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ORIGINAL PAPER

Stratigraphy and depositional environments of the Upper Cretaceous Aruma Formation, Central Saudi Arabia

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Abstract The Upper Cretaceous Aruma Formation in central Saudi Arabia is subdivided into three members. The Khanasir Member at the base is characterized by dasycladecean-rudist biofacies. The middle Hajajah Member is characterized by coral-stromatoporoid biofacies, while the upper Lina shale Member contains few badly preserved molluscs. Fifty macrofossils species have been identified from the studied section, 25 of them belong to gastropods, 17 belong to scleractinian corals, and 8 species belong to bivalves. The identified macrofossils have close affinity to Tethyan faunas and previously known from the Cretaceous rocks in Asia, Africa, and Europe. The most recorded microfacies types are wackestones, packstones, and floatstones with green algae, benthic and rare planktonic foraminifers, ostracods, and corals. The studied section revealed a major Campanian-Maastrichtian marine transgression followed the continental siliciclastics of the Wasia Formation with progressive deepening upward, from a shallow marine lagoonal environment to relatively more open marine conditions.

Keywords Stratigraphy · Depositional environments · Upper Cretaceous · Aruma Formation · Central Saudi Arabia

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Introduction

Since the old studies of Steineke and Bramkamp (1952); Steineke et al. (1958); Powers et al. (1966); Powers (1968), (El As'ad 1977, 1983a, b, 1984), and Vaslet et al. (1988), there are no studies dealt with stratigraphy and depositional environment of the Aruma Formation in central Saudi Arabia. Skelton and El Asa'ad (1992) identified new genus and species of canaliculated rudist from of the Campanian Khanasir Member of the Upper Cretaceous Aruma Formation in Central Saudi Arabia. Al-Furaih (1984a, 1984b, 1986) studied the Maastrichtian ostracods of Aruma Formation from Wadi al-Atiq. He identified, described, and illustrated one new genus and 15 new species.

Studies of Okla (1991, 1992, 1994, 1995) were on Cretaceous fossil algae, especially dasycladaceans. He identified new dasycladecean species from surface samples of the Aruma Formation in northeast of Riyadh, Saudi Arabia. Recently, Gameil and El-Sorogy (2015) identified 15 gastropod species from the present section, mainly from the Hajajah Member and indicated shallow marine lagoonal and relatively open marine environment.

None of the last mentioned studies have dealt with stratigraphy and depositional environments; therefore, the present work aims to study stratigraphy and to document the depositional environments of the Upper Cretaceous Aruma Formation in Central Saudi Arabia based on microfacies analysis and macrofossils content.

Materials and methods

A composite section was measured and macrofossils and rock samples were collected from Khashm Bowaibiyat area, Northeast Riyadh (Fig. 1) Gastropods, scleractinian corals,

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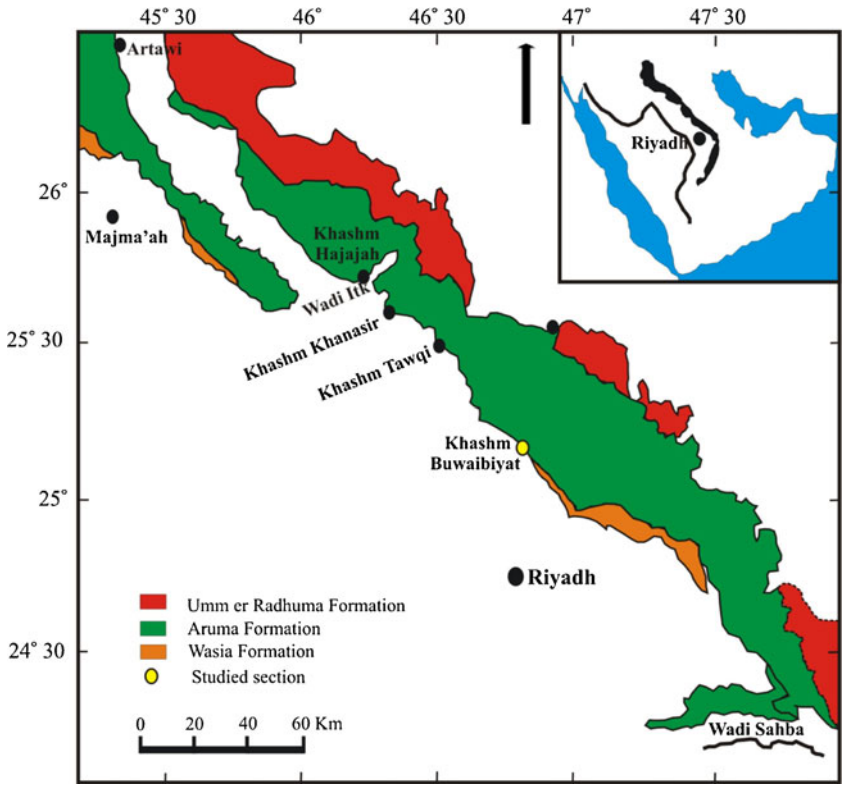

Fig. 1 Outcrop of the Upper Cretaceous (Coniacian-Maastrichtian) Aruma Formation in Central Saudi Arabia (after Gameil and El-Sorogy 2015)

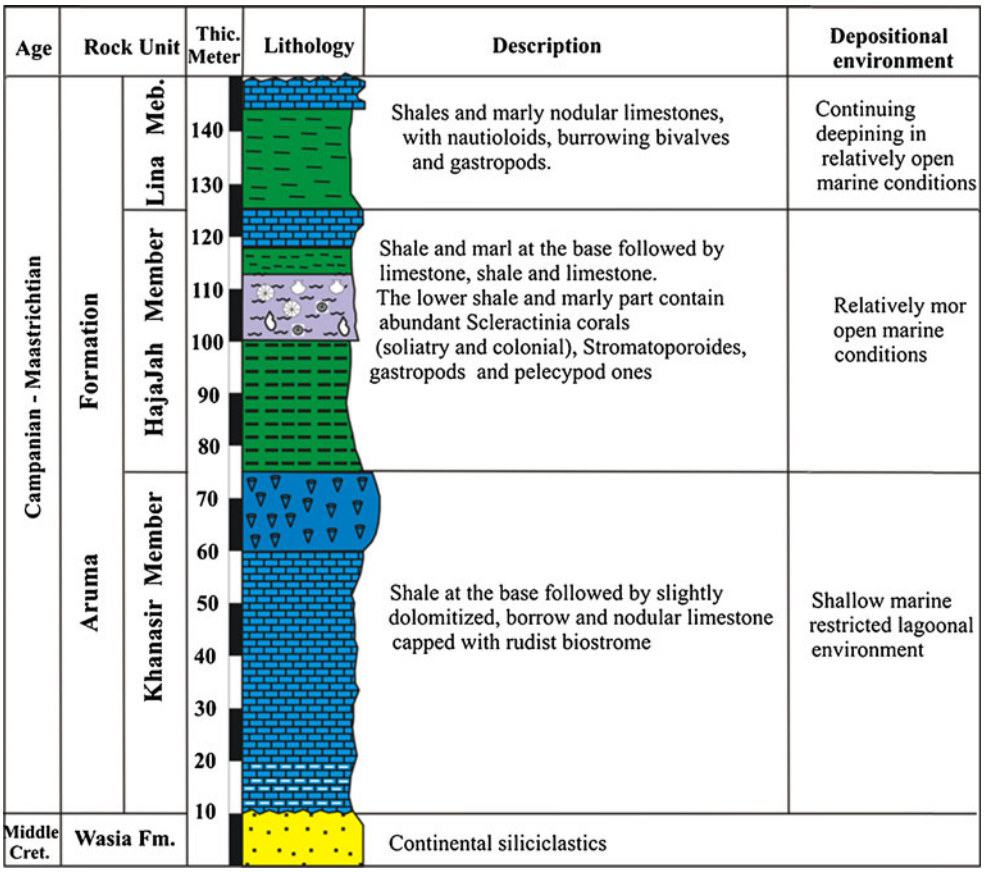

Fig. 2 Lithostratigraphic section of the Aruma Formation, Khashm Bowaibiyat area, Northeast Riyadh

Fig. 3 Field photographs of the Aruma Formation. **a** The Khanasir Member disconformably overlies siliciclastics of Wasia Formation. **b** Close up view of the rudist limestone in the upper most part of the lower member. **c** General view of the Hajajah Member. **d** Slightly massive heads of scleractinian corals in the Hajajah Member. **e** Small corals and stromatoporoids in the marly limestone of the Hajajah Member. **f** Shale and limestone of the Lina Member

and bivalves were cleaned and identified. Twenty-two representative hard limestone samples were chosen for thin sections. Fossils are stored in the Department of Geology and Geophysics Museum, College of Science, King Saud University.

Results and discussion

Stratigraphic setting

The Aruma Formation was named for its occurrence in the Al 'Aramah plateau, a broad upland surface related to the easternmost of the Najd escarpments (Powers et al. 1966). Rocks of the Aruma Formation crop out from Wadi ad Dawasir in southern Saudi Arabia beyond the Iraq-Saudi Arabia border, a distance of more than 1600 km. Width of the Aruma outcrop band is somewhat erratic, but from a regional point of view, it persistently increases from southeast to northwest. About 20 km wide at Wadi ad Dawasir, the formation is spread out over nearly 200 km where it passes into Iraq.

The Aruma Formation disconformably overlies the continental siliciclastics of the Cenomanian Wasia Formation (Steineke et al. 1958). The upper limit is taken at the change from yellow-brown dolomitic shale below to gray crystalline *Lockhartia*-bearing dolomite of the Umm er Radhuma Formation above. The first formal references to the Aruma Formation appeared in Steineke and

Table 1 Invertebrate megafossils identified from the Aruma Formation

Class	Species	Khanasir Mb.	Hajajah Mb.	Lina Mb.
Gastropoda	*Pleurotomaria* sp.	×	×	×
	Keilostoma morgani (Douville)		×	×
	Architectonica conoideum (Sowerby)	×	×	
	Architectonica karapandiensi (Stoliczka)		×	×
	Nerineopsis cuckhamsliensis Woods		×	
	Cerithium (*Fibula?*) *detectum* Stoliczka		×	
	Cerithium tenouklense Conquand		×	×
	Scala dupiniana (d' Orbigny)	×	×	
	Scala (*Confusiscala*) *dupiniana* (d' Orbigny)	×	×	
	Chemnitzia undosa Sowerby		×	×
	Aporrhais marginata (Sowerby)		×	
	Pterodonta deffisi Peron		×	×
	Pterodonta ovata d' Orbigny	×	×	
	Strombus bellasensis Choffat		×	×
	Strombus cascaensensis Choffat	×	×	
	Strombus fischeri Choffat		×	×
	Cypraea cunliffei Forbes		×	
	Megalocypraea sp.	×	×	
	Tylostoma pallaryi (Peron & Fourtau)		×	×
	Sycostoma pervinquieri (Boelenev)		×	
	Vasum sp.	×	×	×
	Rostellinda pergaensis Boelenev	×	×	
	Lyria subcrassicostata Basse		×	×
	Drillina morgani Douville	×	×	
	Drilluta curta Boelenev	×	×	
Bivalvia	*Spondylus calcaratus* (Forbes)			×
	Spondylus subserratus	×	×	
	Spondylus latus Sowerby		×	×
	Ostrea (*Alectryonia*) *pectinata* Lamarck	×		
	Ostrea telugensis Stoliczka	×		
	Gryphaea cf. *oldhami* Noetling		×	×
	Apricardia sp.	×	×	
	Durania arnaudi Choffat	×		
Anthozoa	*Aulosmilia cuneiformis* (Milne-Edwards & Haime)		×	
	Aulosmilia vidali Mallada		×	
	Aulosmilia compressa Lamarck		×	
	Rennensismilia subinduta (Reuss)		×	
	Rennensismilia oldhami (Duncan)		×	
	Conicosmilotrochus parkinsoni (Edwards & Haime)		×	
	Conicosmilotrochus figuierensis Alloiteau		×	
	Acrosmilia cf. *fromenteli* Alloiteau		×	
	Stylina regularis Fromentel		×	
	Columactinastrea torallolensis (Reig Oriol)		×	
	Aulosmilia cuneiformis (Milne-Edwards & Haime)		×	
	Aulosmilia vidali Mallada		×	
	Aulosmilia compressa Lamarck		×	
	Rennensismilia subinduta (Reuss)		×	
	Rennensismilia oldhami (Duncan)		×	
	Conicosmilotrochus parkinsoni (Edwards & Haime)		×	
	Conicosmilotrochus figuierensis Alloiteau		×	
	Acrosmilia cf. *fromenteli* Alloiteau		×	

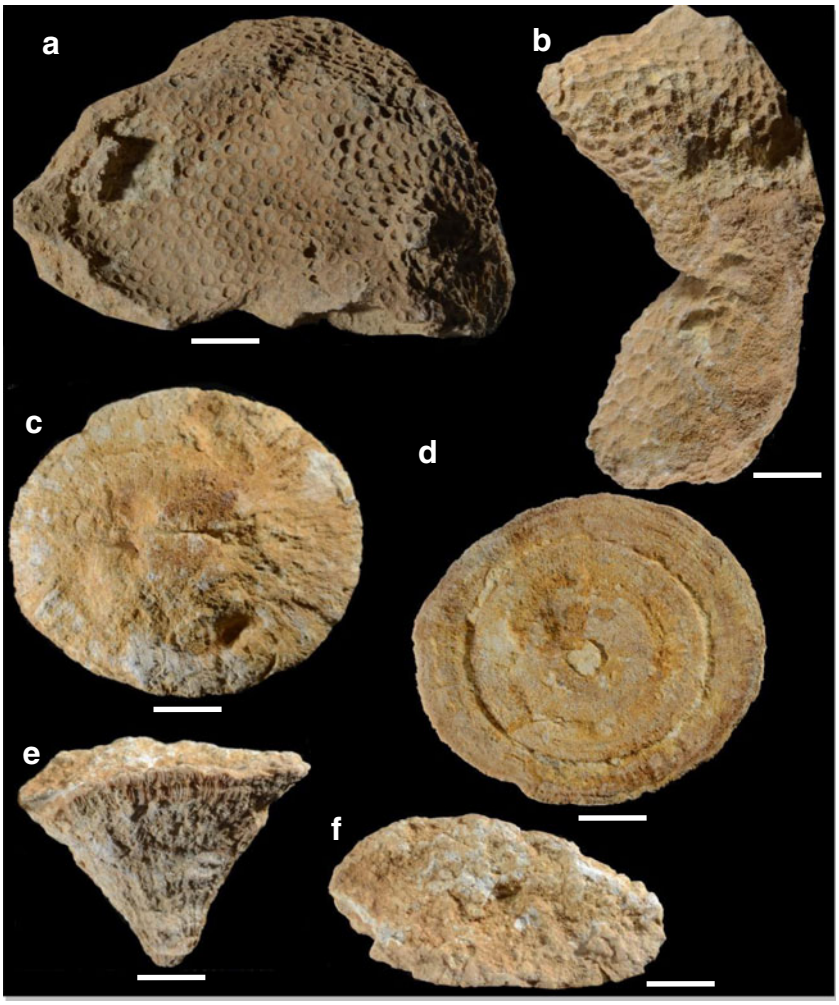

Fig. 4 Examples of the identified scleractinians from Hajajah member. **a** *Stylina regularis* Fromentel, calicular view. **b** *Columactinastrea torallolensis* (Reig Oriol), calicular view. **c** and **d** *Acrosmilia* cf. *fromenteli* Alloiteau, calicular view and lower view. **e** and **f** *Aulosmilia compressa* Lamarck, side view and calicular view

Bramkamp (1952). The type locality was described by Steineke et al. (1958).

In the type locality, the Aruma Formation is 140 m thick and composed of limestone, shales, and dolomites (Powers 1968). At first, the formation was divided into four lithological units that were grouped into two members, namely the Atj and Lina members. Later, the formation was subdivided into three members, in ascending order: the Khanasir Member, the Hajajah Member, and the Lina Member (El Asa'ad 1984; Vaslet et al. 1988; Skelton and El Asa'ad 1992).

The following is a detailed description of the three members of Aruma Formation at Khashm Buwaibiyat (Lat. 25° 12′ 12″, Long. 46° 49′ 27″) in northeast Riyadh, central Saudi Arabia (Fig. 2).

The Khanasir Member

The lowermost limestone member (up to ~65 m) comprises shale at the base followed by slightly dolomitized, burrow, and nodular limestone caps with 12 m of local rudist biostrome (Fig. 3a, b). It disconformably overlies the continental Cenomanian siliciclastics of the Wasia Formation with a sharp contact and overlain by the Hajajah Member with very low angle unconformity.

The lower ~20 m of this member comprises a laterally variable association of shaley, marly, and marly limestone facies, in which few gastropod and bivalve molds (Table 1) and badly preserved echinoids were recorded. The member becomes more calcareous upwards with abundant dasycladecean algae and larger foraminifers including *Omphalocyclus marcoporous* (Lamarck). The top most part of the member (6–12 m) is a dense packing rudist biostrome (Fig. 3b), mostly of living position of slender rudist *Eodictyoptychus arumaensis* (Skelton and El Asa'ad 1992).

Powers et al. (1966) reported that the lowermost beds of the Aruma outcrop could be as old as Santonian. Powers (1968) indicated that the top of the lower Aruma Formation is Campanian, where *Monolepidorbis sanctae-pelagiae* Astre is found. This member ranges in age from Coniacian at its base to Campanian in its topmost few meters (El Asa'ad 1983a, 1983b).

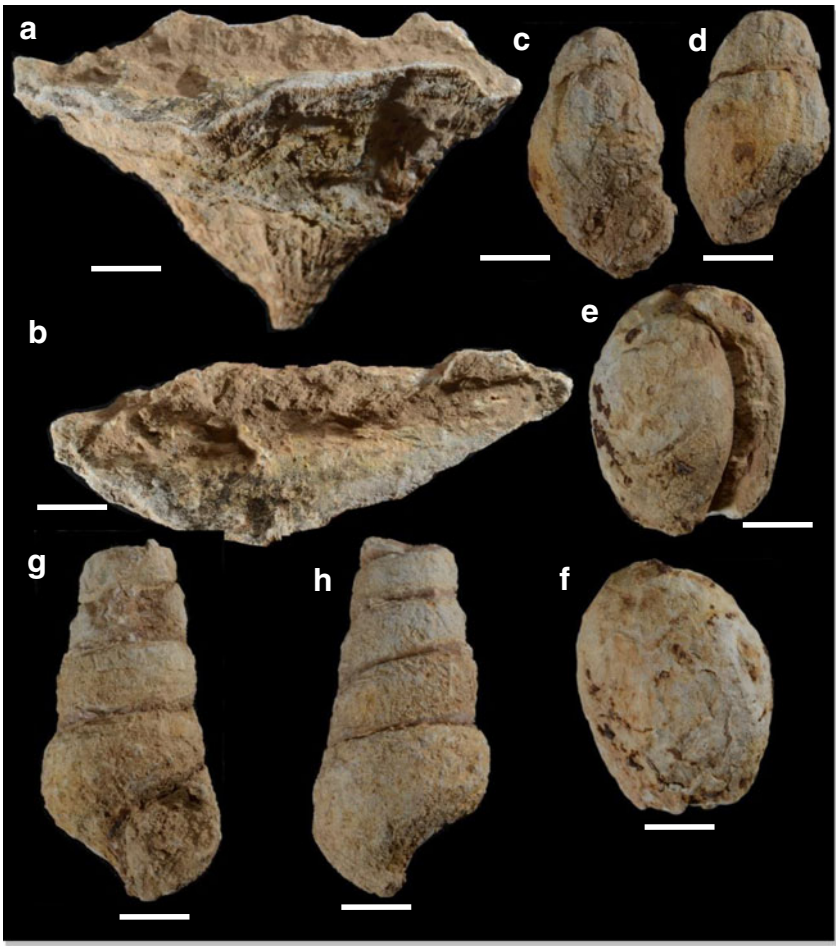

Fig. 5 Examples of the identified scleractinians and gastropods from Hajajah member. **a** and **b** *Rennensismilia subinduta* (Reuss), side view and calicular view. **c** and **d** *Drilluta curta* Boelenev, apertural view and abapertural view. **e** and **f** *Cypraea cunliffei* Forbes, apertural view and abapertural view. **g** and **h** *Strombus fischeri* Choffat, apertural view and abapertural view

The Hajajah Member

This member disconformably overlies the Khanasir Member. It comprises shale and marl at the base followed by limestones (up to ~75 m). The lower shale and marly part contains abundant scleractinian corals (solitary and colonial), stromatoporoids, gastropod molds (Figs. 3c–e, 4, and 5) and few bivalve ones (Table 1). Corals are predominantly domal and platy and rarely branching. The limestone in the upper part includes abundant benthic larger foraminifera [including *Omphalocuclus macroporous* (Lamarck) and *Quenqueloculina* sp.] and dasyclad algae (*Griphoporella* sp.).

The Hajajah Member falls below the level of the lowermost definitely Maastrichtian Foraminifera and above the level of the uppermost definitely Campanian Foraminifera. El Asa'ad (1991) proposed a Late Campanian age for Hajajah Member by discovery of the ammonites *Manambolites amardi* Collignon and Roman, *Libycoseras chargense* Blankenhorn and *pachydiscus* (*P.*) *launayi* (De Grossouvre) in the calcareous part of the member.

The Lina Member

The Hajajah limestone Member passes upwards gradationally into the Lina shale Member (over 40 m) comprising shales and marly nodular limestones (Fig. 3f), with nautioloids, burrowing bivalves, and gastropods (Table 1). Ammonites and foraminifera from this member suggest a late Maastrichtian age (El Asa'ad 1983a).

Fossil record and depositional environment

Fifty invertebrates have been identified from the studied section. Twenty-five species belong to gastropods, 17 to scleractinian corals, and 8 to bivalves (Table 1). Almost all of the invertebrates are recorded from the middle Hajajah Member, while the lower and upper members contain the fewest. The identified species have close affinity to Tethyan faunas and known from Cretaceous rocks in Asia, Africa, and Europe. They were previously recorded from western India, Pakistan, Iran, Baluchistan, Iraq, North Africa, Spain, and Portugal and perhaps Western Europe (El Asa'ad 1984).

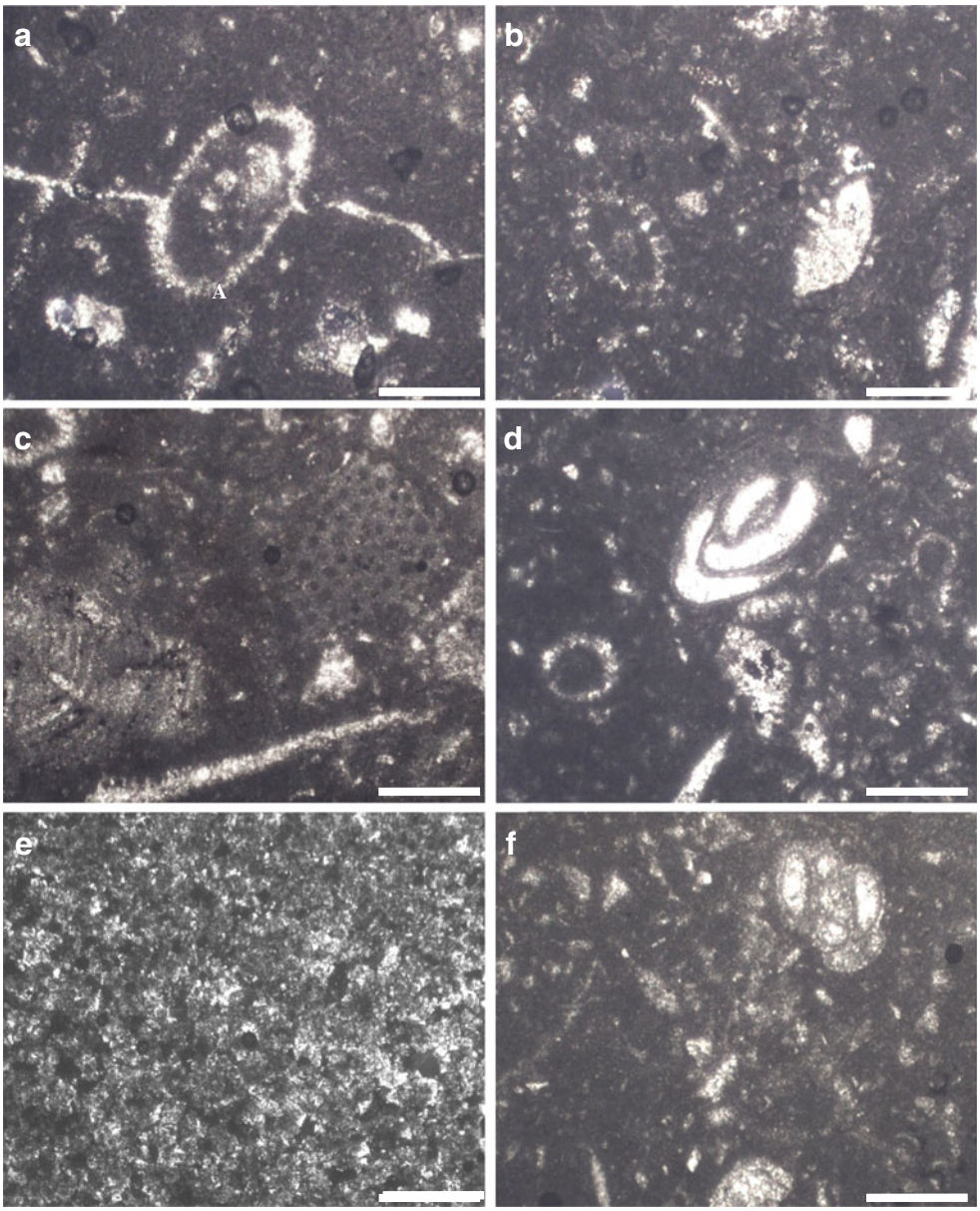

Fig. 6 Thin sections photographs of the Aruma Formation (scale bar = 1 mm, crossed nicols). **a** Algal wakestone with oblique section of *Salpingoporella arumaensis* Okla. All bioclastic fragments are recrystallized, Khanasir Member. **b** Foraminiferal algal wakestone with oblique section of *Salpingoporella arumaensis* Okla and benthic foraminifera, Khanasir Member. **c** Algal packstone with longitudinal section of *Griphoporella* sp. in the lower part, Hajajah Member. **d** Foraminiferal wackestone/packestone with miliolid test (*Quinquiloculina* sp.) and other bioclasts embedded in micritic matrix, Hajajah Member. **e** Dismicites of the Lina Member. **f** Foraminiferal wackestone/packstone with planktonic test (*Globotruncana* sp.) and other bioclasts embedded in micritic matrix, Lina Member

One of the most remarkable features of the Cretaceous carbonate platforms in tropical and subtropical environments of the Tethyan realm was the development of facies complexes dominated by rudists, with or without associated corals (Masse and Philip 1981; Ross and Skelton 1993; Gili et al. 1995; Mansour 2004). The present depositional study of Aruma Formation depends on field remarks, macrofossil content, and microfacies analyses.

The lithological sequence of the Khanasir Member comprises of shale at the base followed by nodular limestone and caps with rudist biostrome. Thin sections of the limestones of this member gave algal wackestone, foraminiferal algal wackestone, and algal packstone (Fig. 6a–d) with abundant dasycladacean algae (*Salpingoporella arumaensis*, *Dissocladella intercedens*, and *Griphoporella* sp.). All bioclastic fragments are recrystallized. These algal floras with the associated macrofossils mostly indicated a shallow marine lagoonal depositional environment (Okla 1995). The occurrence of rudist-dasyclad biofacies and benthic foraminifera clearly supports the interpretation of deposition in a shallow marine environment that was well within the depth limits of the photic zone (Filkorn and Scott 2011). Smith et al. (1995) interpreted the similar upper beds dominated by rudists of the Simsima Formation (Campanian-Maastrichtian of United Arab Emirates) as having been deposited on stable shoals above active wave base. Alsharhan et al. (2000) described these beds as representing a transgressive phase during the deposition of the formation. They attributed their deposition to an open shallow shelf environment, below wave base without or with very rare terrigenous influx.

The lithological sequence of the Hajajah Member comprises of shale and marl at the base followed by limestones with abundant corals, stromatoporoids, and molluscs. Thin sections of the limestones of this member gave foraminiferal wackestone/packstone (Fig. 6e, f), coralline floatstone with abundant miliolid tests (*Quinquiloculina* sp). Smith et al. (1995) interpreted the similar lower beds of the Simsima Formation (Campanian-Maastrichtian of United Arab Emirates) formed of sandy bioclastic limestone with concentrations of solitary corals as having been deposited in shallow water below wave base. Alsharhan et al. (2000) interpreted these beds as having been deposited in open marine depositional conditions. Also, Gameil (2005) indicated the presence of the same hemispherical to dome-shaped morphotypes belonging to cunnolitid corals prevailed during the deposition of the Simsima Formation as better adaptation to a slightly higher energy environment with terrestrial supply by having large and elevated corallites which aided them to lie freely on the soft substrate as well as to free themselves from the fine sands and silts.

The lithological sequence of the Lina Member comprises of shale and limestones with few badly preserved molluscans. Thin sections of the limestones of this member gave wackestones or dismicrites with rare planktonics (*Globotruncana* sp.) indicating continuing deepening in relatively open marine conditions.

The depositional environment of the studied three members has developed as a carbonate platform became deeper upwards. They begin with rudist-dasyclad unit, which represents relatively more restricted marine conditions, followed by the middle coral-stromatoporoid unit, which represents relatively more open, marine conditions and ending with dismicrites in the upper one. This deepening has been a consequence of decrease in sediment accumulation with a rise in relative sea level through deposition of the sequence. The most important factor causing the replacement was probably the decrease in sediment flux, associated with turbidity. This change in the depositional environment eventually favored the establishment of coral-stromatoporoids.

Conclusions

1. The Campanian-Maastrichtian Aruma Formation in Khashm Bowaibiyat area, Northeast Riyadh, Saudi Arabia is subdivided into three members; they are in ascending order: The Khanasir Member, the Hajajah Member, and the Lina Member.
2. Fifty macrofossil species have been identified from the studied section, 25 species of them belong to gastropods, 17 to scleractinian corals, and 8 to bivalves. These fossils are more abundant in the middle member, while the lower and upper ones contain a few.
3. The studied section recorded a major Campanian-Maastrichtian marine transgression and drowning of the area. It began with predominantly carbonate sediments above the continental siliciclastics of the Wasia Formation and changed upward through the section from lagoonal to back reef, rudist-dasycladecean unit, followed by a relatively deeper marine in coral-stromatoporoid in the middle and upper units.

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