Diagnosis. Pedinopsis with biserially arranged pores adapically only. Ambulacral plating trigeminate adorally, becoming quadrigeminate adapically.

Type species. Pedina sinaica Agassiz & Desor, 1847, p. 67.

Age and distribution. Cenomanian of Algeria, Egypt, Israel and Oman.

Pedinopsis (*Sinaiopsis*) *sinaica* (Agassiz & Desor, 1847)
Figures 12f–h, 15, 16

1847 *Pedina sinaica* Desor; Agassiz & Desor, p. 67.
1852 *Echinus syriacus* Conrad, in Lynch, p. 212, pl. 1, fig. 1, pl. 22, fig. 127.
1914 *Pedinopsis sinaea* Fourtau, p. 18, pl. 2, figs 3–4.
1925 *Pedinopsis sinaica* Des?; Blanckenhorn, p. 89.

Diagnosis. Subconical, somewhat inflated in profile, with one primary tubercle differentiated on each ambulacral and interambulacral plate.

Age and distribution. Cenomanian of Lebanon, Israel, Egypt, Algeria and Oman.

Material studied. One specimen from the Echinoid Marker Bed, Natih Formation, late middle Cenomanian of Jebel Madamar.

Description. The test is circular in outline and subconical in profile, with swollen sides and the ambitus lying slightly below mid-height (Figures 12a–c). Test diameter is 25.3 mm and test height 14.2 mm (56% of the diameter).

The apical disc is relatively small and approximately circular, 18% of the test diameter. No apical disc plates are preserved in position.

Ambulacral width is 16% of the test diameter at the ambitus. Pore-pairs are strictly unigeminate adorally and ambitally but become biserially arranged towards the apex. All plates up to the ambitus are trigeminate and, except for the lowest two or so plates, only one of the three elements reaches the perradial suture (Figure 15a). Above the ambitus, where pore-pairs start to become biserially arranged, there is a fourth element in each compound plate (Figure 15b). This style of compounding continues to the apex. There is a single larger primary tubercle on each compound plate lying close to the pore zone. This tubercle straddles two of the three elements in trigeminate plates and two or three elements in quadrigeminate plates. A secondary tubercle, about half the diameter of the primary, lies at the lower perradial edge of each plate. The remainder of the compound plate has scattered miliaries (Figure 15a).

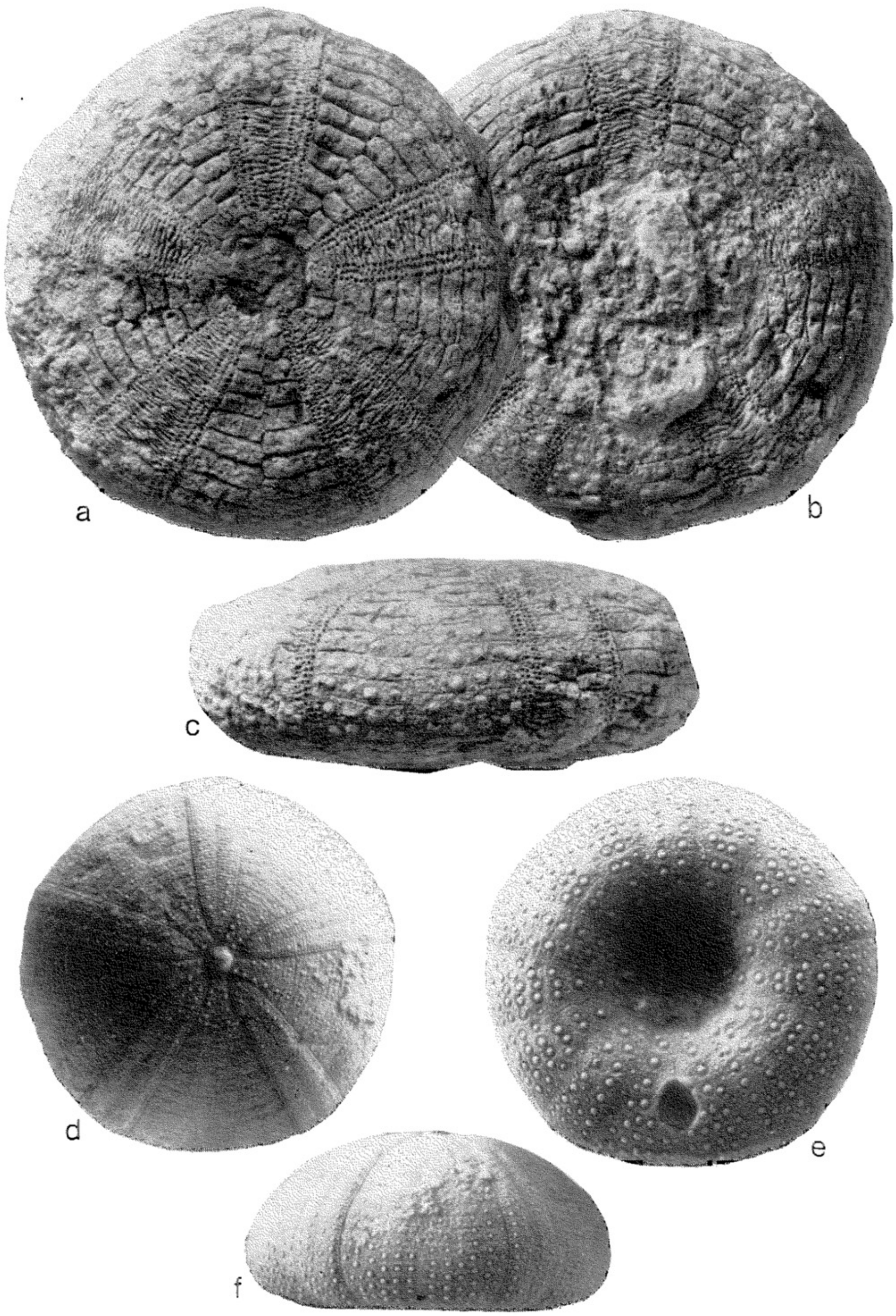


Figure 14. All specimens from the Echinoid Marker Bed, Member c, Natih Formation, late middle Cenomanian, at Jebel Madamar, ×2; a–c, *Pedinopsis* (*Pedinopsis*) *humilis* Fourtau, BMNH E83283, apical, oral and lateral views, ×2. d–f, *Coenholectypus larteti* (Cotteau), BMNH E83129, apical, oral and lateral views.

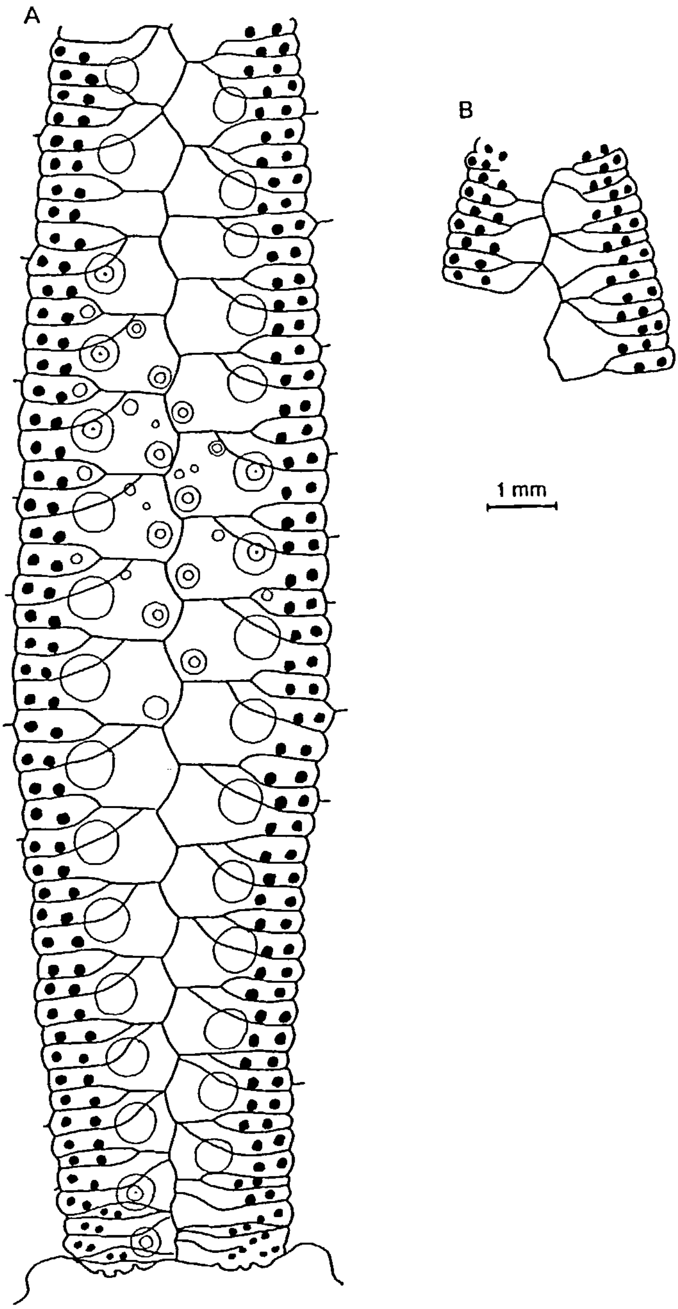


Figure 15. Camera lucida drawings of *Pedinopsis* (*Sinaiopsis*) *sinaica* (Agassiz & Desor), BMNH E83289, from the Echinoid Marker Bed, Unit c, Natih Formation, late middle Cenomanian, at Jebel Madamar. Ambulacral plating: A, plating from peristome (bottom) to half-way up the adapical surface; B, plating close to the apex.

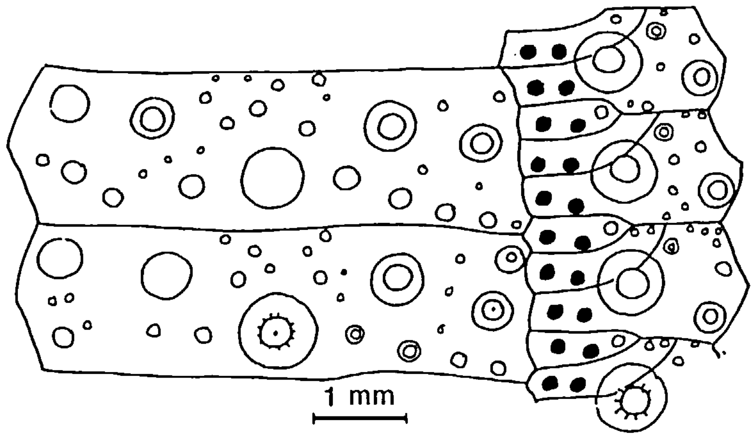


Figure 16. Camera lucida drawing of ambital ambulacral (right) and interambulacral (left) tuberculation in *Pedinopsis* (*Sinaiopsis*) *sinaica* (Agassiz & Desor), BMNH E83289, from the Echinoid Marker Bed, Member c, Natih Formation, late middle Cenomanian, at Jebel Madamar.

Interambulacral plates are rather long and low, ambital plates having a height that is 30% of their length. One larger primary tubercle is differentiated but is relatively small in comparison with the plate (Figure 16). It occupies only about half of the plate height and is situated centrally towards the adoral plate margin. On either side on ambital plates there are two smaller secondary tubercles (about 60% of the primary tubercle's diameter) offset towards the upper edge of the plate (Figure 16). The remainder of the plate surface is covered in sparse tertiary tubercles and miliaries.

The peristome is moderately large, 46% of the test diameter, and somewhat invaginated. Shallow buccal notches are present.

Remarks. *P. sinaica* can be distinguished readily from the two other species of *Pedinopsis* that occur at this level by its shape, tuberculation and pattern of ambulacral compounding. *P. sphaerica* is virtually globular and has a slightly smaller peristome that is not at all invaginated. Interambulacral tuberculation is rather similar but there are more secondary ambulacral tubercles in *P. sphaerica*. Trigeminate plating extends much higher in *P. sinaica* at an equivalent test size and the biserial arrangement of pores is restricted to the adapical portion of the test. *P. humilis* is very much more depressed in form, has larger interambulacral tubercles, more equal in size and occupying very much more of the plate height. It has quadrigeminate plating adorally and polygeminate plating adapically with occluded elements in each compound plate.

The species was first described from the Cenomanian of Sinai, Egypt, and has also been reported from Algeria (Cotteau *et al.*, 1878).

Cohort Irregularia Larteille, 1825
Order Holectypoida Duncan, 1889
Family Holectypidae Lambert, 1899
Genus *Coenholectypus* Pomel, 1883
Coenholectypus larteti (Cotteau, 1869)
Figures 14d–f, 17, 18

1869 *Holectypus larteti* Cotteau; Cotteau, p. 537, text-fig.
1873 *H. larteti* Cotteau; Lartet, p. 81, pl. 9, figs 21–22.
1877 *H. larteti* Cotteau; Lartet, p. 155, pl. 14, figs 1–5.
1879 *H. chauveneti* Cotteau, Peron & Gauthier, p. 172, pl. 12, figs 3–6.
1897 *H. larteti* Cotteau; Loriol, p. 17, pl. 6, fig. 9.
1906 *H. larteti* Cotteau; Gregory, p. 226.
1909 *H. chauveneti* Peron & Gauthier; Fourtau, p. 102.
1912 *H. dowsoni* Fourtau, p. 160, pl. 2, fig. 5.
1914 *H. larteti* Cotteau; Fourtau, p. 44, pl. 3, fig. 8.
1914 *H. larteti* Cotteau race *sinaea* Fourtau, p. 46, pl. 4, figs 1–4.
1914 *H. larteti* Cotteau var. *Dowsoni* Fourtau; Fourtau, p. 47.
1921 *H. larteti* Cotteau; Fourtau, p. 55.
1921 *H. larteti* Cotteau race *sinaea* Fourtau; Fourtau, p. 55.
1925 *H. larteti* Cotteau; Blanckenhorn, p. 90, pl. 7, figs 10–11.
1925 *H. larteti* var *major* Blanckenhorn, p. 91, pl. 7, fig. 12.
non 1989 *H.* (*Coenholectypus*) *larteti* Cotteau; Ali, p. 401, fig. 5(10).

Diagnosis. An inflated species of *Coenholectypus* with a rounded ambitus and the periproct small and opening between plates 4a, b and 8a, b about midway between the peristome and ambitus.

Material studied. Fifteen well-preserved specimens, BMNH E83129-43, from the Echinoid Marker Bed at Jebel Madamar, were used in the biometric study. Other material comes from Jebel Madar and Jebel Salak.

Age and distribution. This is the most abundant species in the Echinoid Marker Bed at Jebel Madamar. It is also known from the Cenomanian of Egypt, North Africa and the Middle East and has been recorded by Roman *et al.* (1989) from the Cenomanian of Dhofar, southern Oman.

Description. Tests range in size from 19 to 29.3 mm in diameter. Test height is 44–61% of the test diameter (mean = 51%, SD = 4.2%, n = 15; Figure 17). The test is circular in outline and has a low conical profile with a well-rounded ambitus that lies 30–40% of test height above the base (Figure 14f). The peristome is deeply invaginated because of the curvature of the test.

The apical disc is small, often somewhat elevated and the diameter is 8–11% of the test diameter (mean = 9%, SD = 0.9%, n = 14). All five genital plates are perforate at these sizes. Genital 2 is at least twice as large as other genital plates and occupies the centre of the apical disc. The madrepores are confined to genital 2, which is usually domed and has a spongy appearance. Gonopores are positioned centrally on the other genital plates. In most specimens ocular plates I, IV and V do not abut genital plate 2 (Figure 18b, c). However, in one large specimen genital plate 2 is extremely large and genital plates alternate with ocular plates around the periphery (Figure 18d). Ocular plates are only slightly smaller than adjacent non-madreporic genital plates.

The ambulacra form 14–17% of the test width at the ambitus. They are composed of simple narrow plates from the subambitus adapically, but distinct triads are developed adorally. Below the ambitus the middle plate in each triad is much enlarged and one or both of the other plates are occasionally occluded from the perradial suture (Figure 18a). Ambulacral pores are undifferentiated and are arranged uniserially throughout. There are 85 pores in a column at about 20 mm test

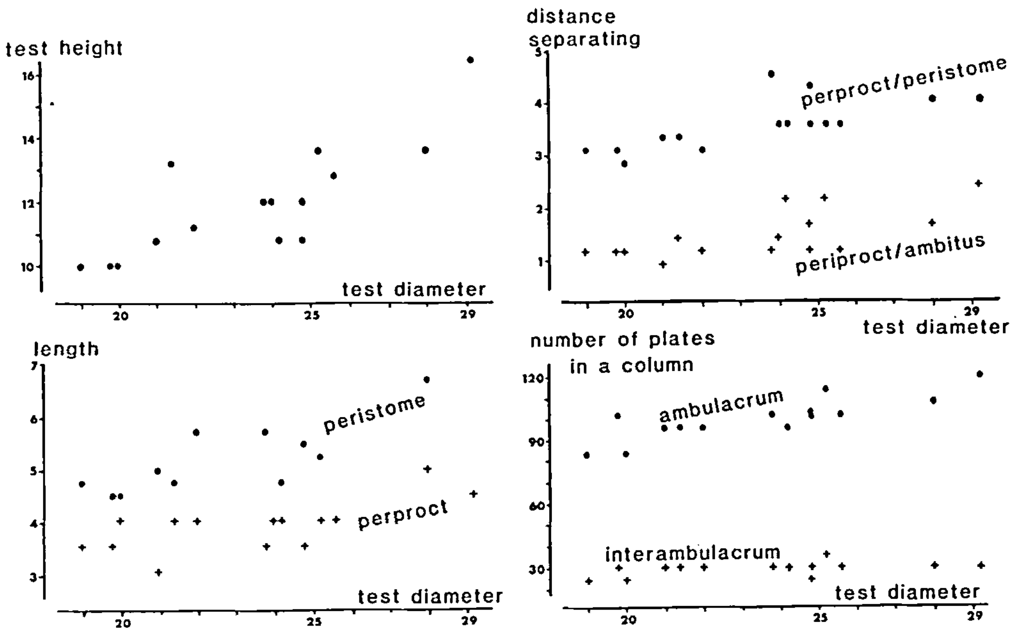


Figure 17. Biometric data on *Coenholectypus larteti* (Cotteau) from the Echinoid Marker Bed, Member c, Natih Formation of Jebel Madamar. All measurements in millimetres.

diameter, increasing to 118 at 29 mm test diameter (Figure 17). There are three and a half to four ambulacral plates opposite a single ambital interambulacral plate. One third of the ambulacral plates lie below the ambitus.

Interambulacral plates are very broad and low at the ambitus. There are 25 plates in a column at about 20 mm test diameter, rising to 32 or 33 at about 29 mm test diameter (Figure 17). 45% of the interambulacral plates occur beneath the ambitus. The most adapical plates have a single differentiated primary tubercle but other plates have up to six equal-sized tubercles arranged in an offset row (Figure 14d–f). Over the remainder of the plate there are semi-regular horizontal rows of miliaries.

The periproct is small, longitudinally elongate and pointed both adorally and adapically (Figure 18a). It is situated about midway between the peristome and the ambitus. Its width is 65–80% of its length (mean = 72%, SD = 4.6%, N = 14), and its length 14–20% of the test diameter (mean = 17%, SD = 1.7, N = 15; Figure 17). The distance separating the periproct from the peristome is 14–19% of the test diameter (mean = 15%, SD = 1.5%, N = 15; Figure 17) and this is composed of the first four, or occasionally five interambulacral plates. The periproct lies between plates 4a, b and 8a, b, or rarely between plates 5a, 4b and 9a, 8b. The distance separating the adapical end of the periproct and the ambitus is 4–9% of the test diameter (mean = 6%, SD = 1.3%, N = 15; Figure 17) and is slightly shorter than the distance from the periproct to the peristome. The peristome is circular and 20–26% of the test diameter in diameter (mean = 23%, SD = 1.8%, N = 11; Figure 17). Buccal slits are sharp and well defined. The peristome is deeply invaginated and the oral surface pulvinate (Figure 14e).

Internally there are feeble thickenings of the test along the adradial margins of interambulacra on the oral surface, where plates thicken to about twice their usual thickness. However, these appear as low undulose features on the interior of the test and not as sharply defined buttresses. There are marked interambulacral ridges

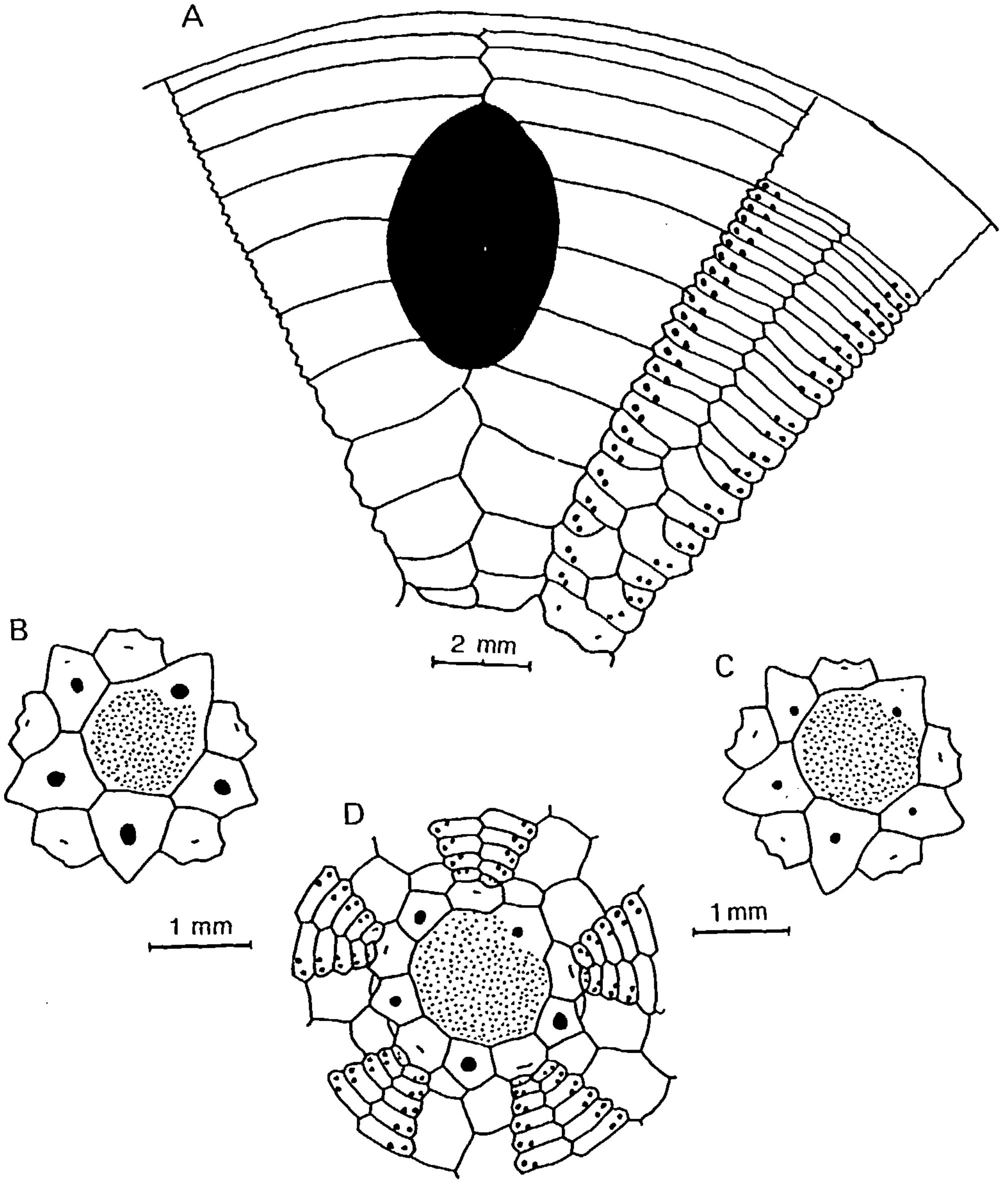


Figure 18. Camera lucida drawings of plating in *Coenholectypus larteti* (Cotteau), from the Echinoid Marker Bed, Member c, Natih Formation, late middle Cenomanian at Jebel Madamar. A, BMNH E83130, oral surface, posterior interambulacrum with periproct and adjacent ambulacrum; scale bar = 2 mm. B–D, apical disc plating, scale bar = 1 mm; B, BMNH E83131: C, BMNH E83129: D, BMNH E83132.

forming a perignathic rim to the peristome, but the structure of this area is not clearly seen and it is not known how large these are in comparison to the auricles.

Remarks. This species was first described from Syria by Cotteau (1869). It is readily distinguished from other species by its inflated shape and rounded profile and by the small size and position of its periproct. A number of subspecies have been described in the literature, but all seem to fall within the range of variation encountered within single populations. The species is known from the Cenomanian of Algeria, where it was described under the name *Holectypus chauveneti*, and from Egypt and the Sinai Peninsula, Israel, Jordan and Syria. It is here transferred to the genus *Coenholectypus* because it has five gonopores, not four. Ali (1989, figure 5(10)) illustrated a *Coenholectypus* from the supposed Maastrichtian of the United Arab Emirates. The figure shows only the aboral surface and is completely undiagnostic. Its apical disc structure is different from that of *C. larteti* in having five equally developed genital plates and it is probably just a depressed form of *C. inflatus* (Cotteau & Gauthier).

Order Spatangoida Claus, 1860
Family Hemiasteridae Clark, 1917
Genus *Hemiaster* Agassiz, 1847
Hemiaster syriacus (Conrad, 1852)
Figures 19a–d, 20

1852 *Holaster syriacus* Conrad, in Lynch, p. 212, pl. 1, fig. 2.
1877 *Hemiaster orbignyanus* Lartet, p. 150, Pl. 13, figs 11, 12.
1878 *H. gabrielis* Cotteau, Peron & Gauthier, p. 116, pl. 4, figs 9–12.
cf. 1888 *H. lusitanicus* Loriol, p. 100, pl. 19, figs 1–7.
cf. 1888 *H. subtilis* Loriol, p. 106, pl. 21, figs 1–3.
1912 *H.* cf. *gabrielis* Fourtau, p. 62.
1914 *H. gabrielis* var. *aegyptiaca* Fourtau, p. 74, pl. 6, fig. 7.
1925 *H. syriacus* Conrad; Blanckenhorn, p. 103, pl. 8, figs 33–35.

Diagnosis. Oval, depressed species of *Hemiaster* tapering slightly posteriorly with the periproct visible from above. Posterior petals about two-thirds the length of anterior petals; both rather narrow and reaching two-thirds of the way to the ambitus. Apical disc lies slightly posterior of centre. Anterior ambulacrum narrow, parallel-sided, anterior notch virtually absent. Peristome crescentic.

Material. Three specimens, BMNH E83144-5, E83284, one of which is crushed, from Jebel Madamar; one, BMNH E83285, from Jebel Salak.

Description. Tests are 17–27 mm in length and 15–24 mm in breadth (83–88% of length). The widest part of the test lies slightly in front of the midpoint, 40–45% of test length from the anterior border. Test height is 60–65% of test length and the tallest part of the test lies well to the posterior, midway between the apical disc and the periproct. The test slopes anteriorly to a rounded anterior margin and there is a slight tallon posteriorly (Figure 19d).

The apical disc is compact with four gonopores. It is slightly longer than broad. Genital plate 2 is long and narrow and separates the two posterior genital plates (Figure 20c). Other genital plates are small and sub-equal and are largely filled by their gonopore. The posterior two ocular plates abut. The apical disc lies about 55% of the test length from the anterior margin.

The petals are more or less straight and are arranged almost cross-like (Figure 19a). The anterior pair reach about two-thirds of the way from the apex to the ambitus while the posterior pair are shorter and reach only slightly more than half way. Anterior petals are 1.5 times as long as the posterior petals. Pores are elongate slits, characteristic of species of *Hemiaster*. The anterior ambulacrum lies in a shallow groove adapically but this depression more or less disappears by the ambitus. The frontal groove is narrow and parallel-sided.

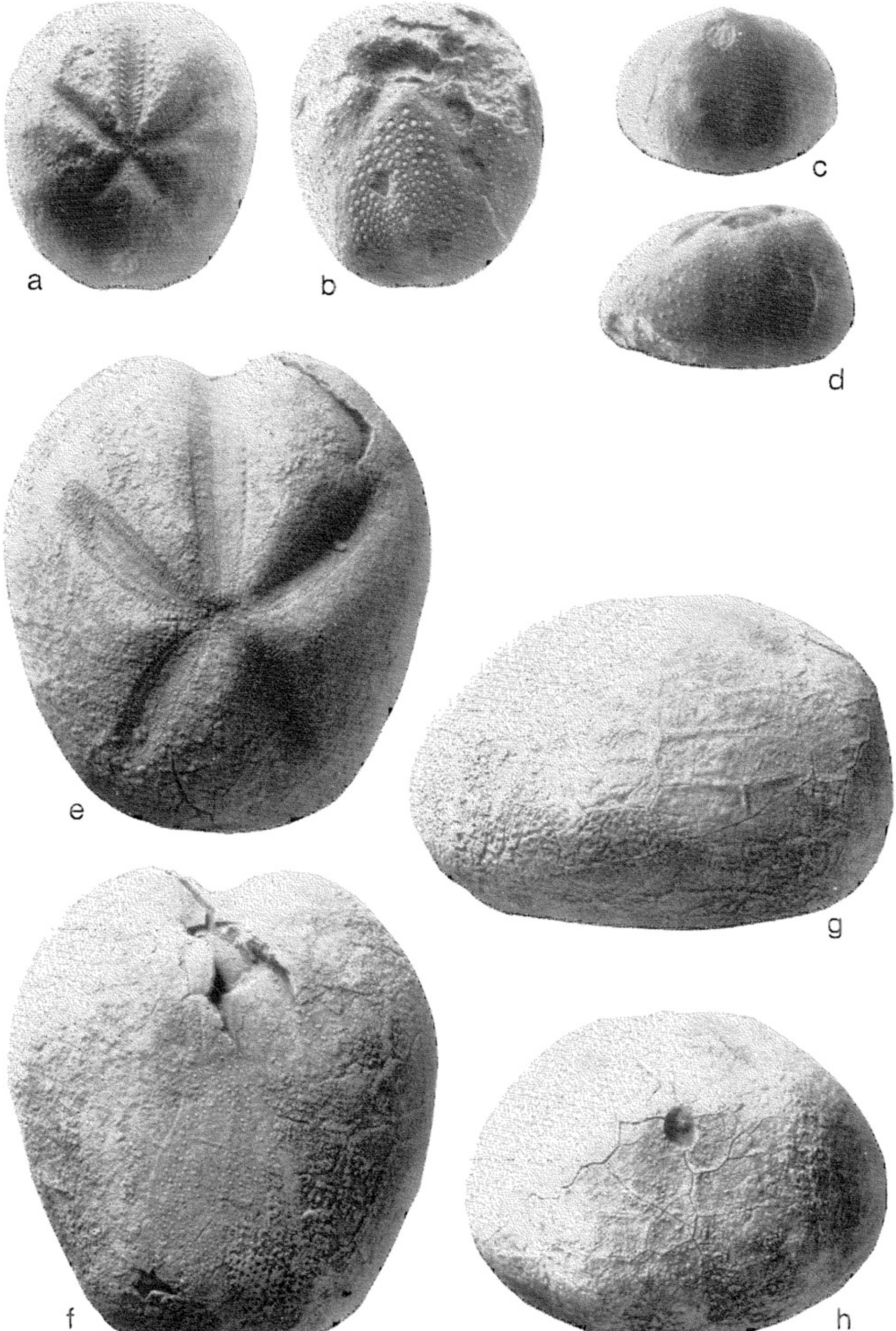


Figure 19. All specimens from the Echinoid Marker Bed, Member c, Natih Formation, late middle Cenomanian, at Jebel Madamar; ×2. a–d, *Hemiaster syriacus* (Conrad), BMNH E83144; apical, oral, posterior and lateral views. e–h, *Hemiaster cubicus* Agassiz & Desor, BMNH E83286; apical, oral, lateral and posterior views.

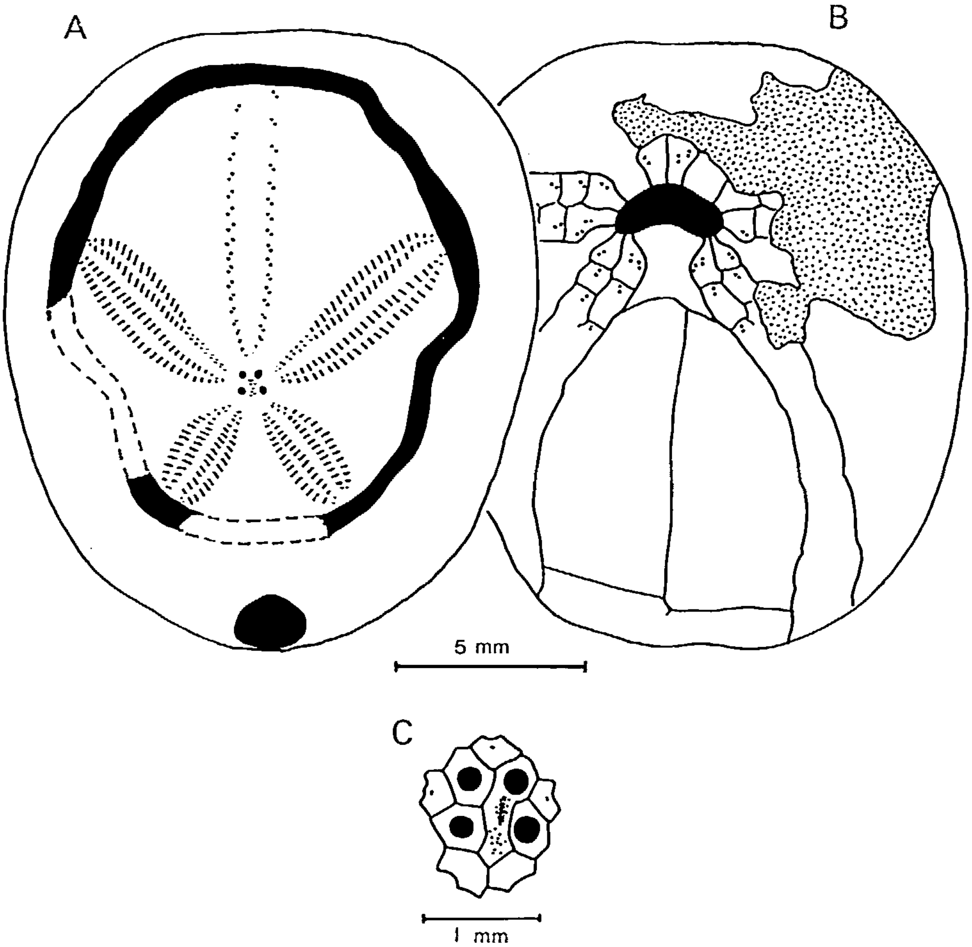


Figure 20. Camera lucida drawings of *Hemiaster syriacus* (Conrad), BMNH E83144, from the Echinoid Marker Bed, Member c, late middle Cenomanian, at Jebel Madamar. A, B, apical and oral views; black band = peripetalous fasciole (dashed segments inferred); stippled region = damaged part of test. C, apical disc plating.

The peripetalous fasciole is thickest at the base of the anterior petals. It forms a semicircle around the anterior of the test and bends sharply behind the anterior petals (Figure 20a).

The periproct is visible from above and lies very high on the test, its base being 75% of the test height above the base. It is relatively small and slightly elongate vertically. The peristome lies 70% of the test length from the posterior and is crescentic in outline due to projection of the labrum. The labral plate is short and broad (Figure 20b).

Remarks. The taxonomy of Cenomanian species of *Hemiaster* is in dire need of revision. In the past a large number of specific names have been erected based on one or a few specimens only and largely distinguished on subtle differences in shape. There are no biometric studies of populations from single localities for any North African or Middle East species. This means that the validity of many of these nominal species is questionable. Unfortunately only four specimens from Oman were collected and it is not possible to establish the variation in morphology quantitatively. The Oman specimens appear identical in all respects to specimens described by Conrad, in Lynch (1852), and later by Blanckenhorn (1925) from Syria under the name *Hemiaster syriacus*. They also bear a very close resemblance to specimens from the Sinai Peninsula and from Algeria described under the name *Hemiaster gabrielis* Cotteau *et al.* (1878). As noted by Fourtau (1914, p. 75), certain species from the Cenomanian of Portugal described by Loriol (1888) also appear to be virtually identical, namely *H. lusitanicus* and *H. subtilis*. Proper biometric analysis of populations of these species is required before we can be certain whether or not they are conspecific.

Hemiaster cubicus Agassiz & Desor, 1847
Figures 19e–h, 21

1847 *Hemiaster cubicus* Desor; Agassiz & Desor, p. 124.
1855 *Hemiaster cubicus* Desor; Orbigny, p. 237, pl. 879, figs 1–7.
1914 *Hemiaster cubicus* Desor; Fourtau, p. 67, pl. 6, figs 1–5.
1921 *Hemiaster cubicus* Desor; Fourtau, p. 87.
1925 *Hemiaster cubicus* Desor; Blanckenhorn, p. 99, pl. 8, figs 28, 29.

Diagnosis. A *Hemiaster* with long, sub-equal petals reaching about three-quarters of the way to the ambitus. Apical disc sub-central. Peristome very far forward, directed anteriorly and largely covered by the labrum in oral view. Labral plate very long and narrow.

Age and distribution. Very common in the Cenomanian of Egypt and Israel; unknown from Algerian or European Cenomanian.

Material studied. Three specimens, BMNH E83286-8, all from the Echinoid Marker Bed at Jebel Madamar. One specimen is incomplete, the other two are large, complete individuals and form the basis for the following description.

Description. The test is subquadrate in outline with a moderately deep and well-defined anterior sulcus (Figure 19e–h). The posterior of the test is squarely truncated and the widest point on the test lies slightly anterior of mid-length. The two complete specimens have test lengths of 35 and 36 mm, maximum widths of 31 and 34.5 mm (89–96% of test length) and heights of 24 and 26 mm (69–72% of test length). In profile the posterior is vertically truncated and the anterior well rounded. The highest point on the test more or less coincides with the apical disc and the upper surface is gently domed (Figure 19g).

The apical disc lies more or less centrally. Its anterior edge lies 47–49% of the test length from the front of the test. It is tetrabasal and genital 2 extends posteriorly separating the posterior two genital plates (Figure 21). The apical disc is much broader than long.

The anterior ambulacrum lies in a moderately deep sulcus that continues to the peristome. There are about 24 small, rather widely spaced pores in each column between the ocular and the peripetalous fasciole, which lies slightly above the ambitus. The petals are long, deeply sunken and sub-equal in length. The posterior petals are some 82–90% of the length of the anterior petals. There are just over 50 pore-pairs in the anterior petals and about 46 in the posterior petals. The anterior petals reach 80–82% of the radial length to the ambitus, while the posterior petals

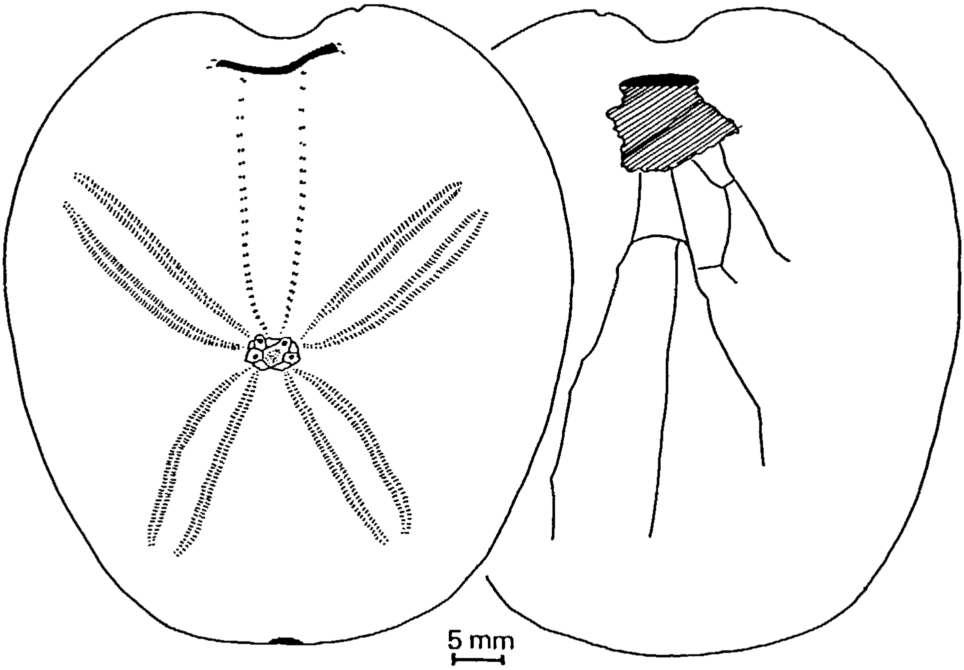


Figure 21. Camera lucida drawings of *Hemiaster cubicus* Agassiz & Desor, BMNH E83286, from the Echinoid Marker Bed, Member c, Natih Formation, late middle Cenomanian, at Jebel Madamar: apical and oral views. Black band = peripetalous fasciole; lined area = missing part of test.

reach about 70% of the radial length. The angle formed between the two anterior petals is 115° while that between the two posterior petals is 65°. There is a peripetalous fasciole but only the anterior portion is preserved, due to weathering. This lies close to the ambitus.

The lower surface is gently rounded. Plating on the oral surface is largely obscured. The peristome, which is about 3.5 mm in width, lies very close to the anterior border and is directed forwards. The distance between the frontal edge of the peristome and the anterior is only about 5% of the test length. The peristome is largely hidden from sight in oral view because it is orientated almost vertically and covered by the labral plate. The labrum is extremely long and slender, and appears to have been about 7 mm in length (the anterior is missing in the specimen that shows plating arrangement). The interradial plastronal suture is inclined towards ambulacrum V.

The periproct is relatively small (12% of the test height) and slightly elongate vertically. It lies towards the top of the posterior surface, its base being about 58–66% of the test height above the base.

Remarks. *H. cubicus* is a very distinctive species because of its long, sub-equal petals, and very anterior and forward-pointing peristome that, in oral view, is largely hidden from sight. The extreme length of the labral plate is also unusual. No other species of *Hemiaster* can be confused.

The species was first described on the basis of material from the Cenomanian of Egypt, where it is common. It has also been reported from the Cenomanian of Palestine (Blanckenhorn, 1925).

7. Conclusions

1. A relatively rich and diverse fauna, consisting of six regular and three irregular echinoids, is present in the Cenomanian Natih Formation of northern Oman. This horizon, termed the Echinoid Marker Bed, forms a distinct, correlatable unit within that region.

2. Cenomanian microfossils are described from this region for the first time. These allow for precise dating of this horizon as late middle Cenomanian. A number of these taxa are not known outside the Middle East region.

3. Microfauna, microflora and lithofacies analyses suggest that the Echinoid Marker Bed represents peri-reefal deposits lying immediately behind a rudist shoal/biostrome complex fringing the Natih carbonate shelf. The preponderance of regular echinoids over irregular echinoids suggests that the sediment must have been predominantly algal bound.

4. The echinoid fauna is very similar to the fauna of the Sinai Peninsula and the Lebanon/Syria region. Eight of the nine species are also known from the Sinai Peninsula. Faunal links with the western Mediterranean region are much weaker.

5. The composition of the genus *Pedinopsis* is reviewed and three species groups recognized and distinguished at subgeneric level. The new subgenus *Sinaiopsis* is erected.

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