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Paleoecology of Benthic Foraminifera in Coral Reefs Recorded in the Jurassic Tuwaiq Mountain Formation of the Khashm Al-Qaddiyah Area, Central Saudi Arabia

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ABSTRACT: Thirty three benthic foraminiferal species belong to 23 genera and 16 families have been recorded from the coral reefs of the Callovian Tuwaiq Formation, Khashm Al-Qaddiyah area, Central Saudi Arabia. Three species: *Astacolus qaddiyahensis*, *Nodosaria riyadhensis, Siderolites jurassica* are believed to be new. Nearly all identified foraminifera are of Atlantic-Mediteranean affinity. The foraminiferal assemblage recorded in the present work is mixed of open marine, moderately deep marine conditions associations and shallow to deep lagoon. The reefal part of upper Twiaq Formation may have been deposited in shallow water of lower to middle shelf depth (20–50 m) as indicated by abundant corals and benthic foraminifera. The coral fauna and bearing benthic foraminifera indicated moderate water energy.
KEY WORDS: coral reef, benthic foraminifera, Jurassic, Tuwaiq Formation, Saudi Arabia.

0 INTRODUCTION

The Jurassic marine carbonate succession is well-developed in the central Saudi Arabia, including the Dhruma, Tuwaiq Mountain, Hanifa, Jubaila, and Arab formations in an ascending order. Of these, the Tuwaiq Mountain Formation is spectacular in the field, with nearly parallel successions of west-facing scarps standing on the Jurassic rocks in central Arabia. This unit forms the largest and most persistent of these escarpments and, as such, constitutes the backbone of the Jabal Tuwaiq. Moreover, the Tuwaiq Mountain Formation is extremely fossiliferous and records one of the best coral reef deposits in the geological past in Middle East region. This formation therefore has long been described and has been constrained as Callovian in age by macrofossils (Hughes, 2006, 2004; Sharland et al., 2001; Al-Husseini, 1997; Vaslet et al., 1991; Le Nindre et al., 1990; Powers, 1968; Powers et al., 1966; Steineke et al., 1958; Arkell, 1952).

Moreover, abundant foraminifera have also been reported from the Middle Jurassic of Saudi Arabia (Al-Saad, 2008; Galal and Kamel 2004; Hughes, 2004, 2002; Banner et al., 1991; Powers, 1968; Powers et al., 1966; Redmond, 1965, 1964a, b). However, little has been published on foraminifers from the Jurassic coral reef ecosystems. Accordingly, this paper aims to document abundant foraminifers from the Callovian reefs recorded in the Tuwaiq Mountain Formation in the Khashm Al-Qaddiyah area, central Saudi Arabia (Fig. 1) and to discuss their paleoecology in a broad context.

1 GEOLOGICAL SETTING AND LITHOSTRATIGRAPHY

During the Callovian, a broad shallow sea along the southern flank of the Tethys deposited clastic-rich limestones from central Arabia eastwards to Iran and Oman, and southwards across Yemen and Aden. Similar neritic limestones extend north through central Iraq (Powers et al., 1966). In central Saudi Arabia, this broad shallow sea deposited very extensive bioclastic limestones and calcarenites of the Tuwaiq Mountain limestone (upper Middle–Upper Callovian), rich in silicified corals and stromatoporoids.

The thickness of the Tuwaiq Mountain limestone reaches a maximum of between 200 and 250 m in the Darb Al-Hijaz (type locality) to Wadi Nisah (lat. 24º15′N) area and thins uniformly away from this region to the north and to the south, where it becomes 45–60 m thick at its northern and southern extremities.

The lower Tuwaiq Mountain limestone comprises a series of fine grained, fairly clayey limestone intercalated with beds of brown calarenites and white bioturbated nodular limestone. The Middle Tuwaiq Mountain limestone comprises a monotonous assemblage of fine-grained or gravelly bioclastic limestones, relatively bioturbated and clayey, containing isolated corals. The upper Tuwaiq Mountain limestone consists of very extensive bioclastic limestone and calcarenite, rich in silicified

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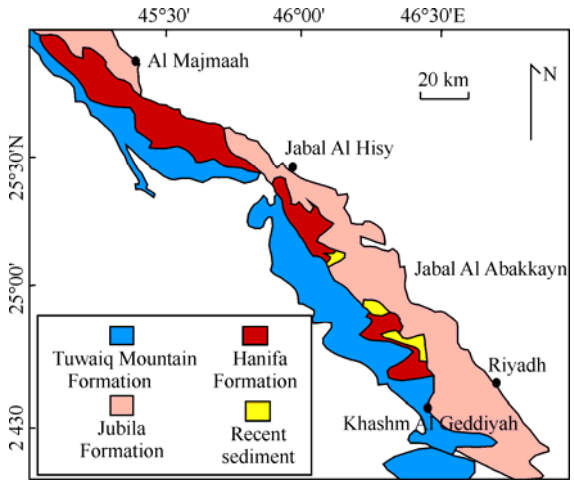

Figure 1. Location and geological map of the study area.

corals and stromatoporoids which give rise to reef forms with bioherms in the middle of the basin.

At Khashm Al-Qaddiyah, the Tuwaiq Mountain limestone attains about 190 m thick of mostly shallow-marine lagoon and stromatoporoid carbonates (Powers et al. 1966). It is composed at the lower part of yellowish green marls with gypsum veinlets intercalated with thin fossiliferous limestones. The middle part of the section is a limestone succession topped by conglomeratic limestone with abundant silicified corals. The upper part of the section is massive bedded, chalky limestone intercalated with chert layers and lenses (Figs. 2, 3).

The uppermost 25–40 m thick of coral bearing, bioturbated limestones with isolated coral heads, with massive hemispherical and globular forms and reach 20–50 cm in diameter. The upper part of these limestones forms an extensive coral biostrome extending for more than 1 000 km in central Saudi Arabia and locally includes bioherms (El-Asa'ad, 1989).

El-Asa'ad (1989) has described the Callovian colonial corals from the Tuwaiq Mountain Formation of Saudi Arabia and identified five scleractinian species: *Meandrarea gazensis* Alloiteau and Farag, *Ovalastrea caryophylloides* Goldfuss, *Trigerastrea collignoni* (Alloiteau), *Columnocoenia lamberti* Alloiteau, and *brachthelia* sp.. He attributed the low diversity of coral species to inimical ecological conditions and paleobiogeographical barriers which could have prevented the historical accumulation of species from neighboring areas.

2 MATERIAL AND METHOD

For measuring section and coral sampling, two field trips are conducted in the Khashm Al-Qaddiyah area during May 2012 and April 2013. The coral specimens have been collected from the uppermost 25–40 m thick of coral, bioturbated limestones. After washing corals, the residue were washed again on 63 sieve. Foraminiferal tests were picked, identified, mounted and photographed using Joel-SEM of South Valley University, Egypt. Fossils are stored in the Department of Geology and Geophysics Museum, College of Science, King Saud University.

3 SYSTEMATIC PALEONTOLOGY

The systematic classifications of foraminiferal species follow Loeblich and Tappan (1988) and Banner et al. (1991).

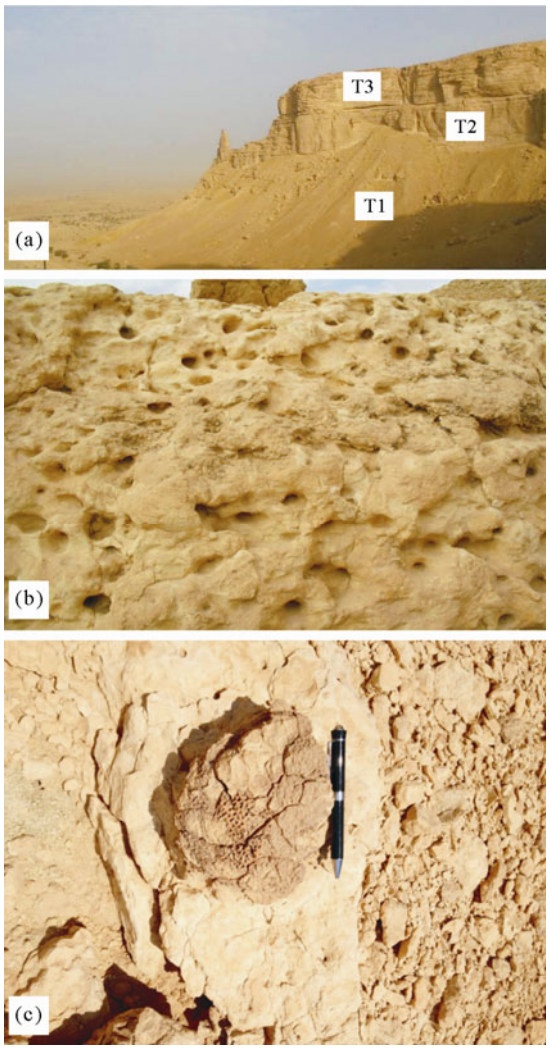

Figure 2. Field Photos. (a) Units T1, T2, and T3 of Tuwaiq Mountain limestone at Khashm Al Giddiyah Section; (b) highly bioturbated limestone of the Callovian Tuwaiq Mountain limestone at Khashm Al Giddiyah Section; (c) massive scleractinian colony in life position, upper part of Tuwaiq Mountain Formation.

Family Nautiloculinidae Loeblich and Tappan, 1985

Genus *Nautiloculina* Mohler, 1938; emend. Bronnimann, 1967

Type-species *Nautiloculina oolithica* Mohler, 1938

***Nautiloculina circularis* (Said and Barakat, 1959, Plate 3, Fig. 11 therein)**

1959 *Nautiloculina circularis* (Said and Barakat), pl. I, Fig. 1.

1966 *Nautiloculina circularis* (Said and Barakat)-Derin and Reiss, Figs. 70, 71, 83, 254, 263, 264, 271, 280, 283, 286–289, 309.

1968 *Nautiloculina circularis* (Said and Barakat)-Bronnimann, p. 64, Fig. 3, Pl. 1, Figs. 1–8, Pl. 2, Figs 1–6.

1985 *Nautiloculina circularis* (Said and Barakat)-Fourcade *et al.*, Pl. 3, Fig. 4.

2001 *Nautiloculina circularis* (Said and Barakat)-Tasli, p. 3, Pl. 1, Fig. 1.

2004 *Nautiloculina circularis* (Said and Barakat)-Galal and Kamel, p. 66, Fig. 5/4.
2008 *Nautiloculina circularis* (Said and Barakat)-Al-Saad, p. 8, pl. I, Figs. 4a–4b.
Material: 6 tests.
Distribution and age: Middle Jurassic of Saudi Arabia and Middle East.

Family: Charentiidae Loeblich and Tappan, 1985
Genus *Melathrokerion* Bronnimann and Conrad, 1967
Type species *Melathrokerion valserinensis* Bronnimann and Conrad, 1967.
***Melathrokerion eospirialis* Gorbatchik, 1985 (Plate 3, Fig. 13)**
1985 *Melathrokerion eospirialis* Gorbachik, p. 82, Pl. Ill, Fig. 7.
1996 *Melathrokerion eospirialis* Gorbatchik-Kuznetsova et al., p. 149, Pl. VI, Figs. 2a, 2b.
Material: 4 tests.
Distribution and age: Tithonian to lower Neocomian of Syria and Upper Tithonian of Crimea.

Family: Hauraniindae Septfontaine 1988
Subfamily: Hauraniinae Septfontaine, 1988
Genus *Haurania* Henson 1948
***Haurania deserta* Henson 1948 (Plate 2, Fig. 11)**
1948 *Haurania deserta* Henson, p. 12, Pl. 15, Figs. 1, 3, 4.
1997 *Haurania deserta* Henson-Banner et al., Pl. 1, Figs. 9, 13, 14.
1996 *Haurania deserta* Henson-Kuznetsova *et al*., p. 154, Pl. XII, Figs. 13, 14, Pl. XIX, Fig. 13.
2004 *Haurania deserta* Henson-Fugagnoli, Pl. 2, Figs. 2, 3.
2007 *Haurania deserta* Henson-Boudagher-Fadel and Bosence, p. 8, Pl. 2, Fig. 6, Pl. 8, Figs. 2–5.
2008 *Haurania deserta* Henson-Al-Saad, p. 8. Pl. I, Figs. 8a–8c.
Material: 3 tests.
Distribution: Upper Sinemurian-Bathonian of Iraq, Morocco, Turkey, and Italy.

Family: Dorothiidae Balakhmatova, 1972
Subfamily: Dorothiidae Balakhmatova, 1972
Genus *Marssonella* Cushman, 1933
Type species *Gaudryina oxycona* Reuss, 1860.
***Marssonella jurassica* Mitjanina,** 1957 (Plate 2, Figs. 9, 10)
1957 *Marssonella jurassica* Mityanina, p. 219, pl. 1, Figs. 5–7.
1996 *Marssonella jurassica* Mitjanina-Kuznetsova et al., p. 156, Pl. X, Fig. 1.
Material: 12 tests.
Distribution and age: Oxfordian of Belorussia and Syria.

Family: Chrysalidinidae Neagu, 1968
Subfamily: Paravalvulininae Banner, Simmons and Whittaker, 1991
Genus *Riyadhella* Redmond, 1965
Type species *Riyadhella regularis* Redmond, 1965.
***Riyadhella regularis* Redmond, 1965 (Plate 1, Fig. 16)**
1965 *Riyadhella regularis* Redmond, p. 138, Pl. I, Figs. 32–34.
1991 *Riyadhella regularis* Redmond-Banner et al., p. 131, Figs. 57–63.

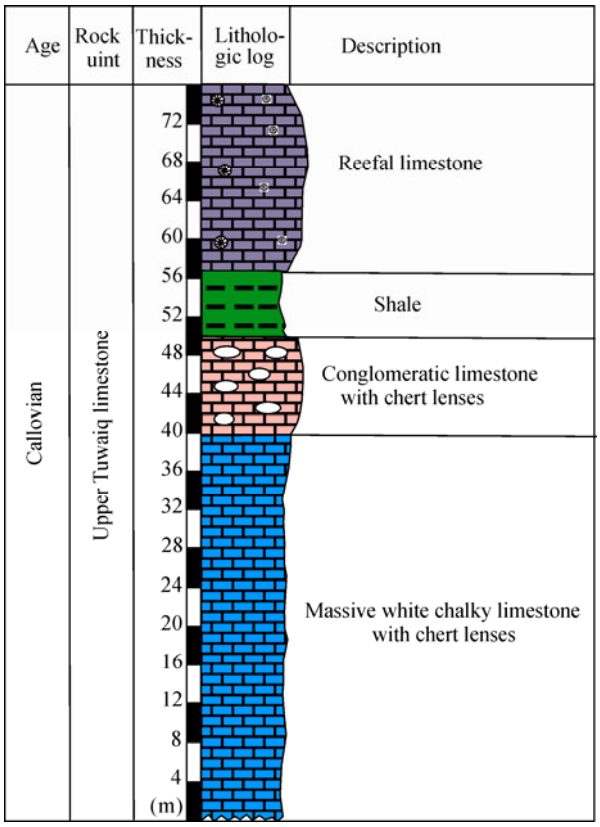

Figure 3. Lithostratigraphic succession of the Callovian Tuwaiq Mountain limestone and part of Oxfordian Hanifa Formation at the Khashm Al Giddiyah Section.

1965 *Riyadhella intermedia*: Redmond, p. 137–138, Pl. 1, Figs. 25–27.
1996 *Riyadhella regularis* Redmond-Kuznetsova et al., p. 156, Pl. XIII, Figs. 13–17, 19, 20, Pl. XX, Figs. 14, 15.
2001 *Riyadhella regularis* Redmond-Clark and Boudagher-Fadel, p. 224, Pl. 2, Fig. 7.
2008 *Riyadhella regularis* Redmond-Al-Saad, p. 8, Pl. II, Fig. 13.
Material: 9 tests.
Distribution and age: Bathonian and Callovian (Dhruma Formation) of Saudi Arabia; Bathonian of Syria. Middle Jurassic of United Arab Emirates, eastern Mediterranean, Near East, India, Eastern Europe and Siberia.

***Riyadhella paraconica* (Levina, 1972, Plate 1, Fig. 15)**
2004 *Riyadhella paraconica* (Levina)-Galal and Kamel, p. 66, Figs. 4/17, 18, 5/9.
Material: 7 tests.
Distribution and age: Callovian (Middle Jurassic) of central Saudi Arabia.
Remarks: *Riyadhella paraconica* differs from *R. regularis* in having shorter and thicker tests.

Genus *Redmondoides* Banner, Simmons and Whittaker, 1991
Type species *Pseudomarssonella media* Redmond, 1965.
***Riyadhoides mcclurei* (Redmond, 1965) (Plate 1, Fig. 17)**
2008 *Riyadhoides mcclurei* (Redmond)-Al-Saad, p. 8, Pl. 2, Fig. 12.

Material: 3 tests.
Distribution and age: Middle Jurassic of the Middle East.

Genus *Redmondoides* Banner, Simmons and Whittaker, 1991

Type species *Pseudomarssonella media* Redmond, 1965.

***Redmondoides medius* (Redmond, 1965) (Plate 2, Fig. 12)**

1965 *Pseudomarssonella media* Redmond, p. 135, Pl. I, Figs. 1–13.
1991 *Redmondoides medius* (Redmond)-Banner et al., p. 120, Figs. 35–37.
1996 *Redmondoides medius* (Redmond)-Kuznetsova et al., p. 157, Pl. X, Figs. 2–4.
2004 *Redmondoides medius* (Redmond)-Galal and Kamel, p. 66, Fig. 5/14.
2008 *Redmondoides medius* (Redmond)-Al-Saad, p. 8, Pl. 2, Fig. 11.

Material: 15 tests.
Distribution and age: Upper Bathonian to Callovian of Saudi Arabia, France and Syria.

Family: Pfenderinidae Smout et Sugden, 1962

Subfamily: Palaeopfenderininae Septfontaine, 1988
Genus *Pfenderella* Redmond, 1964
Type species: *Pfenderella arabica* Redmond, 1964a.

***Pfenderella arabica* Redmond, 1964 (Plate 1, Fig. 12)**

1964 *Pfenderella arabica* Redmond, p. 258, Pl. 2, Figs. 1–3.
1996 *Pfenderella arabica* Redmond-Kuznetsova et al., p. 160, Pl. XIX, Fig. 3.
2004 *Pfenderella arabica* Redmond-Galal and Kamel, p. 66, Figs. 6/4, 5.
2008 *Pfenderella arabica* Redmond-Al-Saad, p. 8, Pl. II, Fig. 2.

Material: 8 tests.
Distribution and age: Bathonian to Callovian of Saudi Arabia, Greece, France, Italy and Syria.

Family: Pfenderinidae

Subfamily: Pfenderininae
Genus *Pfenderina* Henson 1948
Type species *Pfenderina salernitana* Sarton et Crescenti, 1962

***Pfenderina gracilis* Redmond, 1964 (Plate 1, Fig. 14)**

2008 *Pfenderina gracilis* (Pfender)-Al-Saad, p. 8, Pl. I, Fig. 13.

Material: 3 tests.
Distribution and age: Middle Jurassic of the Middle East.

***Pfenderina neocomiensis* (Pfender, 1938) (Plate 1, Fig. 13)**

2004 *Pfenderina neocomiensis* (Pfender)-Galal and Kamel, p. 66, Figs. 6/6, 8, 10, 16, 17.
2008 *Pfenderina neocomiensis* (Pfender)-Al-Saad, p. 8, Pl. I, Fig. 14.

Material: 6 tests.
Distribution and age: Middle Jurassic of Saudi Arabia and the Middle East.
Remarks: *Pfenderina neocomiensis* differs from *P. gracilis* in having the curved and thinner tests.

Subfamily: Kurnubiinae Redmond, 1964

Genus *Praekurnubia* Redmond, 1964

Type species *Praekurnubia crusei* Redmond, 1964.

***Praekurnubia crusei Redmond*, 1964 (Plate 1, Figs. 9–11)**

1964a *Praekurnubia crusei* Redmond, p. 254, Pl. I, Figs. 5–8.
1996 *Praekurnubia crusei* Redmond-Kuznetsova et al., p. 160, Pl. XI, Figs. 6a, 6b.
2004 *Praekurnubia crusei* Redmond-Hughes, p. 175.
2008 *Praekurnubia crusei* Redmond-Al-Saad, p. 8, Pl. II, Fig. 6.

Material: 8 tests.
Distribution and age: Callovian to Bathonian (Dhruma Formation) of Saudi Arabia and Upper Bathonian to Lower Callovian of Syria and Lebanon.

Genus *Kurnubia* Henson, 1948

Type species *Kurnubia palastiniensis* Henson, 1948.

***Kurnubia bramkampi* Redmond (Plate 1, Figs. 6, 7)**

1964a *Kurnubia bramkampi* Redmond, p. 253, Pl. I, Figs. 1–3.
1996 *Kurnubia bramkampi* Redmond-Kuznetsova et al., p. 161, Pl. XI, Figs. 7, 8, Pl. XIX, Fig. 10.

Material: 13 tests.
Distribution and age: Bathonian to Callovian of Saudi Arabia, North Africa and Syria.

***Kurnubia variabilis* Redmond, 1964 (Plate 1, Fig. 5)**

1964 *Kurnubia variabilis* Redmond, p. 254, Pl. I, Figs. 9–10.
1996 *Kurnubia variabilis* Redmond-Kuznetsova et al., p. 162, Pl. XII, Figs. 10–12.
2008 *Kurnubia variabilis* Redmond-Al-Saad, p. 8, Pl. II, Fig. 5.

Material: 7 tests.
Distribution and age: Bathonian to Callovian of Saudi Arabia and Callovian of Syria.
Remarks: *Kurnubia variabilis* is characterized by small, elongate test, distinguished by rounded end.

***Kurnubia wellingsi* (Henson) (Plate 1, Figs. 1–3)**

1948 *Valvulinella wellingsi* Henson, p. 606, Pl. XV, Fig. 9, Pl. XVI, Fig. 5, Pl. XVIII, Fig. I.
1962 *Kurnubia wellingsi* (Henson)-Smoutand Sugden, p. 285, Pl. XIX, Figs. 17–18, Pl. 76, Figs. 1–8.
1996 *Kurnubia wellingsi* (Henson)-Kuznetsova et al., p. 162, Pl. XII, Figs. 5, 6.
2004 *Kurnubia wellingsi* (Henson)-Galal and Kamel, p. 66, Figs. 6/7, 11, 20.

Material: 11 tests.
Distribution and age: Oxfordian of eastern Mediterranean, Italy and France, Lower Oxfordian of Syria and Callovian of Saudi Arabia.
Remarks: *Kurnubia wellingsi* is characterized by small, curved tests and differs from other species by the tapered end.

***Kurnubia jurassica* (Henson, 1948) (Plate 1, Fig. 4)**

1948 *Valvulinella jurassica* Henson, p. 60, Pl. XVI, Figs. 1–4, Pl. XVIII, Figs. 8, 9.
1962 *Kurnubia jurassica* (Henson)-Smoutand Sugden, pl. 73, Fig. 19.
1996 *Kurnubia jurassica* (Henson)-Kuznetsova et al., p. 162, Pl. XII, Figs. 7–9.

2004 *Kurnubia jurassica* (Henson)-Galal and Kamel, p. 65, Figs. 6/12, 14, 15.
2008 *Kurnubia jurassica* (Henson)-Al-Saad, p. 8, Pl. II, Fig. 4.
Material: 14 tests.
Distribution and age: Neocomian of France, Italy, eastern Mediterranean; Barremian to Lower Aptian of Syria and Callovian of Saudi Arabia.
Remarks: *Kurnubia jurassica* differs from other *Kurnubia* species by its thin initial part of the test.

***Kurnubia palastiniensis* Henson, 1948 (Plate 1, Fig. 8)**
1948 *Kurnubia palastiniensis* Henson, p. 608, pl. XVI, Figs. 8, 11, Pl. XVIII, Figs. 10, 11.
1962 *Kurnubia palastiniensis* Henson-Sartoni and Crescenti, p. 283, Pl. XIX, Fig. 2, Pl. L, Figs. 2, 3, 5, 8.
1962 *Kurnubia palastiniensis* Henson-Smout and Sugden, p. 589–590, Pl. 73, Fig. 16.
1967 *Kurnubia palastiniensis* Henson-Hottinger, p. 90–93, Pl. 19, Figs. 30–34, 38–48, text Figs. 45, 46.
1996 *Kurnubia palastiniensis* Henson-Kuznetsova, p. 161, Pl. XI, Figs. 9a, 9b, Pl. XII, Figs. 4, Pl. XIX, Figs. 4, 5, 7–9.
2008 *Kurnubia palastiniensis* Henson-Al-Saad, Pl. II, Fig. 3.
Material: 11 tests.
Distribution and age: Callovian, Oxfordian of Palestine, Syria, Saudi Arabia, France, Morocco, Iraq and former Yugoslavia.
Remarks: *Kurnubia palastiniensis* is characterized by large, elongate, curved tests distinguished by surface nodes network.

Family: Tritaxiidae Plotnikova 1979
Genus: *Tritaxia* Plotnikova 1979
Type species: *Textularia tricarinata* Reuss, 1844
***Tritaxia* sp. (Plate 2, Fig. 1)**
Material: 3 tests.
Remarks: Test triserial, elongate, curved, aperture central and terminal.

Family: Verneuilinidae Cushman, 1911
Subfamily: Verneuilinoidinae Suleymanov, 1973
Genus:*Verneuilinoides* Loeblich and Tappan, 1949
Type species: *Verneuilina schizea* Cushman and Alexander, 1930.
***Verneuilinoides minuta* Said and Barakat, 1958 (Plate 2, Fig. 7)**
1958 *Verneuilinoides minuta* Said and Barakat, p. 242, Pl. 4, Fig. 25.
1966 *Verneuilinoides minuta* Said and Barakat-Maync, Pl. IV, Figs. 10, 11.
1996 *Verneuilinoides minuta* Said and Barakat-Kuznetsova et al., p. 164, Pl. XIII, Figs. 3–5.
2004 *Verneuilinoides minuta* Said and Barakat-Galal and Kamel, p. 66, Fig. 4/3.
Material: 15 tests.
Distribution and age: Kimmeridgian of Sinai (Egypt); Oxfordian and Kimmeridgian of Syria.
***Verneuilinoides maurittii* Terquem** (Plate 2, Fig. 8)
2008 *Verneuilinoides maurittii* Terquem-Al-Saad, Pl. I, Fig. 11.
Material: 3 tests.
Distribution and age: Middle Jurassic of the Middle East.
Remarks: Test small to medium sized, conical, elongate. Aperture slit-like in the middle of the apertural surface. It is longer than *V. minuta*.

***Verneuilinoides attenuata* Said and Barakat, 1958 (Plate 2, Fig. 6)**
2004 *Verneuilinoides attenuata* Said and Barakat-Galal and Kamel, p. 66, Fig. 5/10.
Material: 5 tests.
Distribution and age: Callovian (Middle Jurassic) of central Saudi Arabia.
Remarks: *Verneuilinoides attenuata* differs from *Verneuilinoides minuta* Said and Barakat in its longer test which rapidly increases in width and characterized by interiomarginal arched aperture.

Subfamily: Belorussiellinae Balakhmatova, 1973
Genus: *Palaeograudryina* Said and Barakat, 1958
Type species: *Palaeogaudryina magharaensis*
Said and Barakat, 1958.
***Palaeogaudryina magharaensis:* Said and Barakat, 1958 (Plate 2, Figs. 3–5)**
1958 *Palaeogaudryina magharaensis* Said and Barakat, p. 243, Pl. 4, Figs. 33–36.
1965 *Palaeogaudryina magharaensis* Said and Barakat- Bignot and Guyader, p. 54, Pl. I, Figs. 7–25.
1996 *Palaeogaudryina magharaensis* Said and Barakat-Kuznetsova et al., p. 156, Pl. XIII, 9, 11
2004 *Palaeogaudryina magharaensis* Said and Barakat-Galal and Kamel, p. 66, Fig. 4/20.
2008 *Paleogaudryina magharaensis* Said and Barakat-Al-Saad, p. 8, Pl. I, Fig. 9.
Material: 11 tests.
Distribution and age: Callovian of Sinai (Egypt) and Saudi Arabia; Oxfordian of Syria and Upper Jurassic of Egypt.

Family: Trocholinidae Kristan-Tollman 1963
Subfamily: Trocholininae Kristan-Tollman, 1963
Genus *Trocholina* Paalzow, 1922
Type species *Involutina conica* Schlumberger, 1898.
***Trocholina transversarii* Paalzow, 1932 (Plate 3, Fig. 10)**
1932 *Trocholina transversarii* Paalzow, p. 141, Pl. XI, Figs. 8–10.
1985 *Trocholina transversarii* Paalzow-Grigelis, p. 177, Pl. XV, Fig. 7.
1996 *Trocholina transversarii* Paalzow-Kuznetsova et al., p. 168, Pl. XIII, Figs. 23a–23c.
Material: 8 tests.
Distribution and age: Oxfordian of Europe; in addition, Kimmeridgian of SwabianAlb, Germany; Oxfordian of Syria and Lebabon.

Family: Lenticulinidae Chapman, Parr and Collins, 1934
Subfamily: Lenticulininae Chapman, Parr and Collins, 1934
Genus *Lenticulina* Lamarck, 1804
Type species: *Lenticulites rotulatus* Lamrarck, 1804.
***Lenticulina subalata* (Reuss, 1854) (Plate 3, Fig. 1)**
1854 *Lenticulina subalata* (Reuss), Pl. XVI, Figs. 19a, 19b.

1863 *Cristellaria subalata* Reuss, p. 76, Pl. 8, Fig. 10, Pl. 9, Fig. 1.
1975 *Lenticulina subalata* (Reuss)-Bielecka, p. 337, Pl. VII, Figs. 1, 2, 3.
2004 *Lenticulina subalata* (Reuss)-Galal and Kamel, p. 66, Fig. 5/2.
2008 *Lenticulina subalata* (Reuss)-Al-Saad, p. 8, Pl. III, Fig. 6

Material: 9 tests.
Distribution and age: Callovian of Saudi Arabia, Middle Cretaceous (Albian to Turonian) of Germany and Barremian to lower Aptian of Syria.

***Lenticulina magharaensis* Said and Barakat, 1958 (Plate 3, Fig. 2)**
2004 *Lenticulina magharaensis* Said and Barakat-Galal and Kamel, p. 66, Fig. 5/3.
Material: 9 tests.
Distribution and age: Callovian of Saudi Arabia.
Remarks: *Lenticulina magharaensis* is characterized by smooth, involute, convex, lenticular tests, sharp periphery and raised umbilical area.

***Lenticulina muensteri* (Roemer, 1839) (Plate 3, Fig. 3)**
2008 *Lenticulina muensteri* Roemer-Al-Saad, p. 8, Pl. III, Fig. 4.
Material: 3 tests.
Distribution: Middle Jurassic of the Middle East.
Remarks: Tests smooth, involute, convex, lenticular, with sharp periphery and depressed umbilical area.
***Lenticulina brueckmanni* (Mjatliuk) (Plate 3, Fig. 5)**
1939 *Cristellaria brueckmanni* Myatlyuk, p. 59, Pl. IV, Fig. 49.
1961 *Lenticulina brueckmann* (Mjatliuk)-Kuznetsova, p. 104, Pl. II, Fig. 9.
1985 *Lenticulina brueckmanni* (Mjatliuk)-Grigelis, p. 79, Pl. XVI, Fig. 5.
1996 *Lenticulina brueckmanni* (Mjatliuk)-Kuznetsova et al., p. 173, Pl. XV, Figs. 18–20a, 20b.
Distribution and age: Callovian, Oxfordian of Europe, Syria, Saudi Arabia; also Lower Kimmeridgian of Poland.
Remarks: *Lenticulina brueckmanni* is characterized by smooth, involute, convex, lenticular tests and semicircular outline.

***Lenticulina* sp. (Plate 3, Fig. 4)**
Material: 3 tests.
Remarks: Involute test, subcircular to flattened. Periphery acute, with a narrow keel.

Family Orbitolinidae Martin 1890
Subfamily Orbitolininae Martin 1890
Genus *Palorbitolina* Schroeder, 1963
***Palorbitolina lenticularis* (Blumenbaeh) (Plate 3, Figs. 14, 15)**
1996 *Palorbitolina lenticularis* (Blumenbaeh)-Kuznetsova et al., p. 237, Pl. XIV, Fig. 1.
Material: 9 tests.
Distribution: Barremian-Lower Aptian of Syria.

Family Ellipsolagenidae Silvestri 1923
Subfamily Oolininae Loeblich and Tappan 1961
Genus *Oolina* d'Orbigny 1839
Type species *Oolina laevigata* d'Orbigny, 1839
***Oolina globosa* (Montagu, 1803) (Plate 3, Fig. 7)**
2004 *Oolina globosa* (Montagu)-Galal and Kamel, p. 66, Fig. 5/15.
Material: 3 tests.
Distribution: Callovian (Middle Jurassic) of central Saudi Arabia.

Family: Vaginulinidae Reuss 1860
SubFamily Marginulininae *Marginulininae* Wedekind, 1937
Genus *Astacolus* de Montfort. 1808
Type species *Astacolus crepidulatus* de Mont-fort, 1808
Astacolus qaddiyahensis sp. Nov (Plate 3, Fig. 6)
Type horizon: Callovian.
Type locality: Khashm Al-Qaddiyah.
Etymology: after Khashm Al-Qaddiyah the type section of Tuwaiq Mountain Formation.
Dimension: length=0.43 mm, width=0.26 mm
Material: 6 specimens.
Description: Test elongate in outline, flattened, chambers numerous, broad and low, added on a slightly curved axis in the very early stage, later uncoiling, with strongly oblique, curved depressed sutures, periphery angular, surface smooth.
Remarks: the curvature of the suture is more than it in *Astacolus crepidula* (Jurassic) especially in the uncoiled portion, the periphery is angular where, is rounded in *Astacolus crepidula.*

Family: Nodosariidae Ehrenberg 1838
Subfamily Nodosariacea Loeblich and H. Tappan 1984
Genus Nodosaria Lamarck, 1812
Type species *Nautilus radicula* Linné, 1758
***Nodosaria riyadhensis* sp. Nov (Plate 2, Fig. 2)**
Type horizon: Callovian.
Type locality: Khashm Al-Qaddiyah.
Etymology: after Riyadh City, the capital of Saudi Arabia.
Dimension: length=0.86 mm, width=0.16 mm
Material: 4 specimens.
Description: Test elongate, multilocular, uniserial and rectilinear subglobular to ovate chambers: wall calcareous, hyaline, perforate, surface smooth and unornamented, aperture terminal.
Remarks: the species is longer than *Nodosaria simplex* Terquem and the chambers less globular, also the suture is depressed-flushed.

Family Calcarinidae Schwager, 1876
Genus *Siderolites* Lamarck, 1801
Type species *Siderolites calcitrapoides* Lamarck, 1801
***Siderolites jurassica*sp. Nov (Plate 3, Fig. 12), Text Fig. 4**
Type horizon: Callovian.
Type locality: Khashm Al-Qaddiyah.
Etymology: after the Jurassic.
Diameter: including spines up to 0.34 mm
Material: 5 specimens.
Description: Test globular, with 8 round spines. Sides of the test rounded. Test covered by coarse pustules especially in the central area. Chambers and sutures are not visible from the outside.

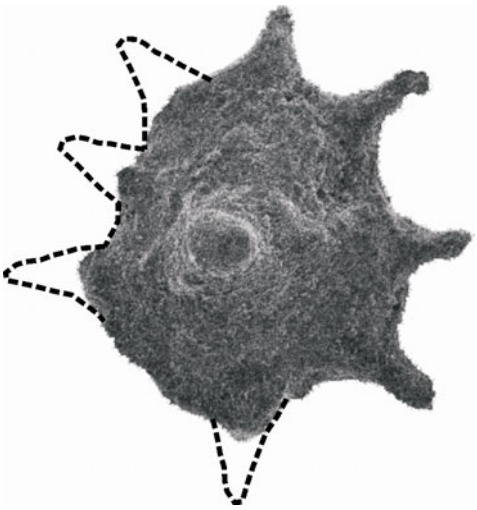

Figure 4. Diagram showing the missed spines of *Siderolites jurassica.*

Spines commonly present in one plane around the periphery, and with longitudinal ribs. The central area is large.

Remarks: This species is more or less rounded than *Siderolites laevigatus* (d'Orbigny) and *Siderolites calcitrapoides* Lamarck.

4 PALEOECOLOGY

Ten scleractinian corals include *Actinastraea pseudominima* (Koby, 1897), *Thamnasteria nicoleti* Koby 1887, *Isastrea hemisphaerica* Gregory 1900, *Enallocoenia crassoramosa* (Michelin, 1843), *Stylina regularis* Fromentel, 1867, *Cryptocoenia wegeneri* Pandey and Fürsich 1993, *Kobyastraea lomontiana* (Etallon, 1864), *Ovalastraea caryophilloides* (Goldfuss, 1826), *Collignonastraea jumarensis* (Gregory 1900), and *Collignonastraea grossouvrei* Beauvais 1972. These corals were previously recorded from the Jurassic rocks of Ethiopia, Somalia, Israel, Jordan, Egypt, the United Kingdom, France, Germany, Czech Republic, Georgia, Greece, India, Switzerland, Poland, Portugal, the Russian Federation, and Spain. They also previously recorded from the Cretaceous rocks of Bulgaria, China, France, Spain,Georgia, Greece, Iran, Mexico, Poland, Romania, Serbia, Montenegro, Slovenia, USSR, and Ukraine.

The morphologies and ecologic features of these described coral taxa show that shoaling of the sea floor persisted throughout the deposition of the Tuwaiq Mountain Formation. It seems that this slow subsidence of the sea floor did not provide adequate space for the buildup of a true reefal barrier system in central Saudi Arabia. A striking feature of the Tuwaiq corals is low diversity of species persisted throughout the development of the formation. This low diversity is the result of interacting factors related to the paleogeographical and the paleoecological conditions of a very shallow platform.

Inadequate (inimical) paleoecological conditions have prevailed throughout the formation of such corals, as high rate of argillaceous materials, which caused turbidity and consequently decreased light penetration. Also the muddy facies might lead to unfavorable soft substrate for coral colonies to grow in large sizes. The sediments of the Tuwaiq Mountain limestone at Khashm Al-Qaddiyah Section were laid down in low-energy of a carbonate shelf in the lower part and grades upward into moderate-energy deposits in water depth ranging from 20 to 30 m, as indicated by abundant corals.

The common occurrence of foraminiferal test linings is indicative of normal marine coastal and/or shallow environment (Tyson, 1995, 1993; Lister and Batten, 1988; Batten, 1979). Accordingly, the carbonate sediments of the Tuwaiq Mountain Formation may have been deposited in shallow water of middle shelf depth (30–50 m) under arid to semiarid climatic conditions (Al-Saad and Ibrahim, 2005).

The deep lagoon biofacies displays the highest species diversity, and includes *Redmondoides medius* (Redmond), *Kurnubia wellingsi* (Henson), *Praekurnubia jurassica* (Henson), *Pfenderina neocomiensis* (Pfender), *Trocholina transversarii* Paalzow and *Nautiloculina oolithica* Mohler. A shallow lagoon environment is concluded for the sparse biofacies in which *Nautiloculina oolithica* Mohler with econoides and algae are typical componenrs (Hughes, 2004). Deep, open marine conditions below wave base are typified by the presence of *Lenticulina* spp., *Nodosaria riyadhensis* n. sp., *Kurnubia palastiniensis* Henson, *Nautiloculina oolithica* Mohler, *Marssonella jurassica* Mitjanina. Open marine, moderately deep marine conditions are typified by agglutinated foranrinifera that include *Pseudocyclammina maynci* Hottinger, *Kurnubia palastiniensis* Henson and *Nautiloculina oolitbica* Mohler.

Finally, the foraminiferal assemblages documented here exhibit the mixture of open marine, moderately deep marine faunas with the lagoon facies assemblage. The former associations comprise *Lenticulina* spp., *Nodosaria riyadhensis*, *Marssonella jurassica* and *Pseudocyclammina maynci*, while the latter includes *Kurnubia palastiniensis*, *Nautiloculina oolitbica*, *Praekurnubia jurassica*, *Pfenderina neocomiensis*, and *Trocholina transversarii*. The presence of these assemblages can be interpreted as they may either have a very wide palaeoenvirinmental tolerance, or their presence may be attributed to an allochthonous, tidal or storm derived cause (Hughes, 2004).

5 CONCLUSIONS

Thirty three benthic foraminiferl species belong to 23 genera and 16 families have been recorded.

Three species believed to be new: *Astacolus qaddiyahensis*, *Nodosaria riyadhensis*, *Siderolites* jurassica.

The Foraminiferal assemblage recorded in the present work is mixed of open marine, moderately deep marine conditions associations and shallow to deep lagoon.

The upper part of Tuwaiq Mountain Formation may have been deposited in shallow water of lower to middle shelf depth (20–50 m).

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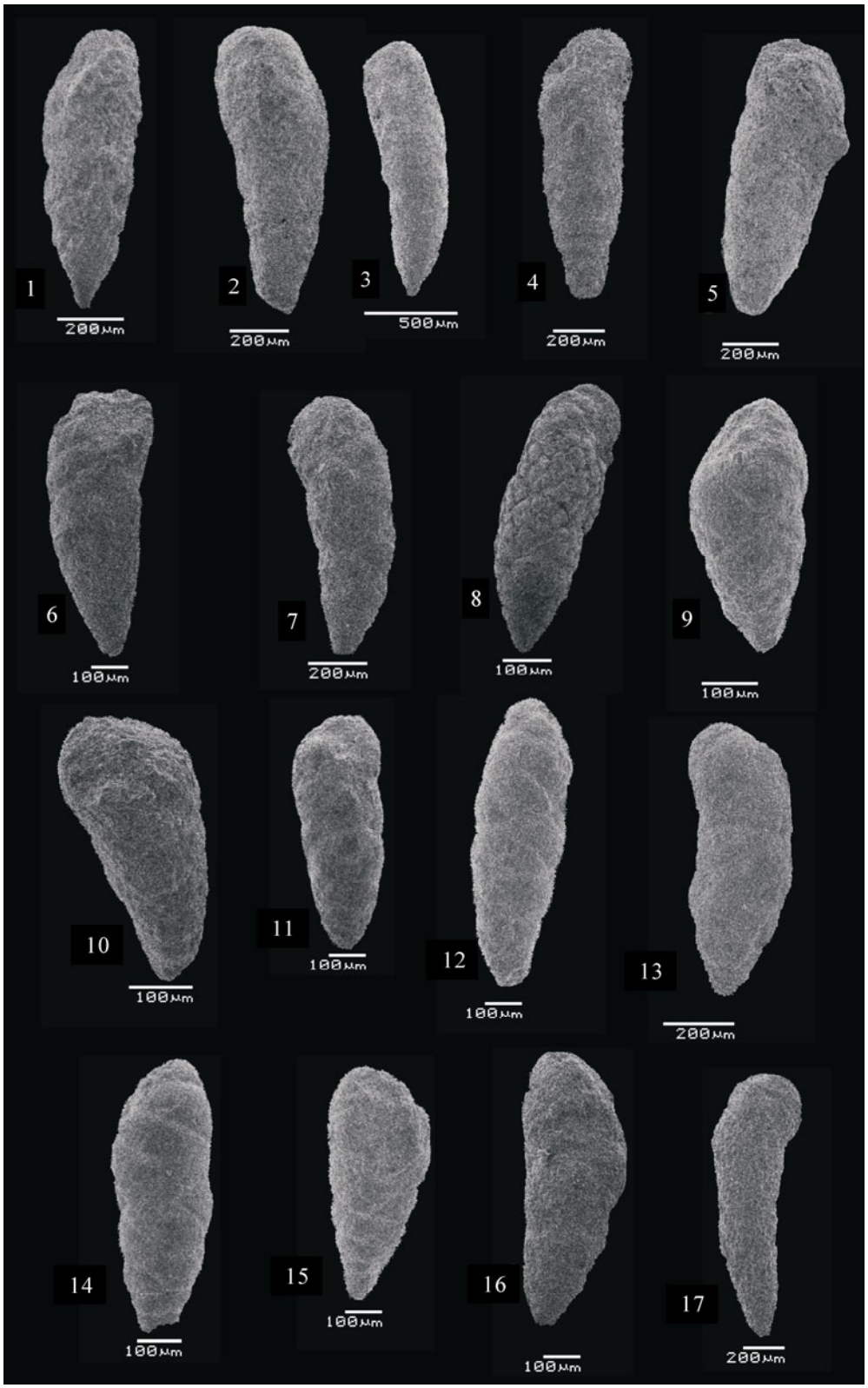

Plate 1. 1–3 *Kurnubia wellingsi* Henson; 4. *kurnubia jurassica* Henson; 5. *Kurnubia variabilis* Redmond; 6, 7. *Kurnubia bramkampi* Redmond; 8. *Kurnubia palastiniensis* Henson; 9–11. *Praekurnubia crusei* Redmond; 12. *Pfendrella arabica* Redmond; 13. *Pfenderina neocomiensis* Pfender; 14. *Pfenderina gracilis*; 15. *Riyadhella paraconica* Levina; 16. *Riyadhella regularis* Redmond; 17. *Riyadhoides mcclurei* Redmond.

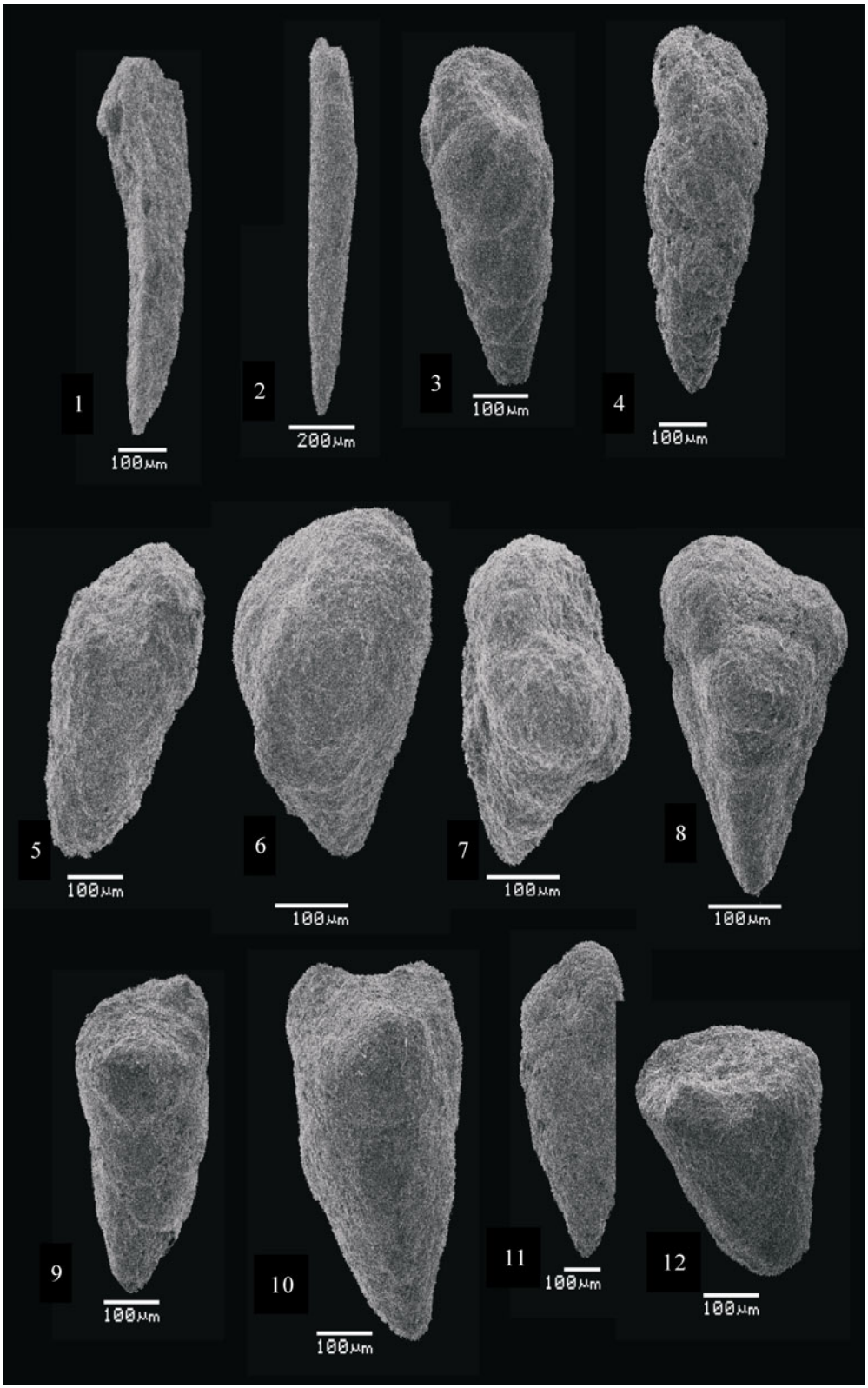

Plate 2. 1. ***Tritaxia*** **sp.; 2.** ***Nodosaria riyadhensis*** **n. sp.; 3–5.** ***Paleogaudryina magharaensis*** **Said and Barakat; 6.** ***Verneuilinoides attenuata*** **Said and Barakat; 7.** ***Verneuilinoides minuta*** **Said and Barakat; 8.** ***Verneuilinoides maurittii*** **Terquem; 9–10** ***Marssonella jurassica*** **Mitjanina; 11.** ***Haurania deserta*** **Henson; 12.** ***Redmondoides medius*** **Redmond**.

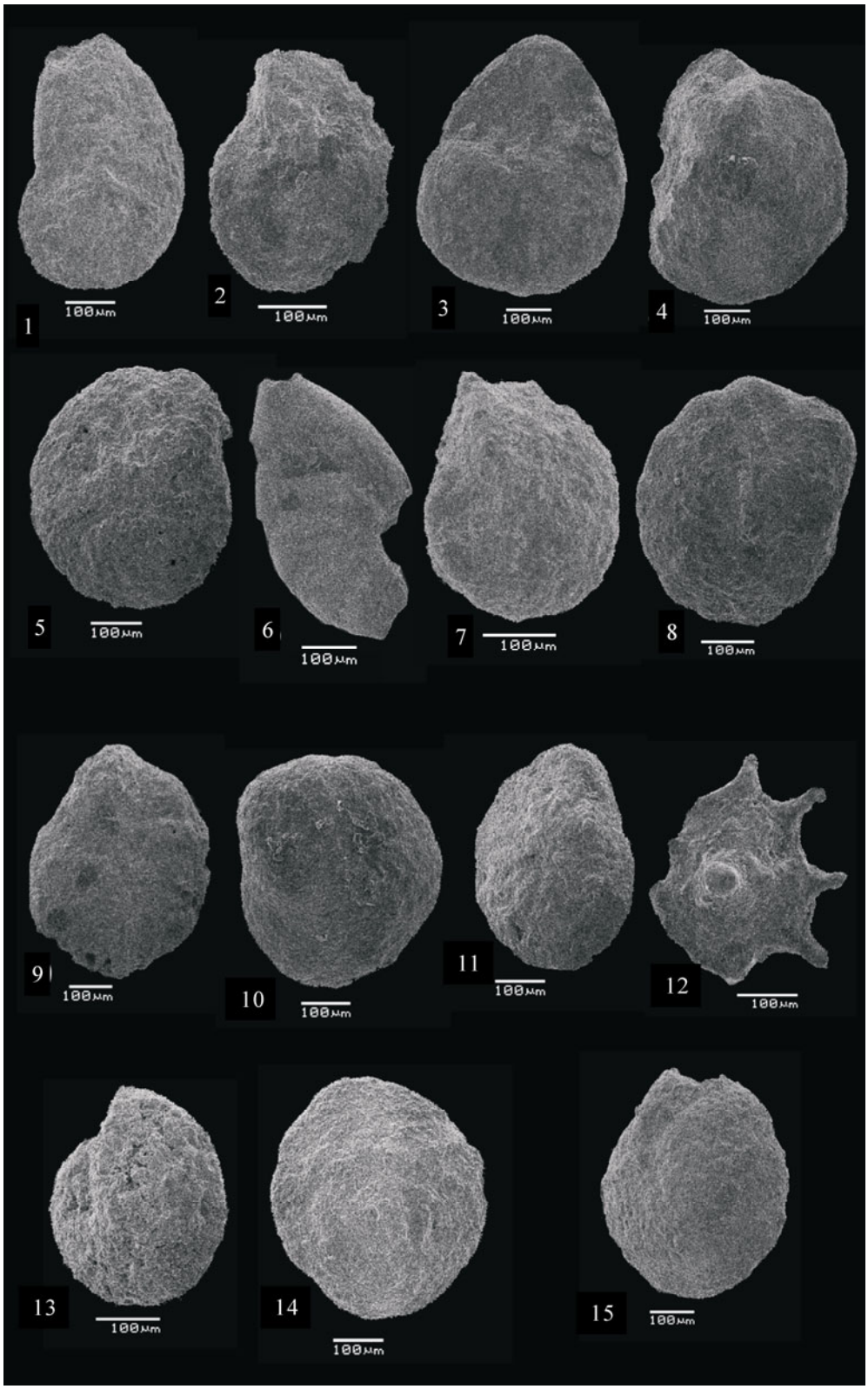

Plate 3. 1. ***Lenticulina subalata*** **Reuss; 2.** ***Lenticulina magharaensis*** **Said and Barakat; 3.** ***Lenticulina muensteri*****; 4.** ***Lenticulina*** **sp.; 5.** ***Lenticulina brueckmanni*** **(Mjatliuk); 6.** ***Astacolus qaddiyahensis*** **n. sp.; 7.** ***Oolina globosa*** **Montagu; 8.** ***Choffatella decipiens*** **Schlumberger; 9.** ***Pseudocyclammina maynci*** **Hottinger; 10.** ***Trocholina transversarii*** **Paalzow Samle; 11.** ***Nautiloculina circularis*** **Said and Barakat; 12.** ***Siderolites jurassica*** **n. sp.; 13.** ***Melathrokerion eospirialis*** **Gorbatchik; 14–15.** ***Palorbitolina lenticularis*** **Blumenbaeh.**