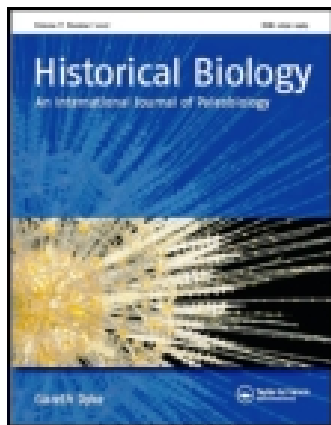


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Contribution to the scleractinian corals of Hanifa Formation, Upper Jurassic, Jabal Al-Abakkayn, central Saudi Arabia

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Eighteen scleractinian coral species belonging to 13 genera, 8 families and 4 suborders have been identified from the lower and upper parts of the Upper Jurassic (Oxfordian) Hanifa Formation at Jabal Al-Abakkayn, central Saudi Arabia. *Actinastrea bernensis*, *A. crassoramosa*, *Coenastrea hyatti*, *Stylina kachensis*, *Cryptocoenia slovenica*, *C. wegneri*, *Isastrea hemisphaerica*, *I. bernensis*, *Montlivaltia cornutiformis*, *M. frustriformis*, *Collignonastraea jumarensis*, *Ovalastrea michelini* and *Vallimeandropsis davidsoni* are believed to be recorded for the first time from the Jurassic rocks of central Arabia. Most corals have massive hemispherical and globular forms, and few corals have dendroid and conical growth forms. They occur as small, isolated patches, about 0.5 m thick and about 10–30 m wide, in argillaceous reefal limestones. The identified corals show Africa, north America, northern, southern and western Europe, and southern or eastern Asia corals. The low diversity and abundance as well as the small size of colonies are attributed to inimical palaeoecological factors throughout the reefoids formation such as muddy substratum, water turbidity, high rate of sedimentation.

Keywords: scleractinian corals; taxonomy; Hanifa Formation; Upper Jurassic; Oxfordian; Saudi Arabia

Introduction

Jurassic rock units in central Saudi Arabia crop out in a graben region known as the Tuwaiq Mountains. They form one of the major topographic features of the Arabian Peninsula, extending in a north–south trend subparallel to the eastern edge of the Arabian Shield. The central Tuwaiq Mountains are intensively dissected by several wadi systems and tectonic grabens of which Wadi Hanifa is one of the largest (El-Asa'ad 1991).

On their study on the shifting biogeography of reef corals during the Oxfordian, Martin-Garin et al. (2012) stated that, during the Oxfordian (a time span of 6 million years in the Late Jurassic), the distribution of tropical coral reefs was limited to about 35°N and near to 25°S. However, in the Middle Oxfordian time, coral reefs were abundant only at higher latitudes and almost entirely missing near the equator. During that time, the area of maximum reef development had shifted poleward to a belt lying between 20° and 35°N, leaving hardly any coral formations at the lower inner-tropical latitudes. After demise towards the end of Middle Oxfordian time, the low-latitude reefs recovered during the Late Oxfordian, accompanied by a southward migration of reef corals in the northern hemisphere.

Studies on Jurassic scleractinian corals of central Saudi Arabia are very few, unlike other invertebrates such as bivalves, gastropods, cephalopods and echinoderms. The two most important studies on corals were El-Asa'ad (1989, 1991). Scleractinians are sporadically scattered in the lower

and upper parts of the middle to late Oxfordian Hanifa Formation. Corals occur as reefoid or parareef and more or less concentrated into small scattered bioherms or patches. The coral patches are small, about 0.5 m thick and about 10–30 m wide. They are built up of almost globular coralla and packed in more or less argillaceous carbonate sediment. The upper surface of coralla is convex and covered by corallites, while the lower surface is subplane to subconvex, without corallites and covered by remnants of holotheca.

The main objectives of this study are identification, systematic description, palaeoecological parameters and palaeogeographic distribution of scleractinian corals of Hanifa Formation at Jabal Al-Abakkayn, central Saudi Arabia (Figure 1).

Geologic setting

The Hanifa Formation was defined by Bramkamp and Ramirez (1958). They defined the type locality of the formation at Jabal Al-Abakkayn in Wadi Hanifa (24°57'N, 46°12' 8"E to 24°55'02"N, 46°17' 02"E). The formation is 101 m thick and composed of relatively soft, chalky limestones with interbedded marl and shale and with several brown, oolitic limestone beds in the middle and upper parts. Based on the presence of an ammonite fragment only, Arkell (1952) assigned an Upper Oxfordian age to the middle part of the Hanifa Formation. Arkell (1952) compared the fragment with *Perisphinctes (kranao-*

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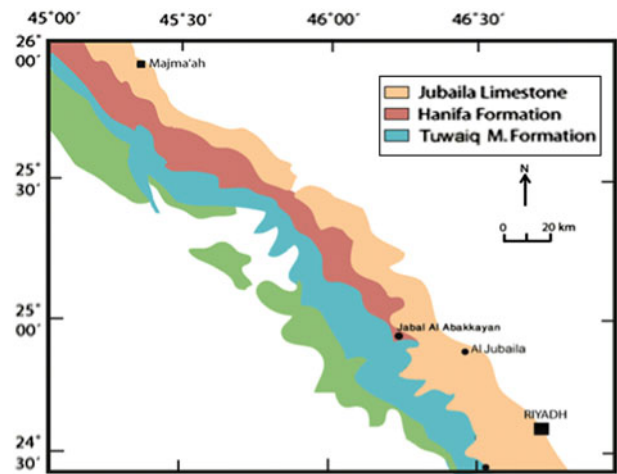


Figure 1. (Colour online) Location map of the study area.

sphinctes) africanus Dacque of middle Oxfordian age from Mombasa.

Powers et al. (1966) described the Hanifa Formation in central Saudi Arabia as composed mainly of calcarenite and sandy limestone in its upper part and calcarenites and shale in its middle and lower parts. A lower Kimmeridgian age was assigned by those authors to the formation, based on the presence of the large forminifers: *Kurnubia morrisi* (Redmond) and *Pseudocyclammina jaccardi* (Schrodt).

The same age was given to the Hanifa Formation by Powers (1968).

Vaslet et al. (1983) subdivided the Hanifa Formation into two informal members (Figure 2): the Hawtah Member (H1), up to 66 m of the lower muddy carbonate unit, and the Ulayyah Member (H2), up to 74 m of the upper stromatoporoid and lagoonal carbonate unit.

Moshrif and El Asa'ad (1984) studied the sedimentology and palaeoenvironments of the Hanifa Formation in the northern side of Wadi Hanifa. The authors concluded that the formation is generally composed of various carbonate lithofacies intercalated with shale units at several levels, these carbonate lithofacies include argillaceous limestones and arenaceous limestones. They assigned a Late Oxfordian–Early Kimmeridgian age for the Hanifa Formation, based on the presence of the foraminifers, *Kurnubia morrisi* (Redmond), *Kurnubia palastiniensis* (Henson), *Kurnubia wellingsi* (Henson) and *Nautiloculina ootithica* Hohler.

Manivit (1987) assigned a Middle Oxfordian–Early Kimmeridgian age for the Hanifa Formation at the southern part of central Saudi Arabia, based on the presence of the echinoids, *Acrocidaris nobitis* Agassiz, *Pseudocidaris thunnani* Agassiz and *Rhabdocidaris orbignya* Agassiz, from the uppermost part of the formation.

Other than ammonites, large foraminifers and colonial corals, the Hanifa Formation contains rich macrofauna

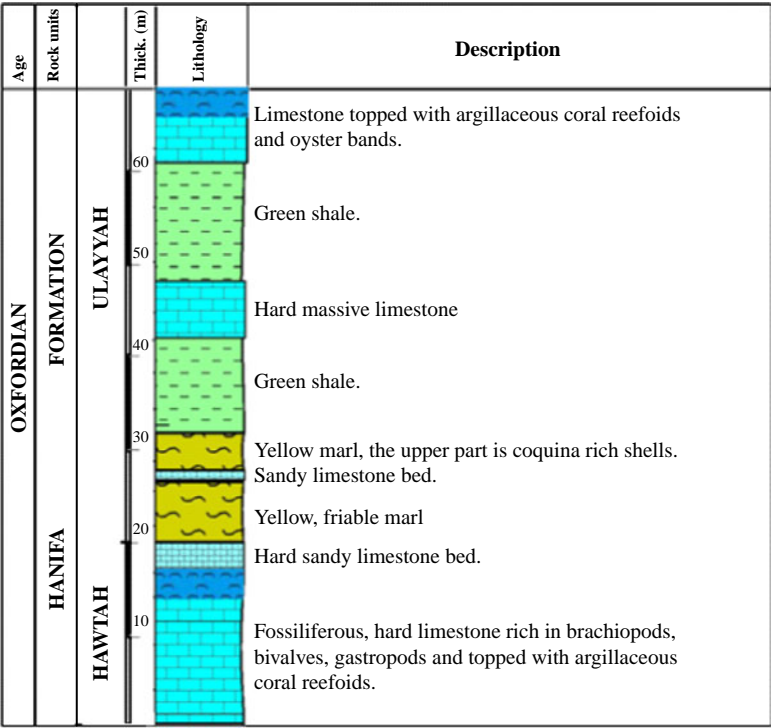


Figure 2. (Colour online) Lithostratigraphic succession of the Oxfordian Hanifa Formation at Jabal Al-Abakkayn section.

belonging to brachiopods, echinoids, large nautiloids, bivalves and gastropods. These macrofauna are long ranged and cannot give important chronostratigraphic information.

In the present study and in the absence of characteristic fauna, the authors would like to follow Arkell (1952) and Enay et al. (1987) in assigning a Middle-Upper Oxfordian age to the Hanifa Formation in central Saudi Arabia.

Systematic description

Eighteen scleractinian coral species belonging to 13 genera, 8 families and 4 suborders have been identified. Samples are stored in the Geological Museum, Geology and Geophysics Department, King Saud University, Riyadh, Saudi Arabia. Abbreviations in measurements mean: d , diameter of corallites; $c-c$, nearest distance between corallite centres; N_s , number of septa; h , height of the corallum. This study followed Alloiteau (1952), Roniewicz (1976), Beauvais (1980) and the recent modifications for the classification of coral genera. Most of the palaeogeographic distribution of the taxa depended on the data of Paleobiology Database (<http://paleodb.org>).

Class **Anthozoa** Ehrenberg, 1834

Subclass **Zoantharia** Blainville, 1830

Order **Scleractinia** Bourne, 1900

Suborder **Astrocoeniina** Vaughan and Wells, 1943

Family **Actinastraeidae** Alloiteau, 1952

Genus **Actinastrea** d'Orbigny, 1849

Type species **Astrea geminata** Goldfuss, 1826

Actinastrea bernensis (Koby, 1886)

(Figure 3(A),(B))

1886 *Astrocoenia bernensis* Koby: 291, pl. 86, figs 9–10.
1900 *Astrocoenia bernensis* Koby – Gregory: 62. pl. 15, figs 6 and 7.

1993 *Actinastrea bernensis* Koby – Pandey and Fürsich: 8, pl. 1, fig. 8.

Material. Seven badly preserved specimens.

Occurrence. Hawtah Member, Middle Oxfordian, Hanifa Formation, Jabal Al-Abakkayn.

Dimensions. $d = 1-2$ mm, $c-c = 2-2.2$ mm, $N_s = 16-25$.

Description. Corallum nodular, cerioid to sub-cerioid. Corallites small, wall septothecal and/or parathecal, prominent. Corallites commonly hexagonal, pentagonal, quadrangular or subcircular and rarely circular. Septa in four cycles. Septa of first and second cycles join in the centre and form a thick styliform columella. Endothecal dissepiments common along the periphery of the corallites. Columella usually thickened by primary septa.

Remarks. Genus *Astrocoenia* Milne Edwards and Haime lacks a styliform columella (Wells 1956). The other genus in the family with similar morphological characters but with a well-developed styliform columella is *Actinastrea* D'Orbigny. Therefore, the authors agree with Pandey and Fürsich (1993) in transferring *Astrocoenia bernensis* Koby to *Actinastrea* d'Orbigny.

Distribution. Bathonian–Oxfordian of Western India.

Actinastrea crassoramosa (Michelin, 1843)

(Figure 3(C)–(E))

1843 *Astrea crassoramosa* Michelin: 109, pl. 25, fig. 2.

1885 *Astrocoenia crassoramosa* (Michelin) – Koby: 295, pl. 87, figs 2 and 3.

1955 *Actinastrea crassoramosa* (Michelin) – Geyer: 320, pl. 1, figs 1–3.

2003 *Enallocoenia crassoramosa* (Michelin) – Pandey and Fürsich: 13, pl. 2, fig. 7.

2011 *Actinastrea crassoramosa* (Michelin) – Kiessling, Pandey, Schemm-Gregory and Mewis: 201, fig. 6(A), (B).

Material. Three small specimens.

Occurrence. Hawtah Member, Middle Oxfordian, Hanifa Formation, Jabal Al-Abakkayn.

Dimensions. $d = 1.3-3.1$ mm, $c-c = 2.1-2.9$ mm, $N_s = 12-23$.

Remarks. Corallum colonial, cerioid with polygonal outline, partially plocoid with pentagonal to hexagonal outlines. Septa compact, moderately thick, occasionally anastomosing near the columella. Septa arranged in three cycles. Septa of first and second cycles join in the centre and form a thick styliform columella. Endothecal dissepiments subtabular to vesicular, occasionally forming a ring in the middle of corallites. Wall septoparathecal.

Distribution. Upper Jurassic of northern Ethiopia, Chile, the Czech Republic, Iran, Mexico, Poland, Portugal, Switzerland, Tunisia. Lower Cretaceous of Iran.

Genus **Coenastrea** Etallon, 1859

Type species **Coenastrea martis** Etallon, 1864

Coenastrea abakkaynata El-Asa'ad, 1991

(Figure 3(F)–(H))

1991 *Coenastrea abakkaynata* El-Asa'ad: 274, pl. 6, fig. 2(a)–(c).

Material. Six moderately preserved specimens.

Occurrence. Ulayyah Member, Upper Oxfordian, Hanifa Formation, Jabal Al-Abakkayn.

Dimensions. $d = 1.5-2.5$ mm, $c-c = 3-3.5$ mm, $N_s = 24$.

Description. Massive and hemispherical corallum. Corallites cerioid. Septa arranged in three cycles. First and

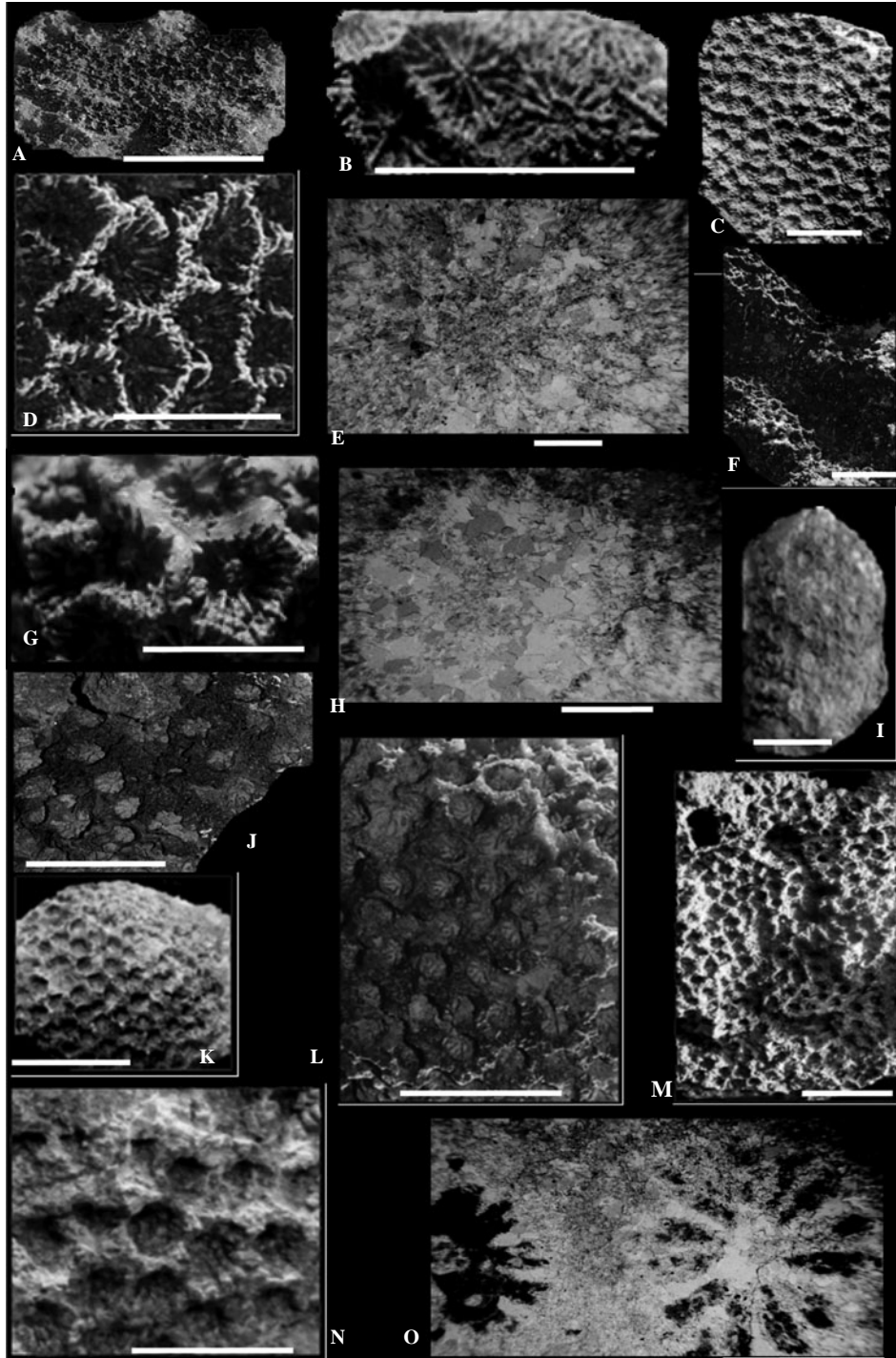


Figure 3. (A, B) *Actinastrea bernensis* (Koby, 1880–1890): (A) calicular surface, Hawtah Member, bar = 1 cm; (B) close up view of another sample, Hawtah Member, bar = 4.5 mm. (C–E) *Actinastrea crassoramosa* (Michelin, 1843): (C) calicular surface, Hawtah Member, bar = 5 mm; (D) close up view of another sample, Hawtah Member, bar = 2.5 mm; (E) recrystallised septa, dissepiments and columella, transverse thin section, plane light, bar = 1 mm. (F–H) *Coenastreaa abakkaynata* El-Asa'ad, 1991: (F) calicular surface, Ulayyah Member, bar = 1 cm; (G) enlarged of the same, bar = 2.5 mm; (H) recrystallised and partial silicification of skeletal elements or materials, transverse thin section, plane light, bar = 1 mm. (I, J) *Coenastreaa hyatti* Wells, 1942: (I) calicular surface, Hawtah Member, bar = 1 cm; (J) enlarged of the same, bar = 5 mm. (K, L) *Styliina kachensis* Gregory, 1900: (K) calicular surface, Ulayyah Member, bar = 1 cm; (L) enlarged of the same, bar = 1 cm. (M–O) *Cryptocoenia slovenica* (Turnšek, 1972): (M) calicular surface, Ulayyah Member, bar = 1 cm; (N) enlarged of the same, bar = 5 mm; (O) partial silicification and micritisation of skeletal elements or materials, transverse thin section, plane light, bar = 1 mm.

second cycles long, join the columella. The third cycle short. Upper septal margins ornamented with small, equal and regular teeth, lateral sides ornamented with rows of granules, perpendicular to the upper surface. Columella styliiform, well developed. Endotheca abundant, dissepiments numerous on the outer margins of the calices. Wall septothecal.

Coenastraea hyatti Wells, 1942

(Figure 3(I),(J))

1942 *Astrocoenia hyatti* Wells: 1, pl. 1, figs 1–6.

1990 *Coenastraea hyatti* Wells – Stanley and Beauvais: 355, figs 3.1–3.3 and 5.2–5.8.

Material. Two moderately preserved specimens.

Occurrence. Hawtah and Ulayyah Members, Middle–Upper Oxfordian, Hanifa Formation, Jabal Al-Abakkayn.

Dimensions. $d = 1–2$ mm, $c–c = 1–3$ mm, $N_s = 12–24$.

Description. Corallum globular. Corallites plocoid. Endotheca abundant. Wall septo-parathecal. Thin dissepiments may join inner edges of the first cycle of septa to columella. Inner edge of septa covered with spiniform granules.

Remarks. The American species, *Coenastraea hyatti* (Wells, 1942) possesses smaller corallite diameters (1–2 mm), non-anastomosing septa, and an isolated columella.

Distribution. Middle Jurassic (Bajocian) of North America.

Suborder **Stylinina** Alloiteau, 1952

Family **Stylinidae** d'Orbigny, 1851

Genus **Stylina** Lamarck, 1816

Type species *Stylina echinulata* Lamarck, 1816

Stylina kachensis Gregory, 1900

(Figure 3(K),(L))

1900 *Stylina kachensis* Gregory: 56, pl. 12, figs 1–17, pl. 13, figs 1–7.

1966 *Stylina kachensis* Gregory – Flügel: 56, pl. 15, fig. 3.5.

1993 *Stylina kachensis* Gregory – Pandey and Fürsich: 9, pl. 1, figs 3–5, text-fig. 7.

Material. Two moderately preserved specimens.

Occurrence. Hawtah and Ulayyah Members, Middle–Upper Oxfordian, Hanifa Formation, Jabal Al-Abakkayn.

Dimensions. $d = 1.5–2.5$ mm, $c–c =$, $N_s = 16–20$.

Description. Corallum hemispherical. Corallites plocoid, slightly projecting beyond the corallum. Corallite wall septothecal or parathecal, occasionally separated by coenosteum. Calices shallow to moderately deep and circular in plan view. Septa well developed, primaries may or may not meet the columella, secondaries short and do not

reach the columella. Distal margin of septa denticulated. Lateral surface of septa either smooth or spinulate. Vesicular and tabular endothecal dissepiments common. Costae well developed, joining with those of the adjoining corallites. Columella styliiform, mostly prominent.

Remarks. The present species differs from *Stylina delabechii* Milne Edwards and Haime (1851) in that, the latter is characterised by projecting calices, more septa and more prominent and confluent costae.

Distribution. Jurassic of Chile, India and Iran.

Genus **Cryptocoenia** d'Orbigny, 1847

Type species *Astrea alveolala* Goldfoss, 1826

Cryptocoenia slovenica (Turnšek, 1972)

(Figures 3(M)–(O))

1972 *Pseudocoenia slovenica* Turnšek: 83, pl. 4, figs 1 and 2, pl. 5, figs 1–4.

2003 *Pseudocoenia slovenica* Turnšek – Pandey and Fürsich: 27, pl. 5, fig. 5, pl. 6, figs 1–6.

2011 *Cryptocoenia slovenica* (Turnšek) – Kiessling, Pandey, Schemm-Gregory and Mewis: 202, fig. 7(a)–(c).

Material. One moderately preserved specimen.

Occurrence. Ulayyah Member, Upper Oxfordian, Hanifa Formation, Jabal Al-Abakkayn.

Dimensions. $d = 1.8–2.7$ mm, $c–c = 2.0–5.4$ mm, $N_s = 12$.

Description. Corallum small. Calices plocoid, small, deep, circular in outline, separated by coenosteum. Coenosteum consisting of costae and tabular and vesicular dissepiments. Costosepta rarely anastomosing, compact, moderately thick, hexamerally arranged in two cycles. Wall septoparathecal. Columella absent.

Remarks. The present species is characterised by smaller diameter (1.8–2.7 mm) than *Cryptocoenia wegneri* Pandey and Fürsich, 2003.

Distribution. Jurassic of the Czech Republic, Ethiopia, Germany, Iran, Portugal, Romania, Slovenia, Spain and Tunisia.

Cryptocoenia wegneri Pandey and Fürsich, 1993

(Figure 4(A),(B))

1900 *Stylina kachensis* Gregory: 58, pl. 13, fig. 6.

1993 *Cryptocoenia wegneri* Pandey and Fürsich: 10, pl. 5, figs 4, 6 and 9, text fig. 8.

Material. Two moderately preserved specimens.

Occurrence. Hawtah and Ulayyah Members, Middle–Upper Oxfordian, Hanifa Formation, Jabal Al-Abakkayn.

Dimensions. $d = 2.5–4$ mm, $c–c = 3.5–4.5$ mm, $N_s = 6–12$.

Description. Corallum moderately large. Corallites plocoid, large, circular in cross section, bounded by

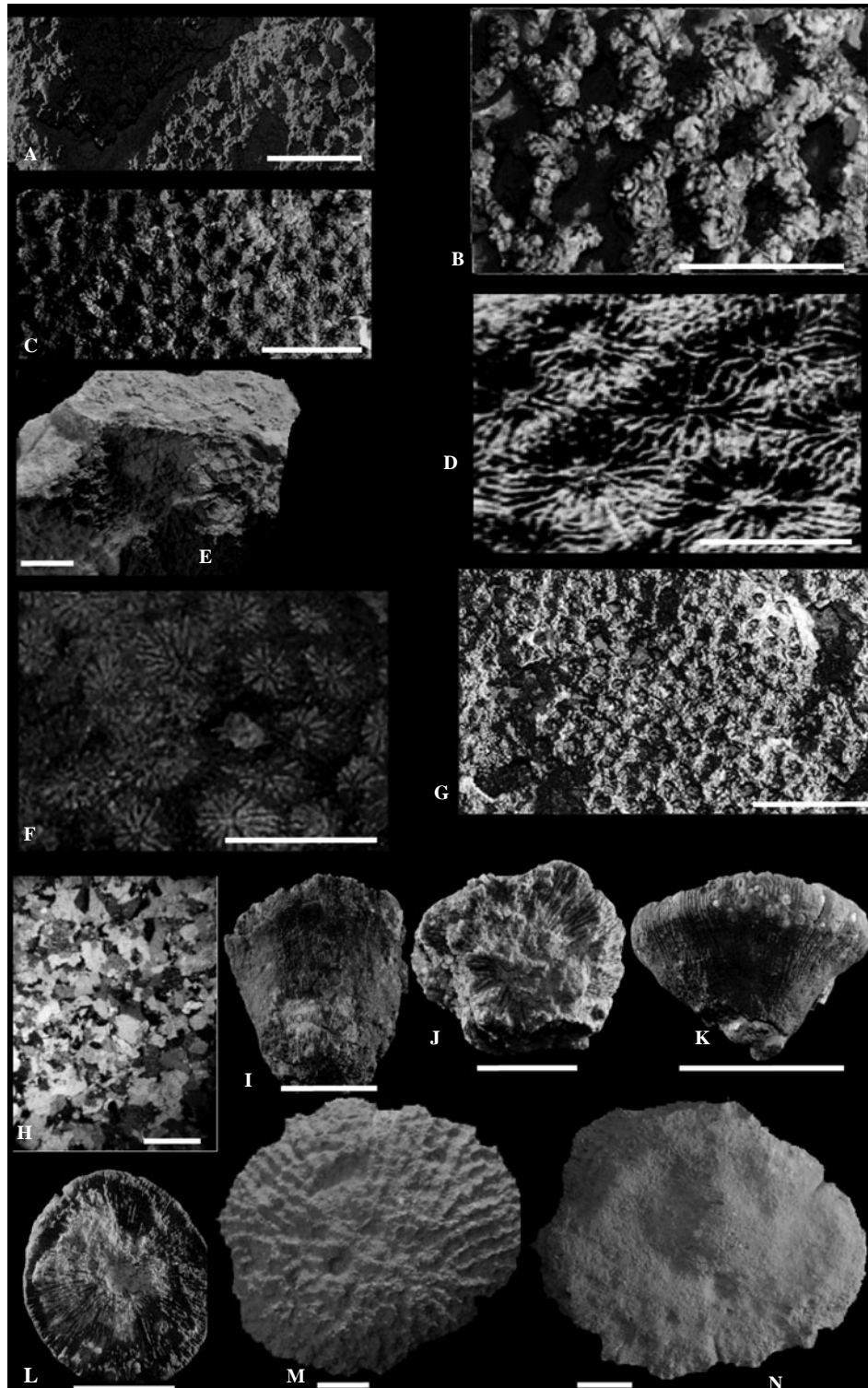


Figure 4. (A, B) *Cryptocoenia wegneri* Pandey and Fürsich, 1993: (A) calicular surface, Hawtah Member, bar = 1 cm; (B) close up view of another corallum, Hawtah Member, bar = 5 mm. (C, D) *Isastrea hemisphaerica* Gregory, 1900: (C) calicular surface, Ulayyah Member, bar = 1 cm; (D) close up view of another corallum, Hawtah Member, bar = 5 mm. (E, F) *Isastrea bernensis* Etallon, 1864: (E) calicular surface, Ulayyah Member, bar = 1 cm; (F) enlarged of the same, bar = 1 cm. (G, H) *Columnocoenia safarratensis* El-Asa'ad, 1991: (G) calicular surface, Ulayyah Member, bar = 1 cm; (H) recrystallised skeletal elements or materials, transverse thin section, crossed nicols, bar = 1 mm. (I, J) *Montlivaltia cornutiformis* Gregory, 1900: (I) side view, Ulayyah Member, bar = 1 cm; (J) calicular view of the same, bar = 1 cm. (K, L) *Montlivaltia frustriformis* Gregory, 1900: (K) side view, Ulayyah Member, bar = 1 cm; (L) calicular view of the same, bar = 1 cm. (M, N) *Collignonastraea jumarensis* (Gregory, 1900): (M) calicular surface, Hawtah Member, bar = 1 cm; (N) lower surface of the same, bar = 1 cm.

septothea and para-thea, usually separated by coenosteum. Septa few in numbers, thick, hexamerally arranged, with small, subangular denticles along the distal margin. Tabular and vascular endothecal dissepiments present. Septo-costae subconfluent. Columella absent.

Distribution. Jurassic of India and Iran.

Suborder **Faviina** Vaughan and Wells, 1943

Family **Isastreidae** Alloiteau, 1952

Genus **Isastrea** Milne Edwards and Haime, 1851

Type species *Astrea helianthoides* Goldfuss, 1826

Isastrea hemisphaerica Gregory, 1900

(Figure 4(C),(D))

1900 *Isastraea hemisphaerica* Gregory: 127, pl. 16, figs 2–4.

1993 *Isastraea hemisphaerica* Gregory – Pandey and Fürsich: 18, pl. 11, fig. 10.

Material. Seven large well-preserved specimens.

Occurrence. Hawtah and Ulayyah Members, Middle-Upper Oxfordian, Hanifa Formation, Jabal Al-Abakkayn.

Dimensions. $d = 3.3\text{--}6.2\text{ mm}$, $c\text{--}c = 4.5\text{--}7.2\text{ mm}$, $N_s = 40\text{--}50$.

Description. Corallum massive. Corallites cerioid to subthamnasteroid, hexagonal, pentagonal and tetragonal in outline. Calices distinct, moderately deep, mostly monocentric, rarely dicentric. Septa compact, thick, covered with granules and spinules. Septa arranged in at least four cycles, anastomosing at the inner edge. Septa of the first and second cycles nearly reaching the centre, occasionally forming a pseudocolumella. Septa confluent with those of adjacent corallites. Vesicular dissepiments common near the wall. Wall parathecal.

Remarks. *Isastrea hemisphaerica* differs from *I. propinqua* Thurmann and Etallon in that the later is characterised by possessing branching septa (at times four secondary septa are joined to primary septum) and a pseudocolumella due to extension of primary septa into the centre of the calices.

Distribution. Jurassic of Chile and India.

Isastrea bernensis Etallon, 1864

(Figure 4(E),(F))

1864 *Isastrea bernensis* Etallon: 392, pl. 55, fig. 12.

1990 *Isastrea bernensis* Etallon – Errenst: 193, pl. 11, fig. 1(a)–(c).

2011 *Isastrea bernensis* Etallon – Kiessling, Pandey, Schemm-Gregory and Mewis: 205, figs 7(G) and 8(A)(B).

Material. Six well-preserved specimens.

Occurrence. Ulayyah Member, Upper Oxfordian, Hanifa Formation, Jabal Al-Abakkayn.

Dimensions. $d = 3.3\text{--}6.2\text{ mm}$, $c\text{--}c = 2.0\text{--}5.2\text{ mm}$, $N_s = 24\text{--}40$.

Description. Corallum massive, cerioid. Corallites hexagonal, pentagonal and tetragonal in outline. Calices moderately deep, mostly monocentric, rarely dicentric. Septa arranged in four cycles. Septa of the first and second cycles nearly reaching the centre, occasionally forming a pseudocolumella. Vesicular dissepiments common near the wall. Wall septothecal.

Remarks. This species is distinguished from similar species of *Isastrea* by its indistinct axial area and corallite dimensions.

Distribution. Jurassic of Azerbaijan, Ethiopia, France, Poland, Portugal, Romania, Spain, Switzerland and the UK.

Family **Placocoeniidae** Alloiteau, 1952

Genus **Columnocoenia** Alloiteau, 1952

Type species *Columnocoenia lamberti* Alloiteau, 1952

Columnocoenia safarratensis El-Asa'ad, 1991

(Figure 4(G),(H))

1991 *Columnocoenia safarratensis* El-Asa'ad: 283, fig. 3.

Material. One badly preserved specimen.

Occurrence. Ulayyah Member, Upper Oxfordian, Hanifa Formation, Jabal Al-Abakkayn.

Dimensions. $d = 1.5\text{--}2.3\text{ mm}$, $c\text{--}c = 2.8\text{--}3.3\text{ mm}$, $N_s = 30$.

Description. Corallum massive. Corallites plocoid. Septa free, compact, arranged in four cycles of hexamerall systems. Septa of first two cycles long-bearing swollen at inner edges. Septa of the third cycle short. Septa of fourth cycle incomplete and rudimentary. Wall septothecal. Coenosteum consists of twice as many costae as septa. Costae confluent with those of adjoining corallites. Common endothecal and exothecal dissepiments. Columella elongated, modified by septa of first cycle.

Remarks. The present species resembles *Stylina hirta* de Fromentel in the general shape but the number of septa of the genus *Stylina* equals half the number of costae while the number of septa equals the number of costae in genus *Columnocoenia*; moreover, the present species has pali-form lobes in front of the septa of the first two cycles.

Family **Montlivaltiidae** Dietrich, 1926

Genus **Montlivaltia** Lamouroux, 1821

Type species *Montlivaltia caryophyllata* Lamouroux, 1821

Montlivaltia cornutiformis Gregory, 1900

(Figure 4(I),(J))

1900 *Montlivaltia cornutiformis* Gregory: 85, pl. 4, figs 5–8, pl. 5, figs 1–3, pl. 9, fig. 11.

1972 *Montlivaltia cornutiformis* Gregory – Beauvais: 49, pl. B, fig. 1.

1993 *Montlivaltia cornutiformis* Gregory – Pandey and Fürsich: 14, pl. 2, figs 1–3.

2007 *Montlivaltia cornutiformis* Gregory – Pandey, Fürsich, Baron-Szabo and Wilmsen: 22, pl. 5, fig. 8(a),(b).

Material. One moderately preserved specimen.

Occurrence. Ulayyah Member, Upper Oxfordian, Hanifa Formation, Jabal Al-Abakkayn.

Dimensions. $h = 26$ mm, $d = 25$ mm, $N_s = 90$.

Description. Coral solitary, trochoid, calice flat with acute or rounded upper margin. Septa simple. Upper margin smooth to very faintly denticulate. Rarely, spines of adjacent septa join to resemble synapticalae. Costae correspond to septa, denticles along the upper margin of the septa rare and inconspicuous. Endothecal dissepiments abundant. Epitheca very thin and fragile, covering costae at places in imperistent rings.

Remarks. The morphological features and the dimensions agree well with specimens of *M. cornutiformis* Gregory described earlier from Jurassic strata of Kachchh and Iran.

Distribution. Jurassic of Afghanistan, France, India, Iran, Madagascar, Serbia and Montenegro and Uzbekistan. Lower Cretaceous of Iran.

Montlivaltia frustriformis Gregory, 1900

(Figure 4(K),(L))

1900 *Montlivaltia frustriformis* Gregory: 98, pl. 5, figs 4–10, pl. 6, figs 8 and 9, pl. 8, fig. 12.

1958 *Montlivaltia frustriformis* Gregory – Alloiteau: 41, pl. 37, figs 10 and 11.

1972 *Montlivaltia frustriformis* Gregory – Beauvais: 48.

1993 *Montlivaltia frustriformis* Gregory – Pandey and Fürsich: 14, pl. 3, figs 1–7, pl. 4, figs 1–5 and 8–10, text figs 10 and 11.

Material. One moderately preserved specimen.

Occurrence. Ulayyah Member, Upper Oxfordian, Hanifa Formation, Jabal Al-Abakkayn.

Dimensions. $h = 12$ mm, $d = 24$ mm, $N_s = 100$.

Description. Corallite conical. Base pointed with small convex attachment area. Calice very shallow to moderately deep with well-marked, acute to rounded upper margin. Septa simple, laminar, thin to thick, prominent, primary septa and a few secondary septa are almost thick, long and reaching up to the axial space. The remaining septa are successively thinner and shorter. The septa may be smooth or bear granules, striae and/or ridges on the lateral surfaces corresponding to trabeculae. Endothecal dissepiments

abundant. Costae correspond to septa, may be slightly coarser and blunt.

Remarks. *Montlivaltia frustriformis* Gregory is an inverted frustrum, either low with large base resulting in a discoid shape or high, resembling a truncated cone. *Montlivaltia cornutiformis* differs from *M. frustriformis* by being more elongate and having fewer septa at the same height.

Distribution. Jurassic of France, India and Madagascar.

Suborder **Microsolenina** Morycowa and Roniewicz, 1995

Family **Latomeandridae** Alloiteau, 1952

Genus **Collignonastraea** Alloiteau, 1958

Type species *Comoseris jumarensis radiata* Gregory 1900

Collignonastraea jumarensis (Gregory, 1900)

(Figure 4(M),(N))

1900 *Comoseris plana* Gregory: 160, pl. 20, figs 6–8.

1978 *Collignonastraea jumarensis* (Gregory) – Beauvais: 65, pl. 6, fig. 4.

1993 *Collignonastraea jumarensis* (Gregory) – Pandey and Fürsich: 39, pl. 10, figs 5, 6, 8–13, 15 and 16.

Material. Two moderately preserved specimens.

Occurrence. Hawtah Member, Middle Oxfordian, Hanifa Formation, Jabal Al-Abakkayn.

Dimensions. $d = 2.4$ – 6.8 mm, $c-c = 2.2$ – 6.0 mm, $N_s = 25$ – 63 .

Description. Corallum low, massive. Corallites sub-circular to subelliptical. Calices distinct, bounded by synapticalochea along the collines. Septa thin, dense, with pointed to rounded granules along the sides. Synapticalae and dissepiments common. Columella either not visible on the calicular surface or with trabecular-like appearance.

Remarks. The morphological characters of the present specimens similar to those of Pandey and Fürsich (1993, p. 39, pl. 10, figs 5, 6, 8–13, 15 and 16) from western India and correspond well to those of *Comoseris jumarensis* and *Comoseris piano*. Gregory (1900) differentiated two varieties in *Comoseris jumarensis* on the basis of the colline pattern. In his var. *radiata*, the six primary collines radiate from the central corallite. With increase in size, secondary and tertiary collines either branch from primaries or independently develop towards the periphery.

Distribution. Jurassic of China, India, Iran and Jordan.

Genus **Latiastrea** Beauvais, 1964

Type species *Latiastrea foulassensis* Beauvais, 1964

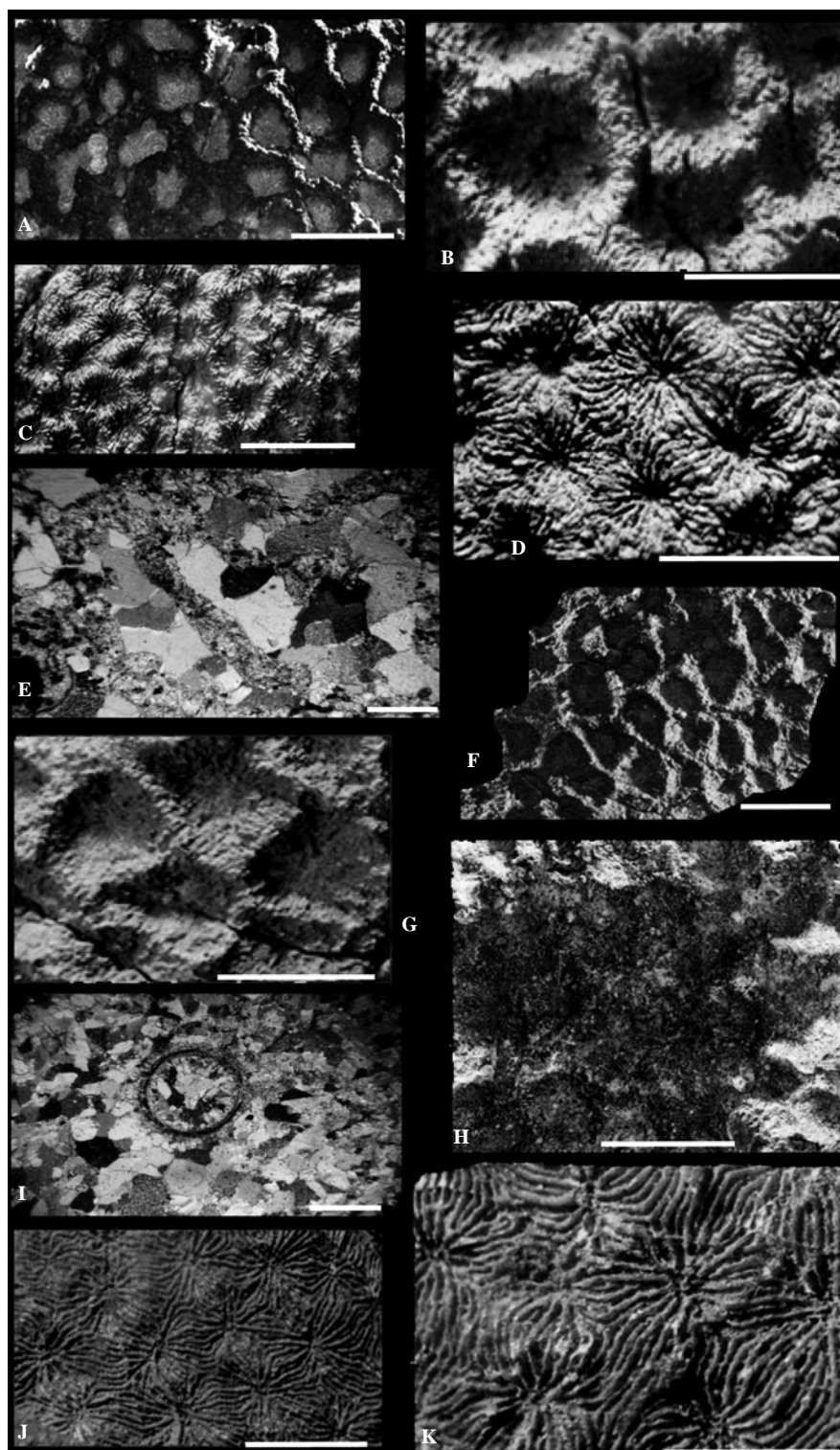


Figure 5. (A, B) *Latiastrea greppini* (Koby, 1880–1890): (A) calicular surface, Hawtah Member; (B) enlarged of the same. (C–E) *Ovalastrea michelini* (Milne Edwards and Haime, 1851): (C) calicular surface, Ulayyah Member; (D) enlarged of the same; (E) recrystallised and micritised skeletal elements or materials, transverse thin section, crossed nicols, bar = 1 mm. (F, G) *Trigerastraea collignoni* Alloiteau, 1958: (F) calicular surface, Hawtah Member, bar = 1 cm; (G) enlarged of the same, bar = 1 cm. (H, I) *Vallimeandropsis davidsoni* (Milne Edwards and Haime, 1851): (H) calicular surface, Ulayyah Member, bar = 1 cm. (I) highly recrystallised skeletal elements or materials, transverse thin section, plane light, bar = 1 mm. (J, K) *Kobyastrea lomontiana* (Etallon, 1864): (J) calicular surface, Hawtah Member, bar = 5 mm; (K) enlarged of the same, bar = 5 mm.

Latiastrea greppini (Koby, 1885)

(Figure 5(A),(B))

1885 *Latimaendra greppini* Koby: 239, pl. 68, fig. 3.

1991 *Latiastrea greppini* Koby – El-Asa'ad: 278, pl. 2, fig. 1(a)–(d).

2011 *Latiastrea greppini* Koby – Kiessling, Pandey, Schemm-Gregory and Mewis: 205, fig. 8(E),(F).

Material. Five preserved specimens.

Occurrence. Hawtah Member, Middle Oxfordian, Hanifa Formation, Jabal Al-Abakkayn.

Dimensions. $d = 6.9–11.5$ mm, $c-c = 5.0–11.6$ mm, $N_s = 56–70$.

Description. Massive and hemispherical corallum. Corallites cerioid, polygonal, mostly pentagonal to hexagonal, moderately deep, mostly monostomodal to distomodal, occasionally dicentric. Multiplication of corallites by intracalicular budding. Calicular centres are distinct. Septa thin, anastomosing, arranged in at least five cycles. Septa of the first and second cycles equal, reaching columella. Septa of third to fifth cycles equally thick but shorter. The upper margins of septa ornamented with small teeth. Endotheca and synapticules present. Wall septoparathecal.

Remarks. The general shape of the present species looks like the genus *Isastrea* Milne Edwards and Haime, 1851 but the structure of its septa is identical to that of the family Latomeandriidae Alloiteau, 1952.

Distribution. Jurassic of the Czech Republic, Ethiopia and Saudi Arabia.

Genus *Ovalastrea* d'Orbigny, 1849

Type species *Astrea caryophylloides* Goldfuss, 1826

Ovalastrea michelini (Milne-Edwards and Haime, 1851)

(Figure. 5(C)–(E))

1884 *Favia michelini* (Michelin) – Koby: 206, pl. 71, figs 1–5.

1993 *Ovalastrea michelini* Milne-Edwards and Haime – Bertling: 100: 153, pl. 5, fig. 1.

2011 *Ovalastrea michelini* Milne-Edwards and Haime – Kiessling, Pandey, Schemm-Gregory and Mewis: 205, fig. 9(A),(B).

Material. Four moderately preserved specimens.

Occurrence. Hawtah and Ulayyah Members, Middle-Upper Oxfordian, Hanifa Formation, Jabal Al-Abakkayn.

Dimensions. $d = 6–11$ mm, $c-c = 6–7.5$ mm, $N_s = 40–50$.

Description. Corallum massive, hemispherical. Calices generally oval or elongate, rarely circular, elevated and separated by a narrow, depressed and costated peritheca. Calicular borders sharp and central part of the calice deep (2–4 mm). Septa confluent or subconfluent and

unequal in size. The second cycle shorter and thinner than the first cycle. The third cycle shorter and thinner than the second cycle. Costae well developed in parallel groups, on the depressed areas between the calices.

Remarks. The morphological characters such as plocoid colony, circular to suboval outlines of the calices and papillose to spongy columella match with *Ovalastrea* d'Orbigny. The dense packing of corallites, the cerioplocoid nature of the colony and diameter of corallites match *O. michelini* (Milne-Edwards and Haime). *Ovalastrea proeminens* (Koby) has similar dimensions but differs from the present species in a thicker coenosteum.

Distribution. Jurassic of Ethiopia, France, Georgia, Germany, Portugal, Spain, Ukraine and Uzbekistan.

Suborder **Fungiina** Verrill, 1865

Family **Andemantastraeidae** Alloiteau, 1952

Genus **Trigerastraea** Alloiteau, 1952

Type species *Isastrea trigeri* Fromental, 1887

Trigerastraea collignoni Alloiteau, 1958

(Figure 5(F),(G))

1958 *Trigerastraea collignoni* Alloiteau: 78, pl. 7, fig. 1, pl. 14, fig. 3.

1989 *Trigerastraea collignoni* Alloiteau – El-Asa'ad: 678, pl. 79, figs 1–3.

Material. Two moderately preserved specimens.

Occurrence. Hawtah Member, Middle Oxfordian, Hanifa Formation, Jabal Al-Abakkayn.

Dimensions. $d = 7–13$ mm, $c-c = 4.5–9$ mm, $N_s = 48$.

Description. Massive, subcerioid, mono-to-distomodoal or tristomodoal intratentacular budding. Calices pentagonal, rarely hexagonal or irregular, with four to six unequal substraight to curved sides. Septa in four cycles, the first two cycles extending to corallite axial region, the last two cycles inserted between long septa and united with them near the distal margins. Columella parietal. Endotheca of fine, strongly inclined dissepiments.

Remarks. *Trigerastraea collignoni* Alloiteau differs from *Trigerastraea irregularis* (Koby) in that the later is characterised by small diameter (2–7 mm in Beauvais 1972).

Distribution. Jurassic of Madagascar and Saudi Arabia.

Genus **Vallimeandropsis** Beauvais, 1965

Type species *Vallimeandropsis davidsoni* (Milne Edwards and Haime, 1851)

Vallimeandropsis davidsoni (Milne Edwards and Haime, 1851)

(Figure 5(H),(I))

1851 *Latomeandra davidsoni* Milne-Edwards and Haime: 137, pl. 27, fig. 10.

1965 *Vallimeandropsis davidsoni* (Milne-Edwards and Haime) – Beauvais: 873, pl. 6, fig. 1, pl. 37, fig. 3.

1970 *Vallimeandropsis davidsoni* (Milne-Edwards and Haime) – Beauvais: 61.

2003 *Vallimeandropsis davidsoni* (Milne-Edwards and Haime) – Pandey and Fürsich: 24, pl. 11, fig. 1.

Material. Two moderately preserved specimens.

Occurrence. Ulayyah Member, Upper Oxfordian, Hanifa Formation, Jabal Al-Abakkayn.

Dimensions. $d = 8.5\text{--}12.5$ mm, $c\text{--}c = 7\text{--}11$ mm, $N_s = 65\text{--}90$.

Description. Corallum massive, submeandroid. Corallites moderately deep with septothecal or parathecal wall. Septa thin, lamellar, closely spaced. Abundant dissepiments in the central part of the corallite and vesicular dissepiments in the outer part. Columella either very small and rudimentary or indistinct.

Remarks. The present two samples are characterised by small micrometric measurements, in comparison with samples of Pandey and Fürsich (2003) from western India.

Distribution. Jurassic of the Crickley, Gloucestershire, UK and Western India.

Family **Kobyastraeidae** Roniewicz, 1970

Genus **kobyastrea** Roniewicz, 1970

Type species ***Thamanastrea lomontiana*** Etallon, 1864

Kobyastraea lomontiana (Etallon, 1864)

(Figure 5(J),(K))

1864 *Thamanastrea lomontiana* Etallon: 399, pl. 56, fig. 14.

1887 *Thamanastrea lomontiana* Etallon – Koby: 366, pl. 98, fig. 4.

1970 *Kobyastraea lomontiana* (Etallon) – Roniewicz: 140, pl. 1, figs 1 and 2, pl. 2, fig. 1, pl. 3, fig. 4.

1975 *Kobyastraea lomontiana* (Etallon) – Turnšek: 15, 10, fig. 3.

1985 *Kobyastraea lomontiana* (Etallon) – Rosendhal: 68, pl. 2, fig. 9.

1991 *Kobyastraea lomontiana* (Etallon) – El-Asa'ad: 282, pl. 4, fig. 1(a)–(c).

2011 *Kobyastraea lomontiana* (Etallon) – Kiessling, Pandey, Schemm-Gregory and Mewis: 206, fig. 9(E), (F).

Material. Two well-preserved specimens.

Occurrence. Hawtah and Ulayyah Members, Middle-Upper Oxfordian, Hanifa Formation, Jabal Al-Abakkayn.

Dimensions. $d = 3.3\text{--}7.1$ mm, $c\text{--}c = 3.2\text{--}6.3$ mm, $N_s = 36$.

Description. Massive and thamnasterioid corallum with shallow, dense calices. Extracalicular and rarely intracalicular budding. Septa confluent, three to four cycles. Septa of the first cycle long and reach the columella, the second cycle shorter and thinner, and the third cycle join the second inner margins. The upper margins of the septa ornamented with equal teeth while the internal margins ornamented with regularly arranged trabecular lobes. The lateral sides of the septa covered by sharp granules. Columella is small, styliform and sometimes slightly flattened.

Remarks. The corallites are much larger than in the similar genus *Thamnasteria*. Dimensions fit *Kobyastraea lomontiana* (Etallon).

Distribution. Jurassic of Azerbaijan, Croatia, the Czech Republic, Ethiopia, Portugal, Saudi Arabia, Switzerland, Uzbekistan and Saudi Arabia.

Discussions and conclusions

Thirteen of the identified scleractinians have believed to be recorded for the first time from the Jurassic rocks of central Arabia, they are *Actinastrea bernensis*, *A. crassoramosa*, *Coenastraea hyatti*, *Stylina kachensis*, *Cryptocoenia slovenica*, *C. wegneri*, *Isastrea hemisphaerica*, *I. bernensis*, *Montlivaltia cornutiformis*, *M. frustriformis*, *Collignonastraea jumarensis*, *Ovalastrea michelini* and *Vallimeandropsis davidsoni*. These species were previously recorded from the Jurassic rocks of Jordan, Iran, India, Georgia, Azerbaijan, Afghanistan, Serbia, Montenegro, the Czech Republic, Ukraine, Germany, Poland, Portugal, Romania, Switzerland, Slovenia, Poland, Spain, France, the UK, Chile, Mexico, North America, Ethiopia, Madagascar, Tunisia and the Cretaceous rocks of Iran.

Oxfordian coral reef distribution was found to be determined by suitable substrate, bathymetry, oxygen availability and nutrient content of the seawater (Leinfelder et al. 1994, 1996; Leinfelder 2001), as well as by light intensity, hydrodynamic energy and sediment balance (Insalaco 1998; Martin-Garin et al. 2012). Diminishing water transparency as a result of rising turbidity levels will contract the photic zone (Dupraz 1999; Dupraz and Strasser 1999, 2002).

During Oxfordian time, the Tethys was an epicontinental tropical sea, and coral reefs flourished in its shallow waters. They did not form a continuous fringing reef but rather occurred as isolated build-up, may be biohermes (<1 m thick and few metres wide) in more or less argillaceous carbonate sediments, and parallel to the palaeoshoreline. Most corals have hemispherical or globular forms, while few have subramose and solitary forms.

Inadequate (inimical) palaeoecological conditions have prevailed throughout the formation of such reefoids, as high rate of argillaceous materials, which caused turbidity and consequently decreased light penetration. Also, the muddy facies might lead to unfavourable soft substrate for coral colonies to grow in large sizes. This is indicated by the presence of the solitary species *Montlivaltia cornutiformis* and *M. frustiformis* [in contrast to the proposal by El-Asa'ad (1991)] and also by the small size of colonies in comparison with those along the Red Sea coast.

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