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Middle Jurassic–Early Cretaceous foraminiferal biozonation of the Amran Group, eastern Sana'a Basin, Yemen

Mohammed Al-Wosabi[1,2*], Mohammed El-Anbaawy[3] & Khalid Al-Thour[4]

[1]Earth and Environmental Sciences Department, Faculty of Science, Sana'a University, P.O. Box 11903, Sana'a, Yemen
[2]Earth Sciences Department, College of Science, Sultan Qaboos University, P.O. Box 36, PC 123, Al-Koud, Muscat, Sultanate of Oman
[3]Geology Department, Faculty of Science, Cairo University, Giza, Egypt
[4]Earth and Environmental Sciences Department, Faculty of Science, Sana'a University, Yemen
*corresponding author, e-mail: ma_wosabi@yahoo.com

Abstract

Two sections of strata assigned to the Amran Group at Jabal Salab and Jabal Yam in the eastern Sana'a governorate were sampled and correlated. These sections are part of a carbonate platform that extends from the city of Marib in the east to Naqil Ibn Ghailan, 20 km east of the city of Sana'a to the west. Palaeontological analysis of samples recovered has resulted in identification of 123 foraminiferal species, which are used to subdivide the sequence of the Amran Group into five biostratigraphic zones, aged between Bathonian (Middle Jurassic) and Berriasian (Early Cretaceous). The proposed biozones are those of *Riyadhella rotundata*, *Kurnubia jurassica*, *Ammomarginulina sinaica*, *Alveosepta jaccardi* and *Pseudocyclammina sulaiyana/Furitilla caspianseis*. These biozones were constructed and correlated with the equivalent zones reported from several localities.

Key words: Biostratigraphy, Bathonian, Berriasian, Jabal Salab, Jabal Yam

1. Introduction

The Amran Group is considered to be one of the most important rock units in Yemen and in the Arabian Peninsula due to its economic potentiality as main hydrocarbon system in the Marib, Al-Jawf and Shabwa basins, as well as its mineralisations (lead, zinc, copper and silver) in the Jabali area (Al-Ganad et al., 1993). The Amran Group was introduced by Lamare (1923) and Lamare et al. (1930) as the 'Amran Series' to describe carbonate rocks that conformably overlay the Kuhlan Formation near the town of Amran, about 40 km northwest of Sana'a. Those authors dated it as Dogger-Malm on the basis of fossils on record from the Amran-Kuhlan area. The rank of this rock unit was emended to that of a group by Beydoun (1964, 1966), who subdivided it into four formations: Shuqra, Madbi, Sabatain and Naifa (Table 1) and dated the Group as Middle Jurassic (Callovian) to Early Cretaceous (Berriasian) on the basis of fossil content.

The lithostratigraphy of the Amran Group in different areas of Yemen was discussed in detail in several published papers and unpublished works such as those by Botez (1912), Lamare (1923), Lamare et al. (1930), Basse et al. (1954), Beydoun (1964), Geukense (1966), El-Anbaawy (1984), El-Nakhal (1990), Al-Wosabi (1993, 2001, 2005), Simmons & Al-Thour

Table 1. Main lithostratigraphic subdivisions of the Amran Group in Yemen and the study area.

Age		Author	Lamare (1930)	Beydoun (1964, 1966) & Beydoun et al. (1998)	El-Anbaawy (1984)
Cretaceous	Early	Berriasian	Transition Series	Naifa Fm	Jabal Salab/Wadi Al-Ahjur
Jurassic	Late	Tithonan	Amran Series	Madbi Fm/Sabatain Fm	Shuqra Fm
		Kimmeridgian			
		Oxfordian		Shuqra Fm	Shuqra Fm
	Middle	Callovian			
		Bathonian		Kuhlan Fm	Kuhlan Fm
		Bajocian			
	Early		Kuhlan Series		

(1994) and Howarth & Morris (1998). Finally, Beydoun et al. (1998) discussed the position of the group when they introduced the lithostratigraphic subdivisions of Yemen in the international Lexicon of Stratigraphy. They subdivided the Amran Group into four formations: Shuqra, Madbi, Sabatain and Naifa (Table1). Brown et al. (1989) studied this rock unit in the shield area of western Saudi Arabia. The biostratigraphy of the Amran Group has not been discussed by these researchers, with the exception of Al-Wosabi (1993, 2001) and Simmons & Al-Thour (1994).

The Amran Group consists mainly of limestone, marly limestone, shale beds and thick beds of evaporites (salt rocks and gypsum), characterised as the Sabatain Formation in Shabwa "surface outcrops" and Safer "subsurface" areas. The Shuqra Formation consists mainly of limestone with thin shale, siltstone and marl interbeds at several horizons, deposited in a shallow-marine environment. The Madbi and Sabatain formations are lateral equivalents. The former consists of marly clastics which were deposited in an open, shallow-marine environment, while the latter comprises evaporites (gypsum and rock salt) and black shales which were deposited in isolated basins. In the present paper, the subdivision by El-Anbaawy (1984) will be used. He subdivided the Amran Group in northern parts of Yemen, in particular the eastern and western Sana'a basin and neighbouring areas. He introduced the Shuqra and Jabal Salab formations in the eastern parts and Shuqra and Wadi Al-Ahjur formations in the western parts. The Jabal Salab and Wadi Al-Ahjur formations are equivalent with the Naifa Formation of Beydoun (1964) in eastern and southeastern parts of the country (Table 1).The Jabal Salab Formation consists mainly of marl-argillite, bioclastic sandstone and pisolitic limestone, whilst the Wadi Al-Ahjur Formation is characterised by thick beds of marly limestone intercalated with limestone beds.

The present study aims to introduce a foraminiferal biozonation of the Amran Group in the study area and to compare this with equivalent strata in Yemen as well as from other localities.

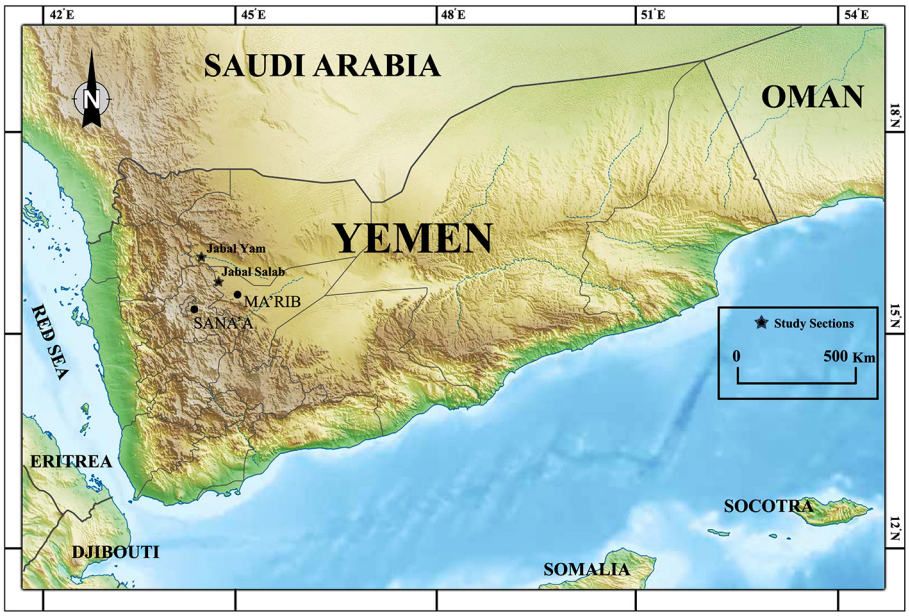


Fig. 1. Location map of the sections studied.

2. Study area

The study area, which is located to the east of the city of Sana'a (Fig. 1), contains Precambrian to Recent rocks including a sedimentary sequence of the Kuhlan Formation, Amran Group, Cretaceous Tawilah Group and Cenozoic volcanics.

The Amran Group overlies the Early to Middle Jurassic Kuhlan Formation (Al-Wosabi & Wasel, 2011) and is represented by the Shuqra and Jabal Salab formations (Table1). The Madbi and Sabatain formations are missing from the sections studied. The Sabatain Formation is well developed in the neighbouring Al-Ghiras area and in the eastern regions of the country such as the Safer and Shabwah areas, while the Madbi Formation is distributed along the southeasterly regions of the country and in the western areas of Sana'a (Beydoun et al., 1998; El-Nakhal, 1990).

Two sections belonging to the Amran Group at Jabal Salab "44°45′E, 15°37′N" and Jabal Yam "44°33′E, 15°50′N" have been measured and described (Figs. 1–3). The Amran Group in these sections consists mainly of thick limestone beds intercalated with marl and marly limestone and occasional dolomitised horizons at different levels (Figs. 2, 3). The Jabal Salab section also contains lead-zinc and silver mineralised horizon. Jabal Yam is accessible along the road from Sana'a to Marib, whilst access to the Jabal Salab section is too difficult through mountainous rough roads by 4-wheel drive vehicles and by walking long distances.

3. Material and methods

Eighty-eight samples were collected from these two sections; 40 samples from Jabal Yam and 48 from Jabal Salab, according to changes in lithology, and from the bottom, middle and top of thick beds (i.e., 1 m or more), with the focus on marl and marly limestone beds (Figs. 2, 3). One hundred and twenty-three foraminiferal species were identified and used for the present study. The biozonation is classified as assemblage zones or taxon range zones. The proposed zonation is correlated with previous works on Jurassic-Early Cretaceous foraminiferal biozones from Yemen, the Middle East, India and Canada.

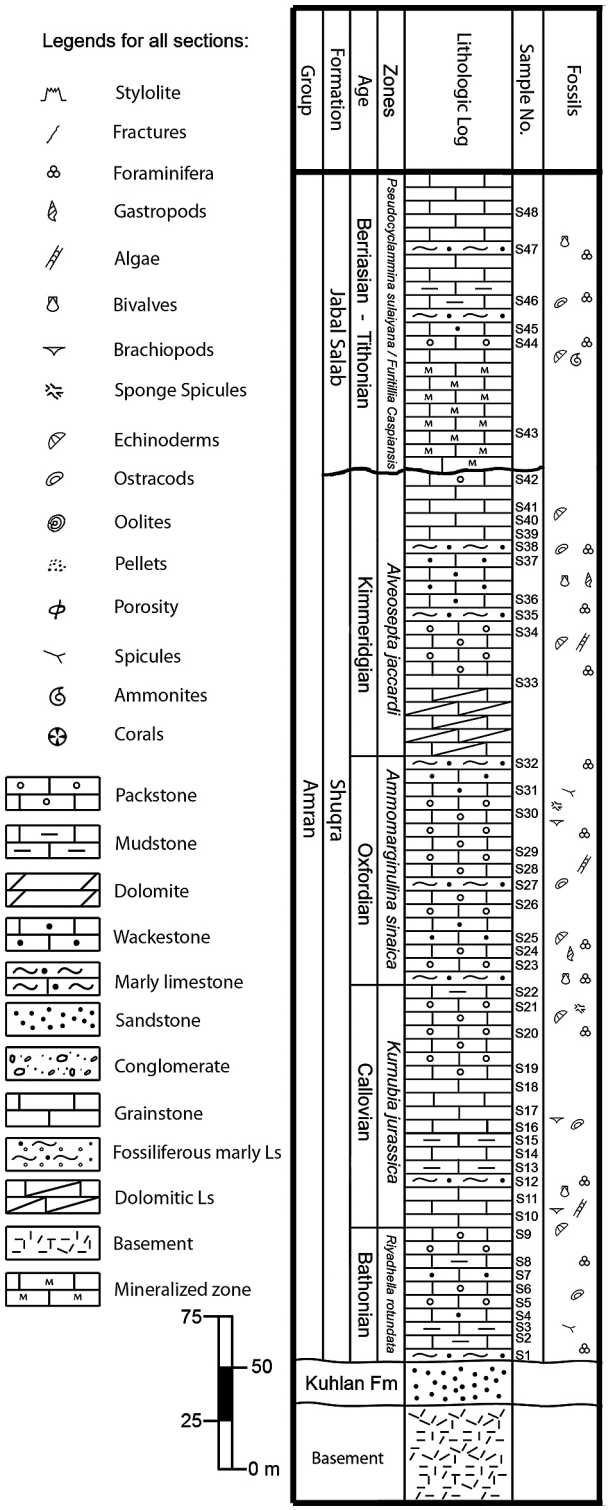
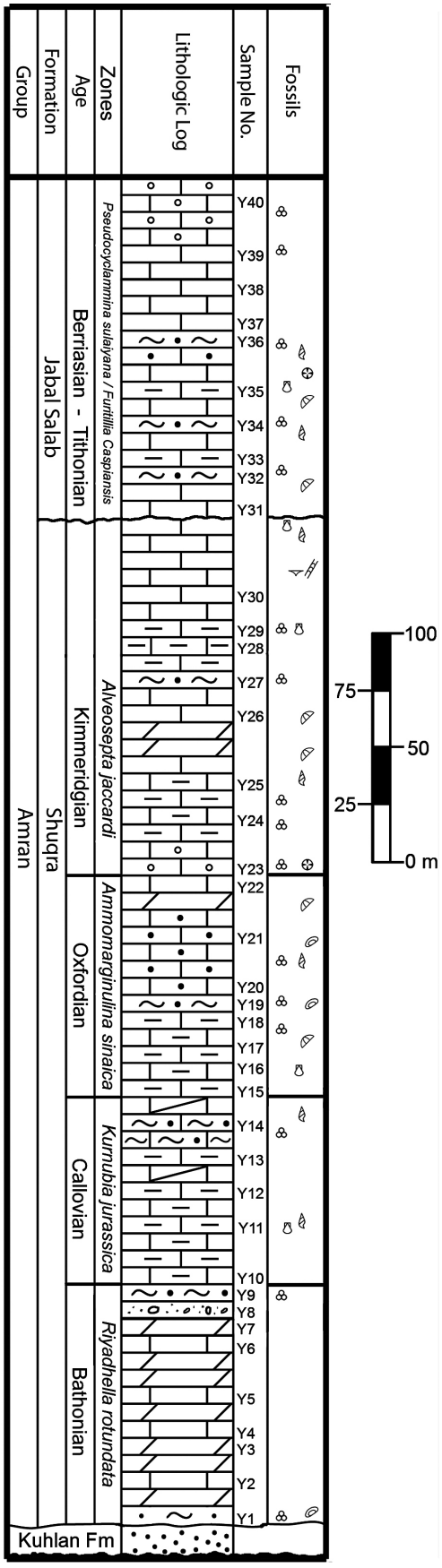


Fig. 2. Lithostratigraphic column of the Jabal Salab section, showing provenance of samples and distribution of the foraminiferal zones proposed.



4. Palaeontology

The Amran Group is a highly fossiliferous limestone sequence. Invertebrate fossils recorded during fieldwork including bivalves, gastropods, ammonites, belemnites and brachiopods. Micropalaeontological analysis of collected samples from studied sections has led to the identification of 123 foraminiferal species as well as sponge spicules, algal species (e.g., *Acicularia* sp., *Salpingoporella* sp. and *Revularia* sp.), bryozoans and ostracods. The recorded foraminiferal species are listed in Table 2 and their distribution in the Amran Group is shown in Table 3. The recorded foraminiferal species are represented by 67.4% textulariines, 0.81 miliolines, 25.2% lagenines, 2.43% involutines, 2.43% spirillines and 1.62% robertines (Table 2). The identified foraminiferal assemblage is characterised by a predominance of simple arenaceous and nodosariid species, a rarity of miliolines and the absence of planktonic forms (Table 2). This distribution is consistent with the distribution of foraminifera of the Middle Jurassic in the Middle East (Al-Saad, 2008).

The lower part of the sequence, which constitutes the lower part of the Shuqra Formation (*Riyadhella rotundata* Zone), contains arenaceous species with simple interiors. This, in addition to the rarity of calcareous forms, indicates that this part of the Shuqra Formation was deposited in a shallow, near-shore environment (Bandy, 1960, 1963; Gordon, 1970; Bhalla & Abbas, 1978; Grigelis & Ascoli, 1995; Grigelis & Norling, 1999). The middle portions of the Shuqra Formation (*Kurnubia jurassica* and *Ammomarginulina sinaica* zones) and the upper part (*Alveosepta jaccardi* Zone) are rich in both arenaceous and nodosariid species which suggests a moderately deep, open marine environment (Norton, 1930; Natland, 1933; Glaessner, 1945; Bielecka & Pożaryski, 1954; Wall, 1960; Redmond, 1964a, b; Bhalla & Abbas, 1978; Banner & Simmons, 1994; Grigelis & Ascoli, 1995; Grigelis & Norling, 1999). The uppermost part of the *Alveosepta jaccardi* Zone (upper part of the Shuqra Formation) and the *Pseudocyclammina sulaiyana/Furitillia caspiansis* Zone (Jabal Salab Formation), which constitute the upper part of the Amran Group, are characterised by a predominance of simple arenaceous forms and a rarity of calcareous ones which suggests a shallow, near-shore environment.

Fig. 3. Lithostratigraphic column of the Jabal Yam section, showing provenance of samples and distribution of foraminiferal zones proposed.

Table 2. Foraminiferal species recorded from the sections studied.

Suborders	Species	Species	Species
Textulariina	*Reophax densa* Tappan	*A. laevigatus* Lozo	*T. limbata* Kalantari
	R. sp.cf. helviticus Haeusler	*A. spongiphillus* Seibold & Seibold	*T.* sp. cf. *pullchra* Ziegler
	R. liasica Franke	*A. subaequalis* Myatliuk	*T. robusta* Ziegler
	R. metensis Franke	*A. subcretaceous* Cushman & Alexander	*T. squammata* Jones & Paker
	R. sterkii Haeusler	*A. suprajurassicum* Schwager	*Riyadhella regularis* Redmond
	R. suivicus Franke	*A. venustus* Loeblich & Tappan	*R. rotundata* Redmond
	Evolutinella darwini (Dain)	*Ammomarginulina aegyptiaca* Osman & Hassanein	*Paleogaudyina magharaensis* Said & Barakat
	E. subevoluta Nikitina & Myatliak	*Am. baryntica* Loeblich & Tappan	*Verneuilinoides gracious* Dain
	Haplophragmoides sp.cf. arabicus Hassan & Others	*Am. minuta* Osman & Hassanein	*V. minuta* Said & Barakat
	H. barrowensis Tappan	*Am. pullucida* Said & Brand	*V. neocomiensis* Myatliuk
	H. bartensteni Kalantari	*Am. sinaica* Osman & Hassanein	*V. tryphera* Loeblich & Tappan
	H. barthouxi Said & Barakat	*Haplophragmium aequala* (Roemer)	*V. zerqaensis* Basha
	H. circularis Said and Barakat	*Alveosepta jaccardi* (Schrodt)	*Gaudryina vadaszi* Cushman & Glazewski
	H. hagni Bhalla	*Al. Powersi* Redmond	*Verneuilina anglica* Cushman
	H. kingakensis Tappan	*Everticyclammina contorta* Redmond	*Pfenderina gracilis* Redmond
	H. tryssa Loeblich and Tappan	*E. eccentrica* Redmond	*P. inflata* Redmond
	Nautiloculina oolithica Mohler	*Bramkampella arabica* Redmond	*Steinekella steinekei* Redmond
	Ammobaculites alaskensis Tappan	*Feuritillia caspiansis* Kalantari	*Kurnubia jurassica* (Henson)
	A. alexanderi Cushman	*Pseudocyclammina rogalia* Cushman & Glazewski	*K. morissi* Redmond
	A. barrowensis Tappan	*P. sulaiyana* Redmond	*K. palastiniensis* Henson
	A. braunsteini Cushman & Applin	*Bimonilina variana* Eicher	*K. variabilis* Redmond
	A. cobbani Loeblich & Tappan	*Plectinella aegyptiaca* Said & Barakat	*Praekurnubia crusi* Redmond
	A. coprolithiformis (Schwager)	*Textulariopsis jurassica* (Gumbel)	*Marssonella oxycona* (Reuss)
	A. crespinae Bhalla	*Trochammina bartensteni* Said & Barakat	*Pseudomarsonella bipartita* Redmond
	A. fontinensis (Tappan)	*T. concava* Seibold & Seibold	*P. reflexa* Redmond
	A. hofkeri Bhalla	*T. conningensis* Tappan	*P. maxima* Redmond
	A. indicus Bhalla	*T. gryci* Tappan	*P. plicata* Redmond
	A. irregulariformis Bartenstein & Brand	*T. inflata* (Montagu)	
Involutinina	*Trocholina conica* (Schlumberger)	*T. delicatissima* Kalantari	*T. nodulsa* Seibold & Seibold
Spirillinina	*Spirillina amphilicata* Loeblich & Tappan	*S. infima* Strickland	*S. polygyrata* Gumbel
Miliolina	*Massilina rediclaffensis* Gordon		
Lagenina	*Dentalina plebeia* Terquem	*Saracenaria cornucopiae* (Schwager)	*Vaginulina composa* Loeblich & Tappan
	Nodosaria fontinensis Terquem	*S. triangularis* (D'Orbigny)	*Eoguttulina amygdalina* Loeblich & Tappan
	N. kuhni Franke	*Astacolus aphrastus* Loeblich & Tappan	*E. bilocularis* (Terquem)
	N. nitidana Brand	*A. crepidula* (Fichtel & Moll)	*E .inovroclaviensis* (Bielecka & Pozaryski)
	Frondicularia dentaliniformis (Terquem)	*A. pediacus* Tappan	*E. liasica* (Strickland)
	Lenticulin audax Loeblich & Tappan	*Vaginulinopsis enodis* Loeblich & Tappan	*E. polygona* (Tarquem)
	L. muensteri (Roemer)	*V. epicharis* Loeblich & Tappan	*E. triloba* (Terquem)
	L. quenstedti (Gumbel)	*V. misrensis* Said & Barakat	*Globulina lacrima* (Reuss)
	L. subalata (Reuss)	*Planularia anceps* (Terquem)	*G.* sp. cf. *prisca* Reuss
	L. varians (Bornemann)	*P. beierana* (Gumbel)	*Guttulina pera* Lalicker
			G. physalia Loeblich and Tappan
Robertinina	*Epistomina caracolla* (Roemer)	*Epistomina mosquensis* Uhlig	

5. Age and biostratigraphy

The biostratigraphy of the Amran Group in Yemen was studied by Al-Wosabi (1993), who used the foraminiferal species that were recorded from the Jabali area, east of Sana'a, and by Simmons & Al-Thour (1994), who constructed a biozonal scheme on the basis of foraminiferal and algal contents from the western areas of Sana'a region. The succession of the Amran Group in the sections studied includes the Shuqra and Jabal Salab formations. The total count of identified foraminiferal species from the two studied sections reaches 123. Ninety-eight species are recorded from Jabal Yam and one hundred and three from Jabal Salab with some duplication. The stratigraphical range of these species was restricted between Bathonian (Middle Jurassic) and Berriasian (Early Cretaceous) (Table 3). Biostratigraphic subdivision of the Amran Group based on foraminiferal data does not provide high-resolution zones which is a result of the slower rate of evolution of Jurassic foraminifera, which is substantiated by rather long geological ranges for most of the species. However, within a basin, local associations and their distribution provide a fair basis for biostratigraphic classification. Few of the recorded species displayed a wide range; two examples are *Reophax suevica* Franke "Rhaetian–Tithonian" and *Lenticulina muensteri* (Roemer) "Rhaetian-Hauterivian". Several of the recorded species were considered index species ranging in age from Late Jurassic to earliest Cretaceous, particularly in Middle East countries, including *Bramkampella arabica* Redmond and *Pseudocyclammina sulaiyana* Redmond. On the other hand, there are many species which recorded as an index fossils of the Middle-Late Jurassic such as *Kurnubia jurassica* Henson, *K. palastinensis* Henson, *K. morissi* Redmond, *K. variabilis* Redmond, *Pfenderina gracilis* Redmond, *P. inflata* Redmond, *Stienekella stienekei* Redmond, *Pseudomarssonella bipartita* Redmond, *P. maxima* Redmond, *P. plicata* Redmond, *P. reflexa* Redmond, *Riyadhella regularis* Redmond, *R. rotundata* Redmond, *Reophax helveticus* Häusler, *Haplophragmoides arabicus* Hassan, Hassanien & Abd El-Shafy, *H. barthoxi* Said & Barakat, *H. circularis* Said & Barakat, *Ammomarginulina pullucida* Said & Barakat, *Plectinella aegyptiaca* (Said & Barakat), *Vaginulina misrensis* Said & Barakat, *Ammobaculites braunsteini* Cushman and Applin, *A. cobbani* Loeblich & Tappan, *A. venustus* Loeblich & Tappan, *Ammomarginulina baryntica* Loeblich & Tappan, *Astacolus aphrastus* Loeblich & Tappan, *Vaginulina composa* Loeblich and Tappan, *Eoguttulina amygdalina* Loeblich and Tappan, *Alveosepta jaccardi* (Schrodt), *A. powersi* Redmond, *Ammomarginulina aegyptiaca* Said and Barakat, *A. minuta* Osman & Hassanein, *A. sinaica* Osman & Marzouk, *Textulariopsis jurassica* (Gümbel) and many other species.

Based on the vertical distribution of the recorded foraminifera, i.e., first appearance, last disappearance of a certain species and abundance of some species in the sequence, five biozones were recognised (Table 3). In ascending order, these zones are: *Riyadhella rotundata* Zone, *Kurnubia jurassica* Zone, *Ammomarginulina sinaica* Zone, *Alveosepta jaccardi* Zone and *Pseudocyclammina sulaiyana/Furtillia caspiansis* Zone. The proposed zones find confirmation in earlier papers by different researchers such as Kalantari (1969), Souaya (1976), Hassan et al. (1978), Kalia & Chowdhury (1983), Abd El-Shafy (1984),Williams et al. (1990), Al-Wosabi (1993, 2001, 2005), Simmons & Al-Thour (1994), Kuznetsova et al. (1996), Hewaidy & Al-Saad (2000), Al-Saad (2008) and Sarfi & Yazdi-Moghadam (2016).

5.1. *Riyadhella rotundata* Zone

This zone was introduced by Kalia & Chowdhury (1983) in the Bathonian of India. The base of the *Riyadhella rotundata* Zone equates with the first appearance of *Riyadhella rotundata* Redmond, while the top is marked by the disappearance of the foraminiferal species of the *Riyadhella rotundata* Zone and the first appearance of *Kurnubia palastinensis* Henson. Conspicuous species in this zone are *Astacolus pediacus* Tappan, *Nodosaria fontinensis* Terquem, *N. kuhni* Franke, *Dentalina plebae* Terquem, *Trochammina bartensteini* Said & Barakat, *T. robusta* Ziegler, *Ammobaculites braunsteini* Cushman & Applin, *Trocholina delicatissima* Kalantari, *Riyadhella regularis*, *Haplophragmoides barthoxi*, *H. barrowensis* Tappan, *Reophax liasica* Terquem, *R. suevica* Franke, *Paleogaudryina magharaensis* Said & Barakat, *Pfenderina inflata* Redmond, *Verneuilinoides zerqaensis* Basha, *V. minuta* Said & Barakat, *Eoguttulina bilocularis* (Terquem), *Lenticulina varians* Bornemann, *Frondicularia dentaliniformis* (Terquem), *Ammobaculites venustus* Loeblich and Tappan, *A. suprajurassicum* (Schwager), *A. fontinensis* (Terquem), *A. barrowensis* Tappan, *A. alaskensis* Tappan, *A. cobbani*, *Planularia beierana* (Gümbel) and *Pseudomarssonella reflexa* Redmond. This zone represents the lower part of the Shuqra Formation in the sections studied and is of Bathonian age (Table 3).

5.2. *Kurnubia jurassica* Zone

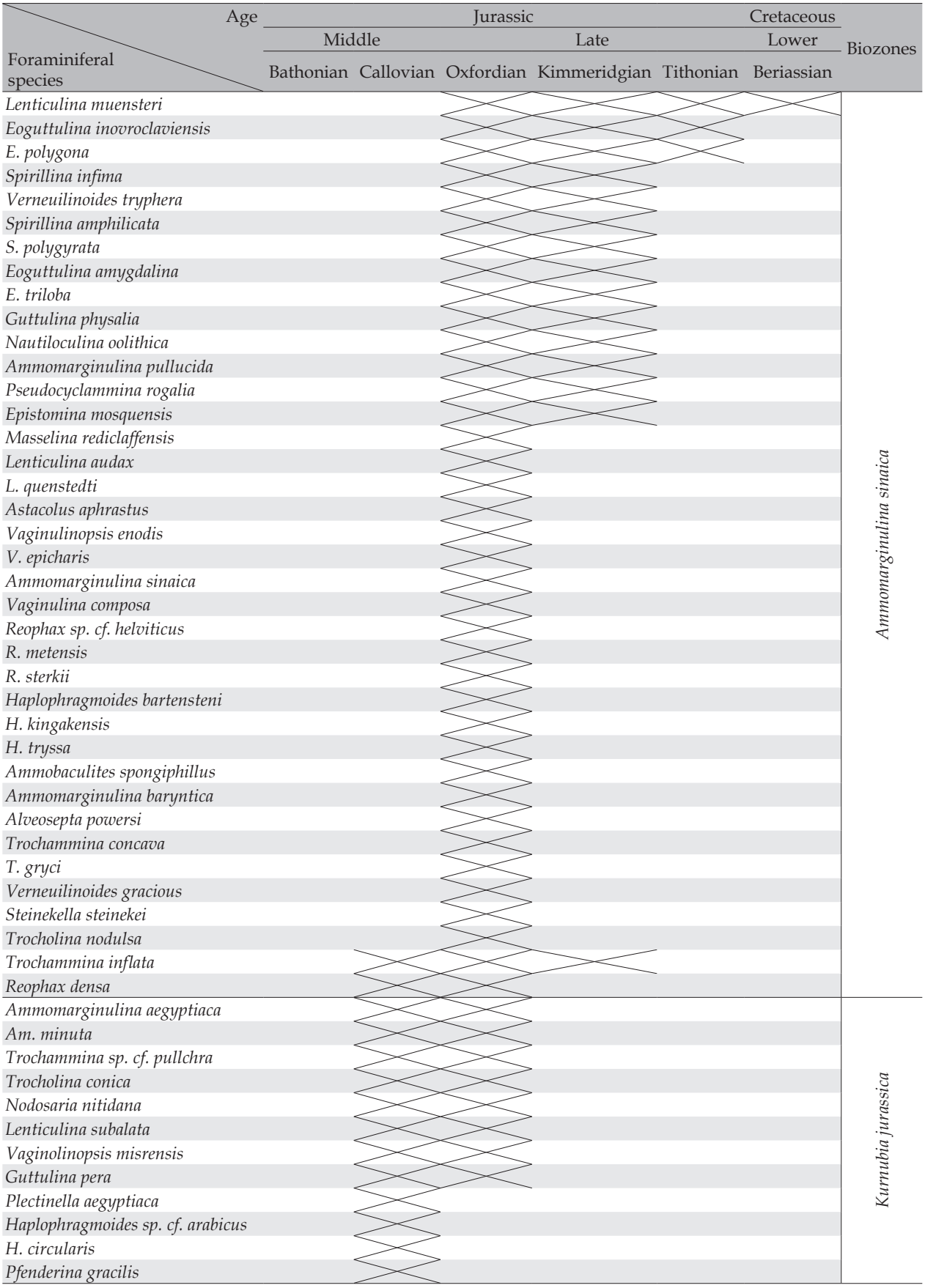
The base of this zone equates with the first appearance of *Kurnubia* species, which is considered

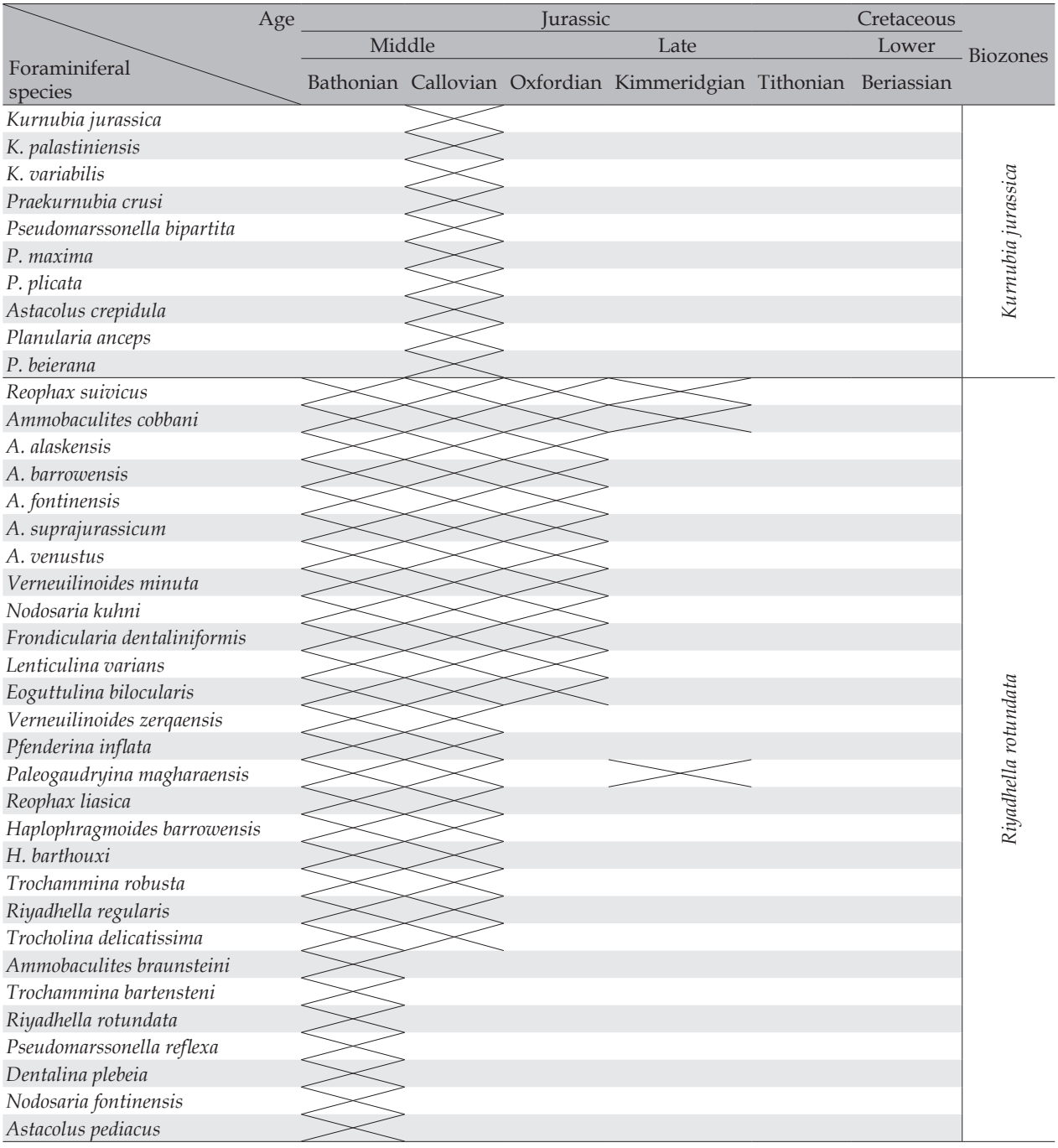
an index species of the Middle-Upper Jurassic in the Middle East. The upper limit of this zone is taken at the disappearance of *Kurnubia jurassica* and the first appearance of *Ammomarginulina sinaica* Osman and Hassanein. This zone is rich in *Kurnubia palastinensis* Henson, *K. jurassica*, *K. variabilis* Redmond, *Planularia anceps* (Terquem), *Astacolus crepidula* (Fichtel & Mole), *Guttulina pera* Lalicker, *Vaginulinopsis misrensis* Said & Barakat, *Lenticulina subalata* Reuss, *Nodosaria nitidana* Brand, *Ammomarginulina aegyptiaca* Said and Barakat, *A. minuta*, *T. inflata* (Montagu), *Trochammina* sp. cf. *pullchra* Ziegler, *Trocholina conica* Schlumberger, *Plectinella aegyptiaca* (Said & Barakat), *Haplophragmoides* sp. cf. *arabicus* Hassan, Hassanein and Abd El-Shafy, *H. circularis*, *Pfenderina gracilis* Redmond, *Praekurnubia crusi* Redmond, *Pseudomarssonella bipartita*, *P. maxima, P. plicata* Redmond and *Reophax densa* Tappan.

The *Kurnubia jurassica* Zone can be correlated with *Trocholina* spp / *Kurnubia palestiniens* of Simmons & Al- Thour (1994), which were identified in the upper Callovian of the Sana'a region and with the *Kurnubia variabilis* Zone of Al-Wosabi (1993). In addition, this zone is equivalent to the *Kurnubia jurassica* Zone (Hassan et al., 1978; Abd El-Shafy, 1984), the *Kurnubia palastinensis* Zone (El-Badry et

Table 3. Foraminiferal biozonation of the Amran Group in the study area.

Age / Foraminiferal species	Jurassic					Cretaceous	Biozones
	Middle			Late		Lower	
	Bathonian	Callovian	Oxfordian	Kimmeridgian	Tithonian	Beriassian	
Ammobaculites sp. cf. crespinae							*Pseudocyclammina sulaiyana/Furitillia caspiansis*
A. irregulariformis							
Haplophragmium aequala							
Everticyclammina contorta							
E. eccentrica							
Feurtillia caspiansis							
Trochammina limbata							
Globulina sp. cf. lacrima							
G. sp. cf. Prisca							
Epistomina caracolla							
Ammobaculites hofkeri							
A. indicus							
A. subcretaceous							
Bramkampella arabica							
Psudocyclammina sulaiyana							
Bimonilina variana							
Trochammina conningensis							
T. squammata							
Verneuilinoides sp. cf. neocomiensis							
Marssonella oxycona							
Saracenaria triangularis							
Saracenaria cornucopiae							*Alveosepta jaccardi*
Evolutinella darwini							
E. subevoluta							
Ammobaculites alexanderi							
A. coprolithiformis							
Textulariopsis jurassica							
Haplophragmoids hagni							
Ammobaculites laevigatus							
Eoguttulina liasica							
Gaudryina vadaszi							
Ammobaculites subaequalis							
Alveosepta jaccardi							
Verneuilina anglica							
Kurnubia morissi							


Age
Jurassic
Cretaceous
Middle
Late
Lower
Foraminiferal species
Bathonian
Callovian
Oxfordian
Kimmeridgian
Tithonian
Beriassian
Biozones
Lenticulina muensteri
Eoguttulina inovroclaviensis
E. polygona
Spirillina infima
Verneuilinoides tryphera
Spirillina amphilicata
S. polygyrata
Eoguttulina amygdalina
E. triloba
Guttulina physalia
Nautiloculina oolithica
Ammomarginulina pullucida
Pseudocyclammina rogalia
Epistomina mosquensis
Masselina rediclaffensis
Lenticulina audax
L. quenstedti
Astacolus aphrastus
Vaginulinopsis enodis
V. epicharis
Ammomarginulina sinaica
Vaginulina composa
Reophax sp. cf. helviticus
R. metensis
R. sterkii
Haplophragmoides bartensteni
H. kingakensis
H. tryssa
Ammobaculites spongiphillus
Ammomarginulina baryntica
Alveosepta powersi
Trochammina concava
T. gryci
Verneuilinoides gracious
Steinekella steinekei
Trocholina nodulsa
Trochammina inflata
Reophax densa
Ammomarginulina aegyptiaca
Am. minuta
Trochammina sp. cf. pullchra
Trocholina conica
Nodosaria nitidana
Lenticulina subalata
Vaginolinopsis misrensis
Guttulina pera
Plectinella aegyptiaca
Haplophragmoides sp. cf. arabicus
H. circularis
Pfenderina gracilis
Ammomarginulina sinaica
Kurnubia jurassica



al., 1981) and the *Kurnubia gigantea* Zone (Abd El-Shafy & Ibrahim, 1987) in Egypt. This zone represents the beginning of the middle part of the Shuqra Formation and is of Callovian age (Table 3).

5.3. *Ammomarginulina sinaica* Zone

The present zone was established by Hassan et al. (1978) in Egypt and later also documented by El-Badry et al. (1981) and Abd El-Shafy (1984). The *Ammomarginulina sinaica* Zone is of Oxfordian age in the study area. It starts with the first appearance of *Ammomarginulin asinaica*. This is the richest zone as far as foraminiferal content is concerned in the sections studied. Some species, which appeared in the underlying zones, are still present in this zone together with newly appearing forms. The foraminiferal species which characterise this zone include *Trocholina nodulsa* Seibold & Seibold, *Steinekella steinekei* Redmond, *Verneuilinoides gracious* Dain, *V. tryphera* Loeblich & Tappan, *Trochammina concava*

Table 4. Correlation of foraminiferal biozones of the Middle Jurassic–Lower Cretaceous in Yemen and other countries.

Age		Author(s) & locality	Kalantari (1969) Iran	Suaya (1976) Canada	Hassan et al. (1978) Egypt	Kalia & Chowdhury (1983) India	Abd El-Shafy (1984) Egypt	Williams et al. (1990) Canada	Kuznetsova et al. (1991), Syria				Al-Wosabi (1993) Yemen	Simmons & Al-Thour (1994) Yemen	Hewaidy & Al-Saad (2000) Eastern Arabia	Sarfi1 & Yazdi-Moghadam (2016), Iran	Present study
									Anti-Lebanon	Coastal Mountains	Kurd-Dag	Palmyrides					
Cretaceous	Berriasian			*Cuneolinamiina bensoni / Pseudocyclammi-na littus*	*Lenticulina turgidula*								*Epistomina aff. Minutereticulata / E. sp / Haplophragmoides concavus*				*Feuritilla caspiansis / Pseudocyclam-mina sulayana*
Jurassic Jur.	Tithonian		*Chofatella decipiens / Iberina lucitanica*	*Haplophragmoi-des kingakensis*		Barren zone		*Epistomina parastelligera / E. stellicoststs / Archispirocy-clina lusitanica / Ammobaculites coprolithiformis*	*Anchispirocyclina lusitanica*	*Bramkampella arabica Beds*			*Ammobaculites laevigatus*	*Everticyclammina virgulina*			
	Kimmeridgian		*Trocholina conica / T elongate / Kurnubia jurassica / K. palestiniens / Clypeina jurassica*	*Gaudryna milleri*		*Ammobaculites* sp.		*Epistomina mosquensis / Planularia tricarinella / neotrocholina solecensis /*	*Alveosepta personata*	*Alveosepta personata Beds*				*Everticyclammina virgulina II*		*Alveosepta jaccardi*	*Alveosepta jaccardi*
														Alveosepta powersi / Everticyclammina virgulina I			
	Oxfordian		*Trocholina nodulsa / Ammobaculites spongiphilus / A. subcretaceous / Saracenella triquarta / Guttulina barnardi / Lenticulina audax*	*Ammobaculites venustus*	*Ammomarginul-ina sinaica / Citharina flabellata*		*Ammomargin-ulina sinaica / Citharina flabella*	*Globuligerina oxfordiana / Conorboides paraspis / Epistomina soldani*	*Alveosepta jaccardi / Lenticu-lina quenstedti*	*Globuligerina oxfordiana / Alveosepta jaccardi*		*Globuligerina oxfordiana*	*Vaginulina epicharis*	*Alveosepta jaccardi*		*Ammomargin-ulina sinaica*
								Epistomina omninoreticulata / E. regularis / E. coronate / Trocholina conica / Globuligerina bathoniana	*Lenticulina brueckmanni / Globuligerina oxfordiana*					*Trocholina spp / Kurnubia palestiniens*			
	Callovian		*Brotzenia mosquensis / B. cf. limbata / B. parastelligera / Arenovirgulina aegyptiaca / Paleogaudryna magharaensis / Vernulina minuta*	*Lenticulina audax / Nodosaria linulata*	*Haplophragmoi-des qattaraensis / Kurnubia jurassica / Steinekella steinekei*	*Dentalina gumbeli / Marginulina batrakensis / Astacolus aphrastus / Saracenaria phaedra / Epistomina ghoshi / Globigerina helvetojurassica*	*Haplophragmo-ides qattaraensis / Kurnubia jurassica / Steinekella steinekei*		*Kurnubia palestiniens / Globuligerina callovianensis*	*Kurnubia palastiniensis /Pfenderina salernitana*		*Unfossiliferous*	*Kurnubia variabilis / Pfendrina gracilis*		*Kurnubia variabilis*		*Kurnubia jurassica*
													Trocholina delicatissima	*Praekurnubia crusei / Kurnubia palestiniensis*			
	Bathonian		*Pfenderina neocomiensis / P. selemitana / Hauronia amiji / H. deserta / Kialianina blancheti*		*Ammodiscus orbis / Pseudomarss-onella media*	*Pseudomarss-onella bipartite / P. inflate / Riyadhella rotundata*	*Trocholina palestiniensis / Ammodiscus orbis*		*Lenticulina polymorpha / Globuligerina bathoniana*	Unexposed	*Kialianina blanchiti / Meyendorffina bathonica*	*Haurania desertia / Protopeneroplis striata*			*Pfenderina gracilis / Pfenderella arabica*		*Riyadhella rotundata*
															Riyadhella arabica		
															Dhrumella evoluta		
															Pseudomarssonella bipartita		
	Bajocian		*Pseudoglandulina bajociana / Brotzenia costitera / B. irregularis / Lenticulina polymorpha / Astacolus stilla / Trocholina delicatissima / Lingulina bamardi*	*Ammodiscus* sp. Cf. *A. baticus*	*Involutina aspes / Ammobaculites chapplensis*		Barren zone		*Lenticulina volubilis / Epistomina coronata*	Unexposed					*Trocholina minuta*		
														Haurania deserta / Amijella amiji			
									Praelamarckina humilis	*Lenticulina "polymorpha"*							

Seibold & Seibold, *T. gryci* Tappan, *Ammomarginulina baryntica* Loeblich & Tappan, *A. pullucida* Said & Barakat, *Ammobaculites spongiphilus* Seibold & Seibold, *Haplophragmoides tryssa* Loeblich & Tappan, *H. kingakensis* Tappan, *H. bartensteini* Kalantari, *Reophax sterkeii* Häusler, *R. metensis* Franke, *R.* sp. cf. *helviticus* Häusler, *Pseudocyclammina rogalai* Cushman & Glazewski, *Nautiloculina oolithica* Mohler, *Eoguttulina inovroclaviensis* (Bielicka & Pożaryski), *E. polygona* (Terquem), *Lenticulina muensteri* (Roemer), *L. audax* Loeblich & Tappan, *L. quenstedti* (Gümbel), *Spirillina amphilicata* Loeblich & Tappan, *S. polygyrata* Gümbel, *S. infima* (Strickland), *Massilina rediclaffensis* Gordon, *Astacolus aphrastus* Loeblich & Tappan, *Vaginulinopsis enodis* Loeblich & Tappan and *V. epicharis* Loeblich & Tappan.

This zone can be correlated in part with the *Trocholina* spp./*Kurnubia palastinensis* Zone and with the *Alveosepta jaccardi* Zone of Simmons & Al-Thour (1994) and *Vaginulinopsis epicharis* Zone of Al-Wosabi (1993). This zone is of Oxfordian age in the study area and characterises the middle part of the Shuqra Formation (Table 3).

5.4. *Alveosepta jaccardi* Zone

This zone is equivalent to the *Everticyclammina virgulina* I, *Alveosepta powersi* and *Everticyclammina* II Zone of Simmons and Al-Thour (1994) and to the *Ammobaculites laevigatus* Zone of Al-Wosabi (1993).

The *Alveosepta jaccardi* Zone was used previously by Ascoli (1981, 1988) and Williams et al. (1990) to characterise the Kimmeridgian of Canada and Sarfi & Yazdi-Moghadam (2016) as a late Oxfordian-early Kimmeridgian zone in northwest Iran.

This zone begins with the disappearance of *Ammomarginulia sinaica* and the first appearance of *Alveosepta jaccardi*. The upper limit of this zone equates with the first appearance of *Pseudocyclammina sulaiyana* Redmond and the foraminiferal species that belong to the youngest zone of the Amran Group. Conspicuous foraminiferal species within this zone are *Kurnubia morissi*, *Verneuilina anglica* Cushman, *Alveosepta jaccardi* and *Ammobaculites subaequalis* Myatliuk, *A. laevigatus* Lozo, *A. alexanderi* Cushman, *A. coprolithiformis* Schwager, *Gaudryina vadaszi* Cushman & Glazewski, *Haplophargmoides hagni* Bhalla, *Evolutinella darwini* Dain, *E. subevoluta* Nikitina & Myatliuk, *Textulariopsis jurassica* (Gümbel), *Eoguttulina liasica* (Strickland) and *Saracenaria cornucopiae* (Schwager). Several species represented in this zone continue into the overlying *Pseudocyclammina sulaiyana/Feurtillia caspiansis* Zone. This zone is of Kimmeridgian age and represents the upper part of Shuqra Formation (Table 3).

5.5. *Pseudocyclammina sulaiyana/Feurtillia caspiansis* Zone

This zone includes many foraminiferal species that are held typical of the uppermost Jurassic and lowermost Cretaceous such as *Pseudocyclammina sulaiyana* Redmond, *Bramkampella arabica* Redmond, *Everticyclammina contorta* Redmond, *E. eccentrica* Redmond, *Trochammina limbata* Kalantari, *Feurtillia caspiansis* Kalantari, *Haplophragmium aequala* (Roemer), *Ammobaculites alexanderi* Cushman, *A. indicus* Bhalla, *A. hofkeri* Bhalla, *A.* sp. cf. *crespinae* Bhalla, *Epistomina caracolla* (Roemer), *Globulina lacrima* (Reuss), *Evolutinella subevoluta* Nikitina & Myatliuk and *E. darwini* Dain. The base of this zone equates with the appearance of *Pseudocyclammina sulaiyana* and its top is defined by the disappearance of the foraminiferal species of the Amran Group. The age of this zone is latest Jurassic (Tithonian)-earliest Cretaceous (Berriasian) (Table 3).

6. Correlations

The foraminiferal biozonation of the Middle Jurassic–Lower Cretaceous in the study area is correlated with previously proposed foraminiferal biozones by different workers locally in Yemen and regionally in different regions (Table 4). In Yemen, this biozonation often corresponds with that of Al-Wosabi (1993) and Simmons and Al-Thour (1994) which have been based on benthic foraminifera and algal contents. Regional correlation is based on previously published papers for different regions such as Iran (Kalantari, 1969; Sarfi & Yazdi-Moghadam, 2016), Canada (Souaya, 1976; Williams et al., 1990), Egypt (Hassan et al., 1978; Abd El-Shafy, 1984), India (Kalia & Chowdhury, 1983), Syria (Kuznetsova et al., 1996) and eastern Saudi Arabia (Hewaidy & Al-Saad, 2000).

7. Conclusions

The foraminiferal biozonation of the Amran Group in the study area is introduced on the basis of 123 foraminiferal species from the samples collected. These biozones include four taxon range zones (*Riyadhella rotundata*, *Kurnubia jurassica*, *Ammomarginulin asinaica* and *Alveosepta jaccardi* zones) as well as a single assemblage zone, *Pseudocyclam-*

mina sulaiyana/Furitilla caspiansis Zone. These zones are restricted in age between the Bathonian and Berriasian. This biozones are correlated with equivalent zones in Yemen and some Tethyan regions.

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