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Facies development and paleoenvironment of the Hajajah Limestone Member, Aruma Formation, central Saudi Arabia

Abdelbaset S. El-Sorogy [a, b, *], Abdelmoneim Ismail [b], Mohamed Youssef [a, c], Hamdy Nour [b]

[a] Geology and Geophysics Department, College of Science, King Saud University, Saudi Arabia
[b] Geology Department, Faculty of Science, Zagazig University, Zagazig, Egypt
[c] Geology Department, Faculty of Science, South Valley University, Egypt

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ABSTRACT

The Campanian Hajajah Limestone Member of the Aruma Formation was formed during two regressive episodes. Each of them formed of three depositional facies, from base to top: 1) intra-shelf basin facies, made up of fossiliferous green shale and mudstone with ostracods and badly preserved foraminifers. 2) fore-reef facies, consists of hard, massive, marly coralline limestone. The upper part is rich with low divers, badly to moderate preserved, solitary and colonial corals, and, 3) back reef and near-shore facies, consists of fossiliferous sandy dolomitized, bioturbated limestone with abundant reworked corals, bivalves, gastropods, and aggregate grains. On the basis of field observations, micro-and macrofossils and microfacies analysis, the Hajajah Limestone Member was deposited in distal marine settings below storm wave base in a low-energy environment changed upward to fore-reef framework in an open marine environment with moderate to high energy conditions and terminated with shallow marine facies with accumulation of skeletal grains by storms during regression.

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1. Introduction

Many previous studies have been done on several fossil groups collected form the Campanian-Maastrichtian Aruma Formation in central Saudi Arabia. Examples of these fossil groups are: ostracods (Al-Furaih, 1984a, 1984b, 1986a,b), dasycladacean algae (Okla, 1991, 1992, 1994, 1995), rudist bivalves (El Asa'ad, 1987; Skelton and El Asa'ad, 1992), corals and ammonites (El Asa'ad, 1990, 1991) and gastropods (Gameil and El-Sorogy, 2015). More recently, Özer and El-Sorogy (2016) recorded for the first time and described *Durania cornupastoris* from the Khanasir Limestone Member of the Aruma Formation in central Saudi Arabia.

Al-Kahtany et al. (2016) identified 50 macrofossil species (25 gastropods, 17 corals and 8 bivalves) from Aruma Formation in northeast Riyadh. They mentioned that "a major Campanian Maastrichtian marine transgression drowning the study area above the continental siliciclastics of the Wasia Formation and changed upward from lagoonal to back reef in Khanasir Member, to a relatively deeper marine in coral-stromatoporoid of Hajajah and Lina members".

None of the former previous studies have tied between presence of fossil groups, microfacies analysis, facies development and paleoenvironment of the Aruma sediments. Therefore, the present work aims to document the facies development and paleoenvironment of the Hajajah Limestone Member (Aruma Formation) in central Saudi Arabia (Fig. 1), using lithological properties, fossil content and microfacies analysis.

2. Geologic setting

The Mesozoic sedimentary sequence of central Saudi Arabia dips very gently towards the Aruma basin to the east. Upper Cretaceous strata form a broadly arcuate outcrop passing to the east of Riyadh (Powers et al., 1966). The Aruma Formation was named according to the Upper Cretaceous sequence outcropping in the Al 'Aramah plateau, a broad upland surface related to the easternmost of the

* Corresponding author. Department of Geology and Geophysics, College of Science, King Saud University, PO Box: 2455, Riyadh, 11451, Saudi Arabia.
E-mail addresses: elsorogyabd@yahoo.com, asmohamed@ksu.edu.sa (A.S. El-Sorogy).

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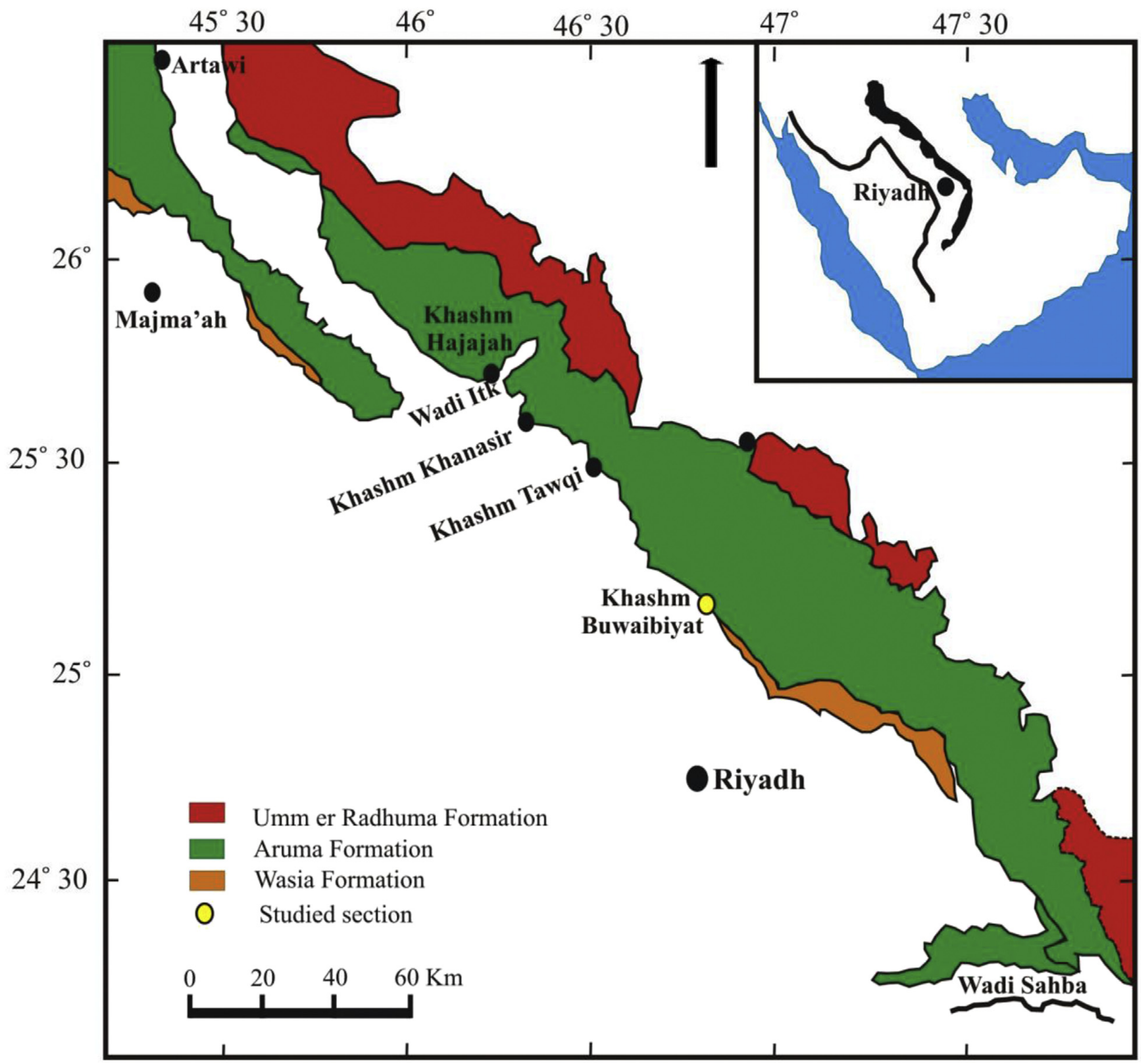

Fig. 1. Location map of the studied sections (after Al-Kahtany et al., 2016).

Najd escarpments in central Saudi Arabia (Steineke et al., 1952). It was subdivided by El Asa'ad (1977, 1983a, 1983b) into three members, namely the Khanasir Limestone Member, Hajajah Limestone Member and Lina Shale Member. The Khanasir Limestone Member is underlain by various colored clastic sediments of the Wasia Formation and the Lina Shale Member is seen at the top of the sequence and overlain by gray crystalline *Lockhartia*-bearing dolomite of the Paleocene Umm er Radhuma Formation.

Our study concentrates on the Hajajah limestone Member in Khashm Buwaibiyat area to the northeast of Riyadh (Fig. 1). The following is a detailed description of studied section, from base to top (Fig. 2):

1 Green shale, brown-weathering, flaky, fissile, laterally may change in part to marl and argillaceous limestone. Fossiliferous with moderately preserved ostracods and foraminifers (~16 m thick).
2 Creamy limestone, brown-weathering, massively bedded, soft, chalky and slightly argillaceous. Fossiliferous with abundant coral and stromatoporid rubbles, gastropod and bivalve molds, ostracods and foraminifers (~5 m thick).
3 Green shale, brown-weathering, flaky, fissile, laterally may change in part to marl and argillaceous limestone with abundant ostracods and foraminifers (~30 m thick.).
4 Creamy dolomitized limestone, tan-weathering, chalky, granular, sparsely detrital, massively bedded, mostly rubbly-weathering; alternately forms strong and weak benches. Fossiliferous with abundant branched and small massive corals, stromatoporoids, gastropod and bivalve molds, echinoids, ostracods and foraminifers (~12 m thick).

3. Materials and methods

A composite section was measured and macrofossils and rock samples were collected from the Hajajah limestone Member at Khashm Buwaibiyat in northeast Riyadh (latitude 25° 12′ 12″ N and longitude 46° 49′ 27″ E), on the dip slope surfaces

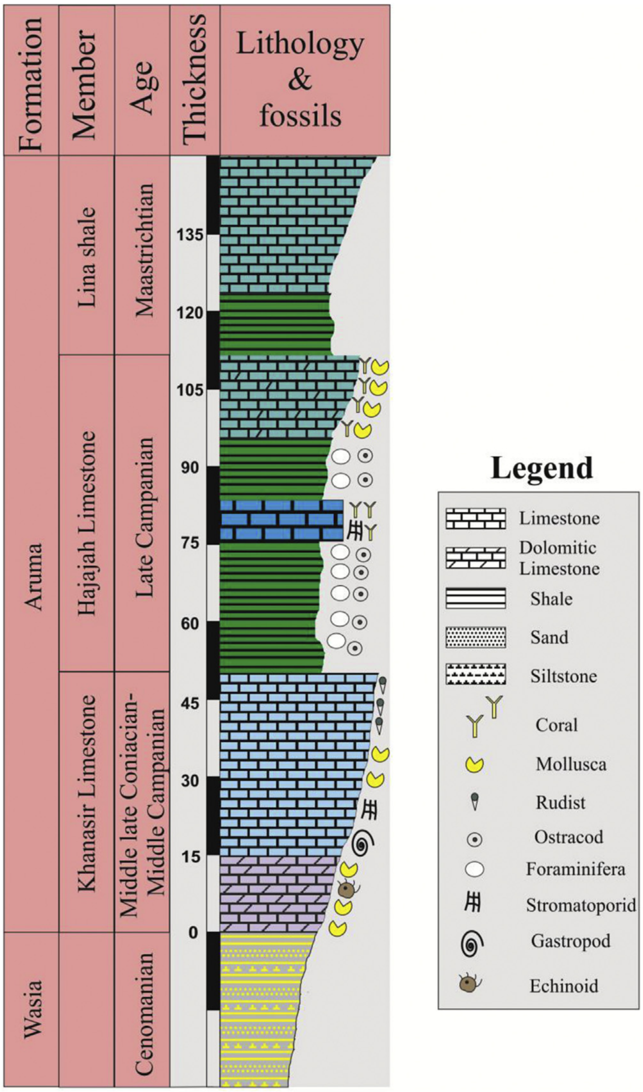

Fig. 2. Composite lithostratigraphic section of the Aruma Formation in the studied localities.

neighboring the crest of the escarpment, on either side of the road which runs NNE to Rumhiyah. For ostracod preparation, 100 g of dry samples were soaked in Na_2CO_3 solution, washed over 630, 125 and 63 μm sieves, and then dried in an oven at 60 °C for at least 24 h. The fraction 125–630 μm was investigated qualitatively under binocular stereomicroscope and photographed using SEM. 35 representative rock samples were chosen for thin sections preparation and microfacies analysis. For microfacies description and interpretation, the classification of Dunham (1962) was followed.

4. Results and discussion

4.1. Facies development

On the basis of field observations, selected micro-and macrofossils and thin section analyses, two regressive depositional cycles were recorded in Hajajah Limestone Member (Fig. 3A). These depositional cycles followed the transgressive episode which corresponds the deposition of Khanasir Member. Each depositional cycle includes three facies belts: intra-shelf basin facies, fore-reef facies and back reef and restricted lagoon facies.

4.1.1. Intra-shelf basin facies

This facies belt was recorded in the lowermost part of Hajajah Member and the base of the second depositional cycle (16 m and 30 m respectively). It consists of fossiliferous green shale and mudstone. Washing and picking of samples from this lithofacies gave ostracods and badly preserved foraminifers. The following ostracod species were identified and illustrated from the green shale of intra-shelf basin facies (Figs. 5 and 6): *Cytherella* cf. *austinensis* Alexander, 1929; *Bairdoppilata pondera* Jennings, 1936; *B. magna* (Alexander, 1927); *Bythocypris* cf. *windhami* Butler and Jones, 1957; *Bythocypris* sp.; *Xestoleberis tripolensis* El-Sogher, 1996 *Brachycythere tumida* Al-Furaih, 1980; *B. undosa* Al-Furaih, 1980; *Kaesleria bilirata* (Al-Furaih, 1980); *K. trahea* (Al-Furaih, 1980); *Digmocythere* sp.; *Hermanites* sp. and *Uroleberis* sp. The first six of these ostracod fauna recorded for the first time from central Saudi Arabia and were recorded previously from Egypt, Libya, Israel and USA (Alexander, 1929; Honigstein, 1984; Shahin and El-Nady, 2001; Abd-Elshafy et al., 2002; Barsotti, 1963; El-Sogher, 1996). Picking sediments from intra-shelf basin facies also gave badly to moderately preserved foraminifers (e.g. *Orbitoides*, *Lepidorbitoides*, *Loftusia and Omphalocyclus*).

4.1.2. Fore-reef facies

This lithofacies deposits followed upward the intra-shelf basin facies in the two recorded cycles (3.5 m and 6.50 m respectively). This reefal lithofacies consists of laminated to massive bioturbated marly coralline limestone. The upper part is rich in low diverse, small isolated corals heads (e.g. *Stylina regularis* and *Columactinastrea torallolensis*) and abundant solitary individuals (Fig. 3B–F). The solitary forma are mostly of *Aulosmilia cuneiformis*, *A. vidali*, *A. compressa*, *Rennensismilia subinduta*, *Cunnolites* sp. and *Cyclolites* sp. Dasycladacean algae are of subsidiary importance, and play a significant role in the construction of the reef facies, where they bind and connect coral colonies and other skeletal and non-skeletal constituents into a coherent mass. The bivalves, gastropods and cephalopods (e.g. *Spondylus*, *Cerithium*, *Aporrhais*, *Pyrazus*, *Tylostoma*, *Cylichna*, *Pachydiscus*, *Manambolites*, *Libycoceras* spp.) act as essential rock forming constituents in this reefal slope lithofacies.

Microfacies analysis of the framebuilders and the sediments filling the spaces in between gave mainly bioclastic wackestone, algal wackestone, bioclastic packstones, coralline framestones, coralline rudstnes and grainstones (Fig. 8). Thin sections contain fragments of corals, stromatoporoids, dasycladacean algae, benthic foraminifera (orbitolinids, miliolids) and ostracods. Most of these fragments were recrystallized due to diagenesis.

4.1.3. Back reef and restricted lagoon facies

This lithofacies belt followed upward the reefal slope facies in the top of the two recorded cycles (1.5 m and 5.5 m thick respectively). It consists of massive, bioturbated limestone with low diverse, small dendroid and massive heads of corals and bivalve (*Pecten* sp., *Oscillolopha* sp., *Pholadomya* sp., *Ostrea* sp, *Apricardia* sp.) and gastropod molds (Fig. 4A–F, Fig. 7). Microfacies analysis of this facies belt gave coralline framestone, bioclastic grainstone, bryozoan grainstone, bioclastic wacke/

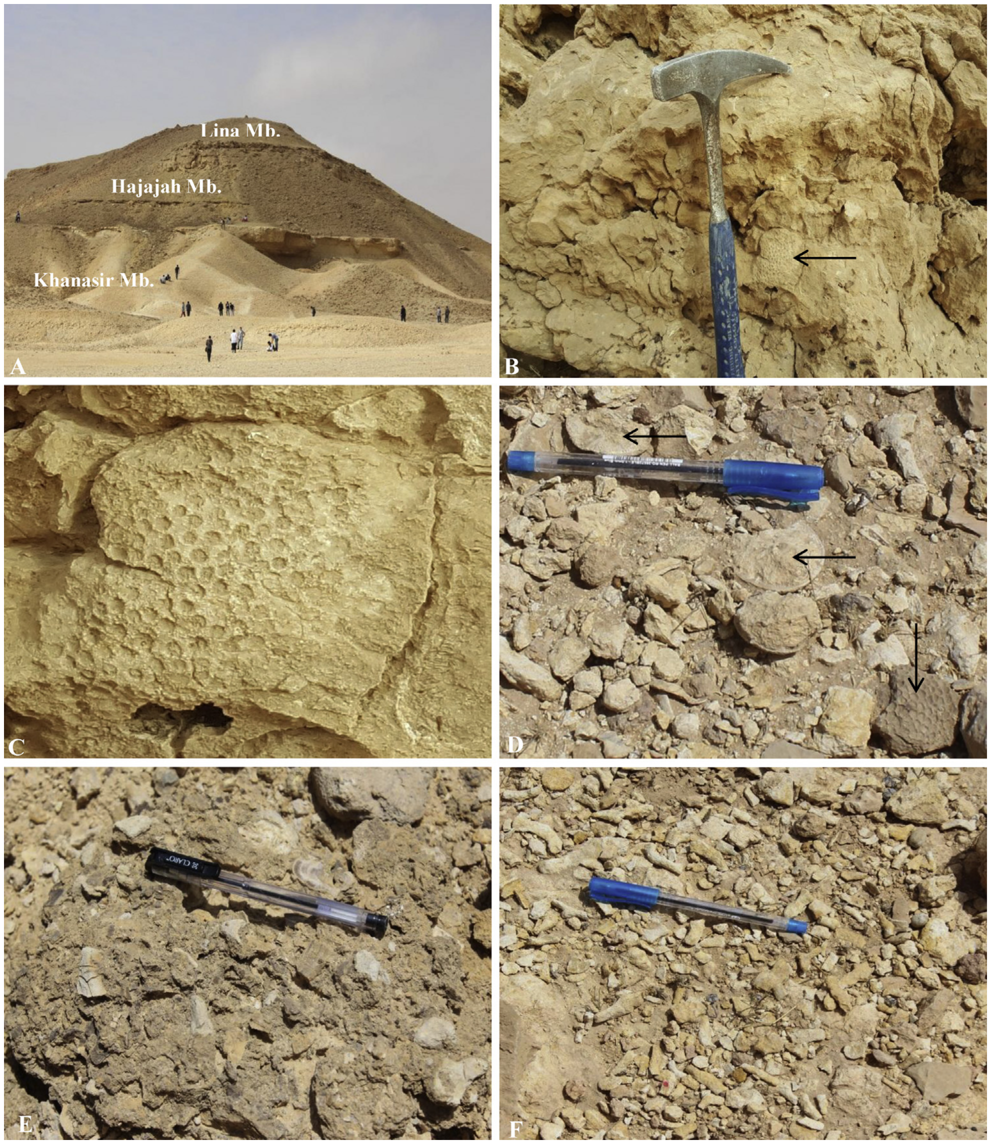

Fig. 3. A, general view of the Aruma Formation in northeast Riyadh with the three successive members; B, marly argillaceous limestone of the fore-reef facies with small massive coral colony (arrow); C, enlargement of figure B (arrowed part) showing the massive coral colony; D, massive and solitary corals (arrows) of the back reef and near-shore facies in the uppermost part of the Hajajah Limestone Member.

floatstones and bioclastic rudstones and dolomitic limestone (Fig. 9). The skeletal grains are dominated by reworked, moderately preserved, small branched, massive and phaceloid corals (*Actinastrea*, *Stylophora*, *Monticulastraea*, *Cladophyllia*), bivalves, gastropods and dascycledean algae. Matrix in most back reef is made up of peloidal micrite with abundant organic matter. Most of the aggregate grains are micritized exhibiting the characteristic lobate outline. Few reworked bioclasts are also recorded in this environment.

4.2. Paleoenvironment

The recorded ostracods and foraminifers in intra-shelf basin facies in the lowermost part of the Hajajah limestone Member suggest deposition in marine conditions of normal salinity in an intra-shelf basin or deep subtidal setting (Pandey and Fürsich, 2003; Löser and Ferry, 2006; Pandey et al., 2009) and in distal marine settings below storm wave base in a low-energy environment (Stemmerik, 1997; Beauchamp and Desrochers, 1997).

The fabric of fore-reef facies is mostly grain-supported fabric indicated by absence of mud, close packing of grains, and abundance of carbonate cement in interparticle pores. The biostromal boundstones contain corals, bivalves, large gastropods, echinoderms, shell debris and bioclasts. Fossil assemblages of these lithofacies indicate an open marine fore-reef setting (Howarth and Morris, 1998; Fuersich and Pandey, 1999; Sepkoski, 2002). The presence of lithoclast rudstone and biostromal boundstone indicates fore-reef breccia in the middle to outer shelf (Flügel, 2010). The composition of intraclasts derived from other reef microfacies indicate that they were deposited by wave and tidal erosion of the in-situ reefs (Armella et al., 2013).

Fig. 4. A, marly reefal limestone in the uppermost part of Hajajah Limestone Member; B and C, branched and small massive coral colonies in the argillaceous limestone of the fore-reef facies; D, branched coral and stromatoporid colonies of the back reef and near-shore facies in the uppermost part of the Hajajah Limestone Member; E and F, *Pecten* sp. and bivalve mold (arrows) in the bioturbated coralline limestone of the back reef and near-shore facies.

The presence of coral fauna in back reef and restricted lagoon facies suggests a well oxygenated water with normal salinity in an open sea back-reef and shallow lagoon shelf environment (Manivit et al., 1990; Holzapfel, 1998; Sepkoski, 2002; Clark and Boudagher-Fadel, 2001; Ivanova et al., 2008). Stromatoporoids require moderately low energy conditions in order to avoid breakage, and are considered to have best developed in the distal part of the lagoon or in back reef settings, where the direct higher wave energy would be inhibited (Hughes, 2006). The presence of aggregate grains grainstone facies and few peloids indicate submarine erosion of lithified carbonates adjacent to a reef zone inner platform behind the platform edge (Flügel, 2010). The occurrence of reworked bioclasts may indicate occasional storm events. In general, the low diversity of coral species is considered to be a result of inimical such as ecological conditions, nutrition level, paleoecological factors and paleobiogeographical barriers which could have prevented colonisation of more diverse species.

5. Conclusions

1 Field observations, fossil content and microfacies analysis proven that, the Campanian Hajajah Limestone Member was deposited during two regressive episodes after a transgressive one of Khanasir Limestone Member. Each of the regressive episode formed of three depositional facies, from base to top: intra-shelf basin facies, fore-reef facies and back reef and near-shore facies.

2 Present study proven that, the Hajajah Limestone Member was deposited in distal marine settings below storm wave base in a low-energy environment changed upward to fore-reef framework in an open marine environment with moderate to high energy conditions and terminated with shallow back reef and

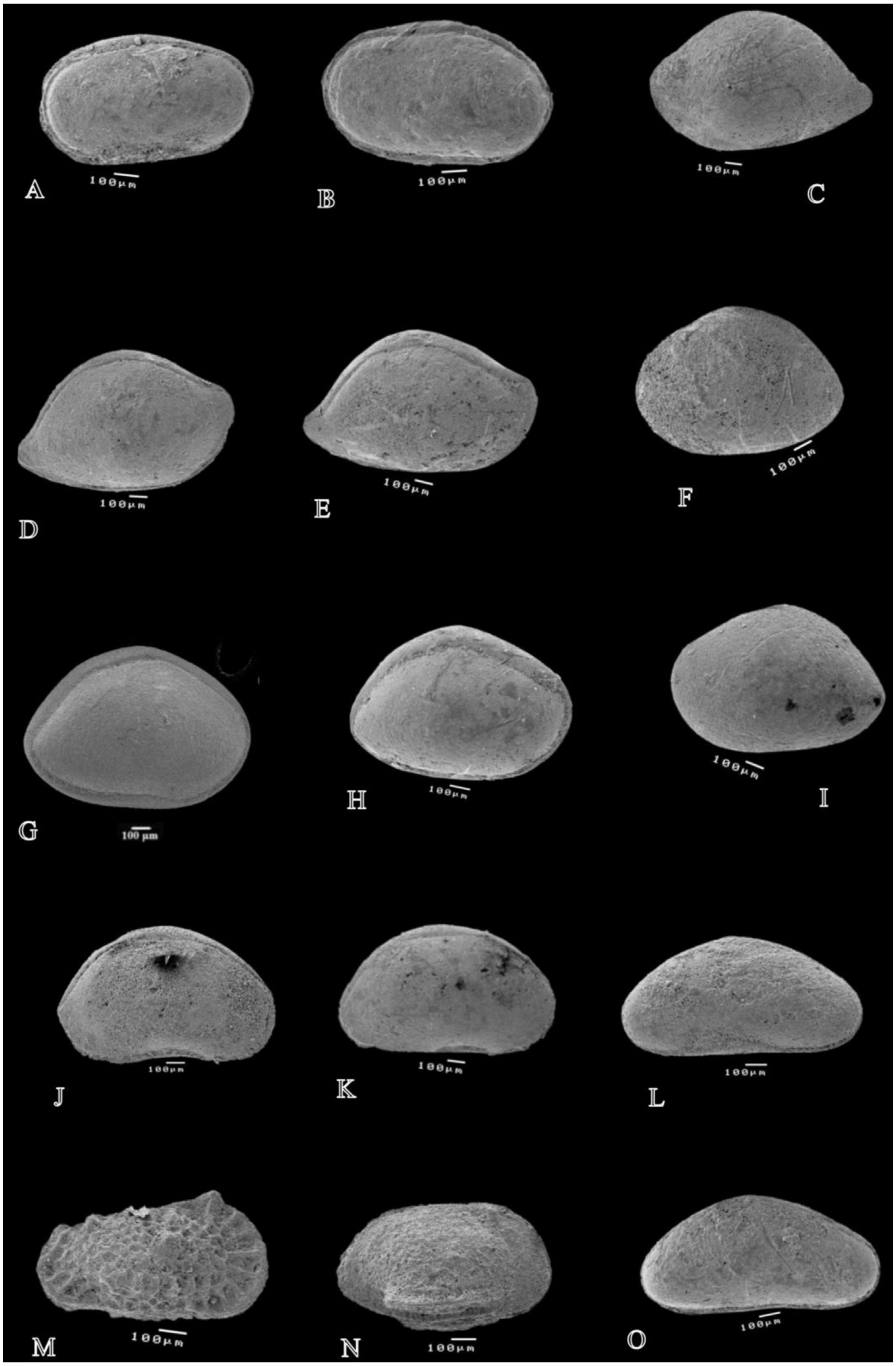

Fig. 5. Examples of the recorded ostracods, mostly from the intra-shelf basin facies. A, *Cytherella* sp.; B, *Cytherella austinensis* Alexander; C-E, *Bairdoppilata pondera* Jennings; F-I, *Bairdoppilata magna* Coryell, Sample and Jennings; J and K, *Bythocypris* cf. *windhami* Buttler and Jones; L and M, *Bythocypris* sp.; N, *Digmocythere* sp.; O, *Hermanites* sp.

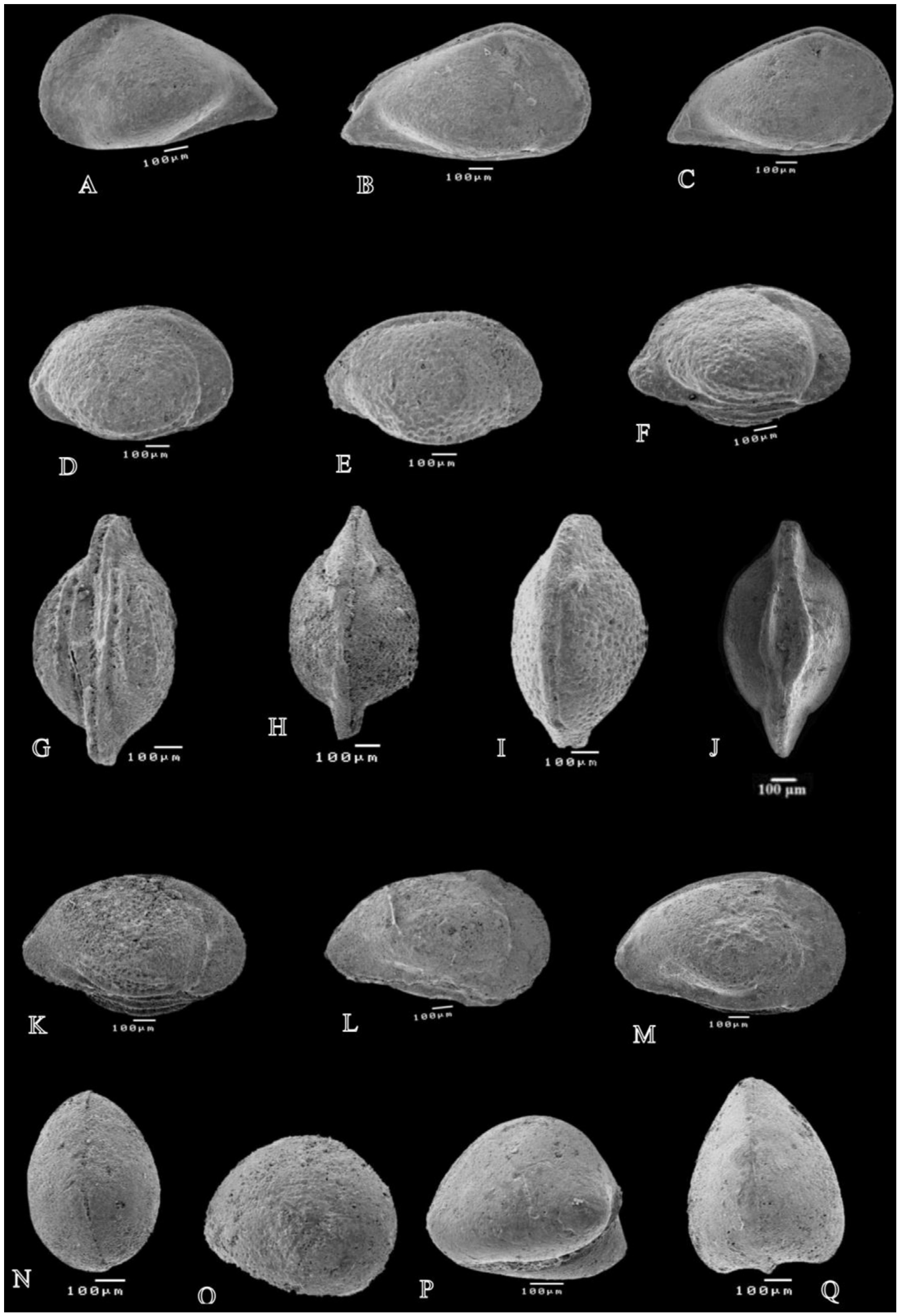

Fig. 6. Examples of the recorded ostracods, mostly from the intra-shelf basin facies. A-C, *Brachycythere tumida* Al-Furaih; D-G, *Kaesleria bilirata* (Al-Furaih); H-J, *Kasesleria trahea* (Al-Furaih); K-M, *Brachycythere undosa* Al-Furaih; N and O, *Xestoleberis tripolensis* El-Sogheir, P and Q, *Uroleberis* sp.

Fig. 7. Examples of the recorded bivalves, mostly from the back reef and near-shore facies. A and B, external and internal views of *Oscillolopha* sp; C and D, different views of *Pholadomya* sp.; E and F, external and internal views of *Ostrea* sp; G, external view of *Apricardia* sp.

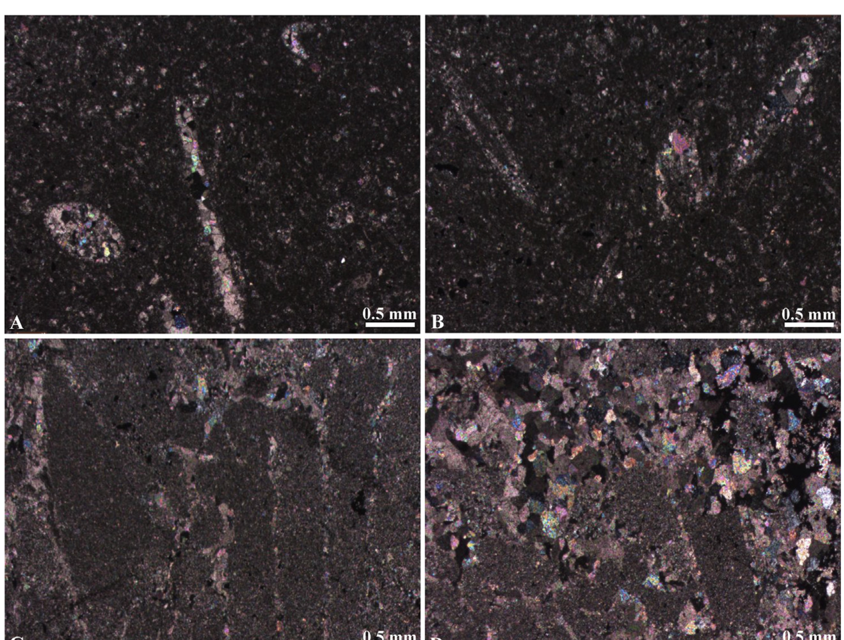

Fig. 8. Examples of the fore-reef microfacies types. A, bioclastic wackestone with ostracod and other fossil fragments; B, algal wackestone with recrystallized fragments of dasyclad algae; C, coralline floatstone; D, coralline rudstone with recrystallized corals.

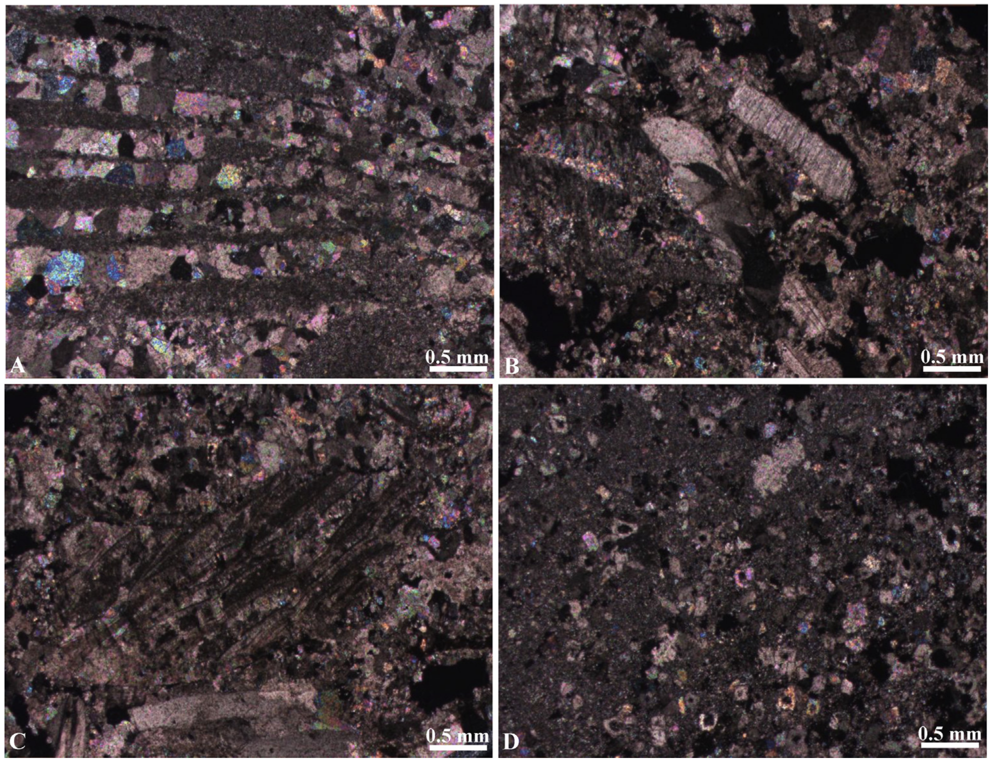

Fig. 9. Examples of the back reef and near-shore microfacies types. A, coralline framestone; B, bioclastic grainstone; C, bryozoan grainstone with fragments of bivalves and corals in sparitic cement; D, dolomitic limestone with euhedral to subhedral dolomite rhombs.

nearshore deposits with accumulation of skeletal grains by storms during regression.

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