

Late Ordovician agglutinated foraminifera from the Ra'an Shale Member, Qasim Formation of Saudi Arabia as indicators of the O40 Maximum Flooding Surface

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ABSTRACT: We report the first finding of Late Ordovician Foraminifera recovered from the Ra'an Shale Member exposed in the Qassim region of Saudi Arabia. The foraminiferal assemblages consist entirely of agglutinated forms, predominantly monothalamids dominated by the genus *Thuramminoides*. Additionally, rare specimens of two-chambered, pseudochambered, and multichambered forms are also found in the assemblages. The O40 maximum flooding surface is placed at the level of maximum diversity of agglutinated foraminifera. The occurrence of the genus *Subreophax* in the Ra'an Shale Member revises the known evolutionary history of the pseudomultichambered agglutinated foraminifera.

Key words: Ordovician, Foraminifera, Ra'an Shale Member, Qasim Formation, Saudi Arabia.

INTRODUCTION

The Lower Paleozoic formations in Central Saudi Arabia consist mostly of siliciclastic sediments; sandstone interbedded with shale members that are interpreted as representing the maximum flooding surfaces (MFS) (Droste 1997; Sharland et al. 2001). In the Ordovician, the Qasim Formation contains two shale members; the Hanadir Shale Member assigned to the early Middle Ordovician and the Late Ordovician Ra'an Shale Member. These shale members contain the regional O30 and O40 maximum flooding surfaces (text-fig. 1). Foraminifera from these shale members are poorly known, yet these microfossils have the potential for accurately pinpointing the MFS. The only previously published study of Ordovician agglutinated foraminifera in the Middle East is the report by Nestell et al. (2016) from the Middle Ordovician of Iran.

In this study we collected samples from the Ra'an Member near its type locality at Al-Qaraa (26° 23' 15.84" N, 43° 45' 38.50" E) in the Qassim District of central Saudi Arabia (text-fig. 2). The section selected for this study is part of the outcrop belt that trends northwest-southeast in the Qasim-Buraydah area. The purpose of this paper is to report the occurrence and taxonomy of Late Ordovician agglutinated foraminifera from Saudi Arabia. This study represents the first report of foraminifera recovered from the Ra'an Member of Saudi Arabia.

Geological Setting

During the Ordovician, much of present-day Saudi Arabia occupied a mid-latitude position at ca. 45°S on the Gondwanan continent (Golonka et al. 2006). During the Middle to Late Ordovician the area experienced marine stable shelf conditions that persisted until the latest Ordovician. A major marine transgression and maximum flooding occurred during the Middle Ordovician resulting in the deposition of the basal shale mem-

ber (Hanadir Shale) of the Qasim Formation (Williams et al. 1986; Vaslet 1990).

The Qasim Formation consists of two coarsening upward prograding sequences, outcropping as a northwest-southeast trending belt along the northern and northeastern margins of the Arabian Shield (e.g., Senalp and Al-Duaiji 2001). The basal marine Hanadir Shale and the overlying Kahfah Sandstone Members (Williams et al. 1986; Vaslet 1990) represent the lower sequence whereas the upper sequence is comprised of the Ra'an Shale and Quwarah Sandstone Members. Each of the depositional sequences commenced with maximum flooding surfaces. The MFS O30 is recognized close to the base of the Hanadir Shale and the MFS O40 is placed near the base of the Ra'an Shale (e.g., Sharland et al. 2001; Senalp and Al-Duaiji 2001).

A long ridge of the Ra'an Shale Member outcrops in its type locality in Khashm ar Ra'an cuesta in Habashi Quadrangle (e.g., Senalp and Al-Duaiji 2001). The Ra'an Shale is named after Khashm ar Raan and was first described as "the Middle shale" (e.g., Pocok and Kobb 1949), whereas Powers (1968) described it as an informal Unit 3 of the Tabuk Formation. Helal (1964; 1965) described it as the *Diplograptus* Shale Member. Al-Laboun (1986) proposed the name Ra'an Shale Member of the Qasim Formation.

A 40-m thick succession of the Ra'an Shale Member was measured at its type locality at Khashm ar Ra'an (Halwani 2001; Senalp and Al-Duaiji 2001; Saudi Stratigraphic Commission 2013), and it reaches up to 90 m thick in its reference section in the Tabuk region (Halwani 2001). The basal 3.5 m portion of the outcrop at the type locality consists of grey to dark-grey, finely laminated, fissile shale and dark brown, micaceous, graptolite-rich siltstone beds (Senalp and Al-Duaiji 2001; Saudi Stratigraphic Commission 2013). This basal unit is overlain by a 27-m thick gypsum bearing dark grey, fissile shale, silty shales and

claystone (Saudi Stratigraphic Commission 2013). The topmost ~9.5 m of the sequence is comprised of grey silty claystone, and partially burrowed to bioturbated siltstone and fine-grained clayey sandstone (Senalp and Al-Duaiji 2001; Saudi Stratigraphic Commission 2013).

In outcrop, the Ra'an Shale Member conformably overlies the nearshore Kahfah Sandstone and in turn, is overlain by the Quwarah Sandstone Member. In places, it is deeply incised by the Late Ordovician glacial paleochannels of the Zarqa and Sarah formations. Its contact with the underlying Kahfah is defined by the occurrence of dark shale beds on top of the thick bioturbated (Scolithos-bearing) Kahfah Sandstone. Its upper boundary is gradational and is delineated by the basal occurrence of sandstone interbedded with minor shale beds of the Quwarah Sandstone (Senalp and Al-Duaiji 2001).

The Ra'an Shale has been interpreted to have been deposited in a quiet outer shelf to lower shoreface setting below wave base and was assigned to the lower part of the Upper Ordovician (Katian) based on graptolites, conodonts, chitinozoans, and trilobites (Williams et al. 1986; McClure 1978; Paris et al. 2000; Al-Shawareb et al. 2017). McClure (1978) reported the Katian graptolite species *Diplograptus* ex gr. *vulgatis* Perner, *Glyptograptus* sp., and *Amplexograptus* sp. from the Ra'an Shale in the Baq'a district. The recovery of the chitinozoan species *Tanuchichitina fistulosa* (Taugourdeau and de Jekhowsky) in the Ra'an Shale (Paris et al. 2000) indicates the age of the Ra'an Shale Member is not younger than early Katian (Al-Shawareb et al. 2017).

Outcrop Description

A 13.6 m thick outcrop section of the upper part of the Ra'an Shale Member is exposed within the Quwarah Member type locality at Kashm Al-Madbaah cuesta near Al Qaraa, situated about 3 km north of the campus of Qassim University (text-figure 3). The section is accessible via a farm road leading from Saudi Route 6260 near the water tower on the east side of Al Qaraa. The exposed section (latitude 26°23'14.75"N; longitude 43°45'42.21"E) was stratigraphically described, logged and sampled for microfossils. The unit in outcrop appears to have been deposited as three depositional cycles or subunits, regarded by Senalp and Al-Duaiji (2001) as parasequences. Each of the subunits is capped by siltstone or a fine-grained sandstone bed. The basal unit consists of a 3 m thick dark grey to grey laminated indurated shale intervened by thin (2–5 cm thick) siltstone beds. The lowermost 1 m of this subunit has gypsum layers and infillings. A fine-grained sandstone intercalated with thin shale laminae described from 2.77–2.99 m, caps this depositional subunit. Seven micropaleontological samples were collected from the basal subunit.

This basal subunit is overlain by a ~3.5 m thick light grey, pinkish to brownish laminated shale intercalated by thin siltstone beds. The 1–2 cm siltstone beds which occur at every 5 to 10 cm are concentrated within the topmost 1.5 m of the interval. A 19 cm thick siltstone to fine sandstone occurring at 6.70 m marks the top of this depositional subunit. Seven micropaleontological samples were collected from this subunit.

The sequence changes to weathered, purple, greyish, graptolite bearing, laminated silty claystone and light grey shale intercalated with thin siltstone laminae at 6.99 m. A 7 cm thick bioturbated siltstone to fine-grained sandstone occurs at 9.56 m, and it is overlain by a 1 m thick homogenous claystone. The up-

permost seven samples were collected from this subunit. The uppermost 3 m of the outcrop section is capped by a white to yellowish, bioturbated (*Cruziana*-bearing), partly rippled cross laminated siltstone to fine grained sandstone bed that contains ferruginous concretions.

METHODS

Approximately 1 kg samples were collected from the Ra'an Shale in the outcrop. Samples were disaggregated by boiling with a small amount of dishwashing liquid, sieved over a 63 micron screen. Dried residues were picked from the >125 micron fraction. In total, 21 samples were examined in this study. Specimens were photographed using a digital camera attached to a Nikon SMZ-1500 binocular microscope. Specimen slides (currently in the author's collection at KFUPM) will be permanently archived in the European Micropalaeontological Reference Center, Micropress Europe, in Kraków Poland.

RESULTS

The recovered assemblage of agglutinated foraminifera from the Ra'an Shale Member consists of common monothalamids strongly dominated by the genus *Thuramminoides*, rare two-chambered or pseudochambered tubothalamids such as *Hyperammina* and *Subreophax* and single specimens of multichambered globothalamids (the genus *Reophax*). Foraminiferal abundance and diversity is highest in the lower subunit of the sampled section, and both faunal parameters decrease markedly upsection (Table 1). A total of 18 species belonging to 12 genera were found in the studied samples.

SYSTEMATICS

In the following section we use the systematics of agglutinated foraminifera published by Kaminski (2014).

Class FORAMINIFERA d'Orbigny 1826
Subclass MONOTHALAMANA Pawlowski, Holzmann and Tyszkiewicz 2013
Order ASTORRHIZIDA Lankester 1885
Suborder ASTORRHIZINA Lankester 1885
Family RHABDAMMINIDAE Brady 1884
Genus *Rhabdammina* M. Sars in Carpenter 1869

Rhabdammina trifurcata Moreman 1933

Plate 1, figure 1

Rhabdammina trifurcata MOREMAN 1933, p. 394, pl. 47, figs 1, 2.

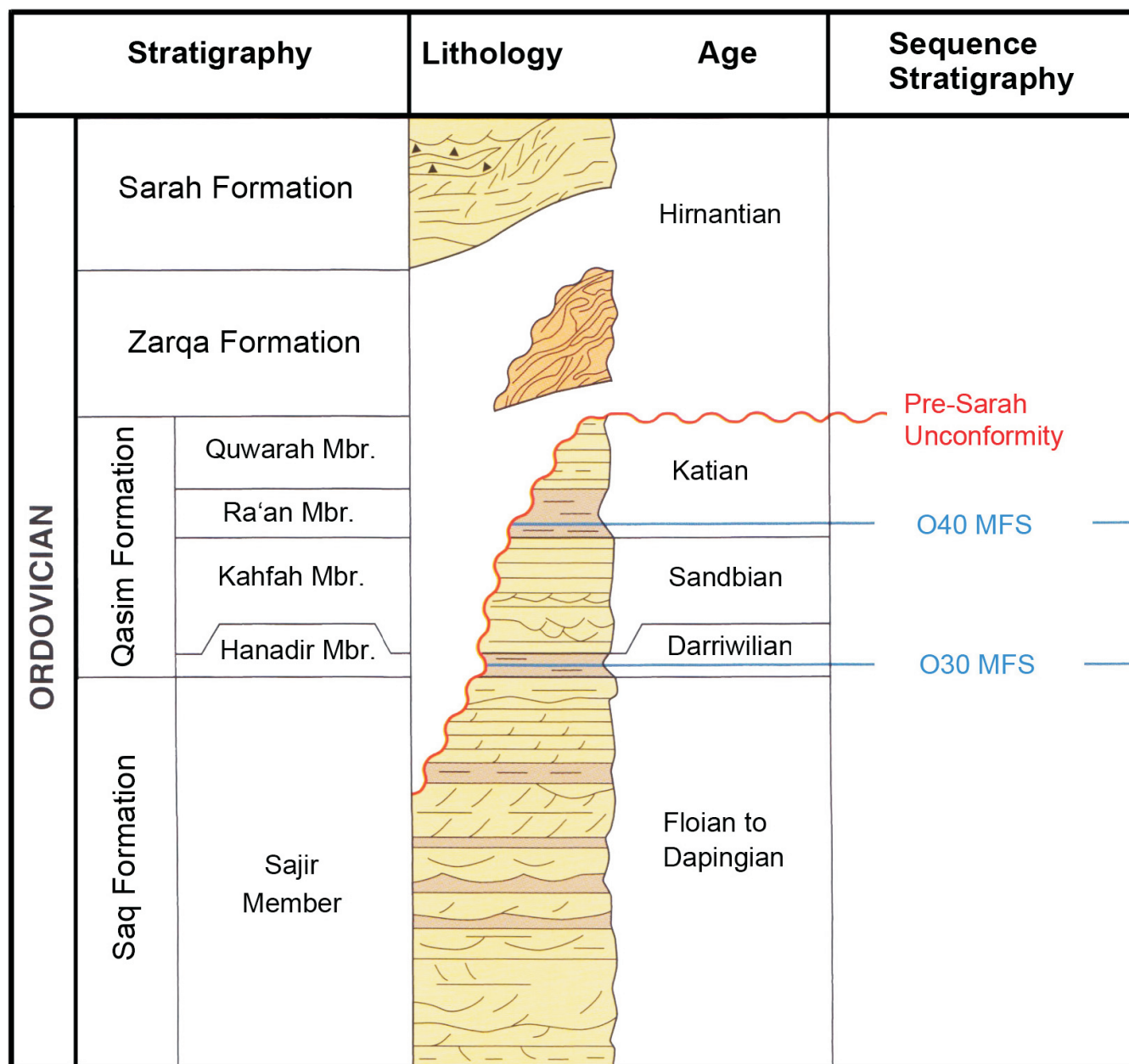
Material: Seven specimens from three samples (Table 1).

Dimensions: Width of the arm is ca. 165 µm.

Remarks: Some specimens exhibit different diameter size of the arms, sometimes possessing one larger arm, and two identical smaller arms. Compared with the holotype, our specimens are more finely agglutinated and have shorter lateral arms.

Stratigraphic range: Upper Ordovician (Moreman 1933) to Silurian (Bell et al. 2000).

Geographic distribution: This species was first recovered from the upper Ordovician (Edenian = early Katian) Viola Formation of Oklahoma, USA (Moreman 1933), and also has been reported from the Silurian succession in New South Wales, Australia (Bell et al. 2000).



TEXT-FIGURE 1

Lithostratigraphy (after Senalp and Al-Duaiji 2001), chronostratigraphy (after Al-Shawareb et al. 2017) and sequence stratigraphy (after Sharland et al. 2001) of the Ordovician of central Saudi Arabia.

Family BATHYSIPHONIDAE Avnimelech 1952

Genus *Bathysiphon* Sars 1872

***Bathysiphon* sp. 1**

Plate 1, figure 2

Material: 15 specimens from three samples (Table 1).

Dimensions: Length 440 µm; maximum width 150 µm.

Description: Test monothalamous, tubular, elongated, curved, with slightly smaller diameter at the initial and terminal stages.

Wall composed of fine siliceous particles. Apertures at the open ends of the tube.

Remarks: Our specimens are mostly fragmentary – both straight and curved specimens are observed.

***Bathysiphon* sp. 2**

Plate 1, figure 3–4

Material: 11 specimens from five samples (Table 1).

Dimensions: Length 450 µm, maximum width 150 µm.

Description: Test monothalamous, tubular, elongated, tapering in the initial stage, then with constant diameter toward the apertural end. Wall agglutinated, composed of fine quartz grains. Apertures at the open end of the tube.

Remarks: Our specimens are mostly fragmentary, and more coarsely agglutinated compared with *Bathysiphon* sp. 1.

Family HIPPOCREPINELLIDAE Loeblich and Tappan 1984
Genus *Lakites* Nestell and Tolmacheva 2004

Lakites ordovicus Nestell and Tolmacheva 2004
Plate 1, figure 5

Lakites ordovicus NESTELL and TOLMACHEVA 2004, p. 257, pl. 1, figs. 1–4, pl. 10, fig. 1.

Material: 11 specimens from six samples (Table 1).

Dimensions: Length 660 µm, width 200 µm.

Description: Test elongated, with central portion only slightly wider than the apertural ends. Wall agglutinated, made of medium-size well-sorted grains. Apertures terminal, one with a small collar.

Remarks: Our specimens are characterized by their elongate test shape and aperture with a collar in well-preserved specimens. Compared with the holotype (Nestell and Tolmacheva, 2004, pl. 1, fig. 1), our specimens have somewhat higher aspect ratio and are more coarsely agglutinated.

Stratigraphic range: Lower Ordovician, Floian (Nestell and Tolmacheva 2004) to upper Ordovician, Katian (this study).

Geographic distribution: First described by Nestell and Tolmacheva (2004) from the Lower Ordovician (Floian) of the Baltic region of NW Russia, the genus was also reported from the Middle Ordovician (Darriwilian) of Argentina (Nestell et al. 2009).

Genus *Amphitremoida* Eisenack 1938, emend. Nestell and Tolmacheva 2004

Amphitremoida citroniforma Eisenack 1938
Plate 1, figure 6

Amphitremoida citroniforma EISENACK 1938, p. 235, pl. 15, figs 27–28; pl. 16 fig. 12. – EISENACK 1954, p. 55, pl. 3, figs. 14–16; pl. 4, figs. 12–13. – RIEGRAF and NIEMEYER 1996, p. 30, figs. 19, 38–41, 44.

Material: Five specimens in two samples (Table 1).

Dimensions: Length 375 µm, width 250 µm.

Remarks: Some of our specimens compare well to the description of Eisenack (1938), but have a more coarsely agglutinated wall. Our specimens are more laterally compressed and are closer to the specimens illustrated by Riegraf and Niemeyer (1996).

Stratigraphic range: Middle Ordovician (Riegraf and Niemeyer 1996) to Upper Ordovician (Nestell and Tolmacheva 2004).

Geographic distribution. This species was first recovered from glacial boulders found on the Samland Peninsula, former East

Prussia (Eisenack 1938). Eisenack (1954) erected a neotype for *Amphitremoida citroniforma* and corrected its reported age. The neotype is from a glacial pebble from the Ordovician “Baltic limestone”, which according to Nestell and Tolmacheva (2004) is equivalent to the Lyckholm Formation (upper Caradoc to lower Ashgill in the British Series) of Estonia. Riegraf and Niemeyer (1996) reported the species from the Plettenberger Bänderschiefer (*Didymograptus bifidus* zone, Darriwilian) of northwest Germany.

Amphitremoida cf. asperella Nestell and Tolmacheva 2004
Plate 1, figure 7

cf. *Amphitremoida asperella* NESTELL and TOLMACHEVA 2004, p. 262, pl. 2, fig. 1, pl. 10, fig. 2.

Material: 23 specimens in six samples (Table 1).

Dimensions: Length 375 µm, width 190 µm.

Description: Test oval in outline, wall agglutinated with medium-size quartz grains, with a sugary appearance. The aperture on one side of the test appears to have a short neck.

Remarks: Our specimens appear most similar in outline to *Amphitremoida asperella* Nestell and Tolmacheva 2004 but differ in possessing a more coarsely agglutinated wall.

Stratigraphic range: Lower Ordovician, Floian (Nestell and Tolmacheva 2004) to upper Ordovician, Katian (this study).

Geographic distribution: This species has been reported from the Lower Ordovician of the Baltic region of NW Russia by Nestell and Tolmacheva (2004).

Order SACCAMMININA Lankester 1885
Suborder SACCAMMINOIDEA Brady 1884
Family STEGNAMMINIDAE Moreman 1930
Subfamily STEGNAMMININAE Moreman 1930
Genus *Stegnammina* Moreman 1930

Stegnammina sp. 1
Plate 1, figure 8

Material: 61 specimens from seven samples (Table 1).

Dimensions: Diameter 75–137 µm.

Description: Test *Rhizammina*-like, a thin, narrow, finely agglutinated tube with a solid wall. The tube may vary in width and may narrow toward one end.

Remarks: Our specimens are mostly fragmentary, as a result the ends of the tube are open, but some longer specimens appear to be closed at one end.

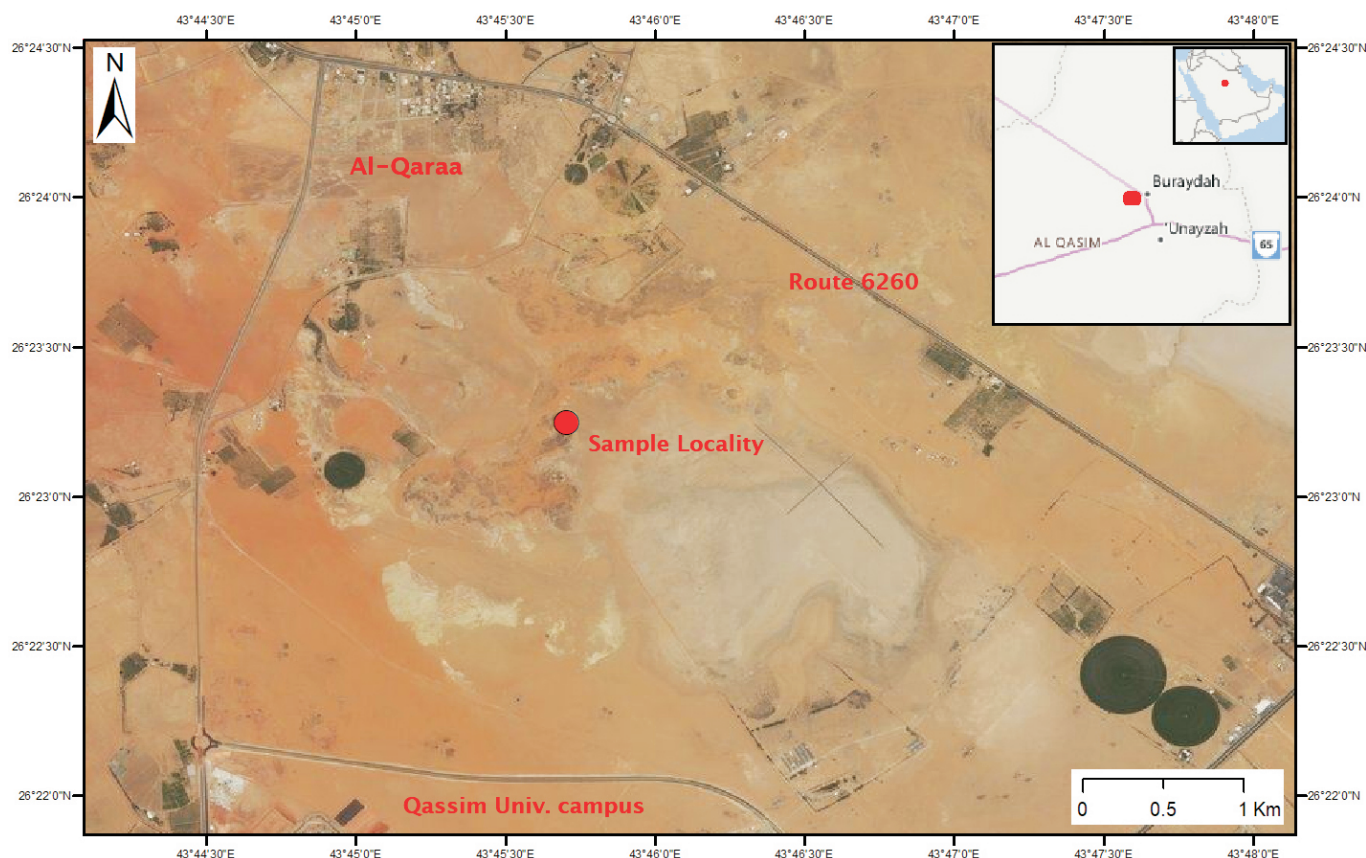
Stegnammina sp. 2
Plate 1, figure 9

Material: 16 specimens from eight samples (Table 1).

Dimensions: Diameter 125–175 µm.

Description: Test robust, a thick-walled tube made of medium to coarsely agglutinated quartz grains.

Remarks: Our specimens are larger and coarser than *Stegnammina* sp. 1.



TEXT-FIGURE 2
Position of the sample locality and the Qassim University campus. Base map is from Google Earth.

Genus *Thuramminoides* Plummer 1945, emend. Conkin 1961

Thuramminoides sphaeroidalis Plummer 1945, emend. Conkin 1961
Plate 1, figure 10; Plate 2, figure 1

Thuramminoides sphaeroidalis PLUMMER 1945, 218, pl. 15, figs 4–10. – CONKIN 1961, p. 243, pl. 17, figs 1–10; pl. 18, figs 1–4. – CONKIN et al. 1963, p. 221, pl. 1, figs 16–17. – CONKIN et al. 1968, p. 168, pl. 1, figs 16–17. – HOLCOVÁ 2002, p. 89, pl. 1, figs 1, 2, 4, 6; pl. 2, figs 6, 8, 14; pl. 3, figs 14; pl. 7, fig. 1; pl. 8, figs 12–15; pl. 9, figs 1, 15–16; pl. 10, fig. 7; pl. 12, fig. 3; pl. 13, fig. 5; pl. 14, figs 8–11.
Thuramina sphaeroidalis (Plummer 1945). – RIEGRAF and NIEMEYER 1996, p. 26, figs 4–6, 8–11, 14–15, 20–23, 25–31, 45, 58–60, 63.

Material: 1,097 specimens from 18 samples (Table 1).

Dimension: Diameter 150–587 μm .

Remarks: *Thuramminoides sphaeroidalis* was originally described as possessing a labyrinthic interior, but Conkin (1961) noted that this is not the case. In his emendation of the species based on a study of topotypes from the Pennsylvanian of Texas, Conkin observed that instead, the species is hollow and surrounded by a thick test that possesses an inner “centripetal tubular structure”. The tubes may or may not pierce the surface of the test. Conkin transferred the genus from the Saccamminidae to the Astrorhizidae. In this study, we follow the classification

of Kaminski (2014), and place the genus in the Stegnammininae.

In the studied material *Thuramminoides sphaeroidalis* is the most abundant taxon, and is common in all samples. Plummer (1945) described the type specimens as “smoothly finished”, but our specimens are more coarsely agglutinated.

Stratigraphic range: Lower Cambrian (Culver 1991) to Lower Permian, Sakmarian (Dixon and Haig 2004).

Geographic distribution: This species has been widely reported from West Africa (Culver 1991), North America (Conkin 1961; Conkin et al. 1963; Conkin et al. 1968), Europe (Holcová 2002), and Australia (Bell et al. 2000; Dixon and Haig 2004).

Thuramminoides sp. 1

Plate 2, figures 1–2

Amphitremoida elongata Eisenack. – RIEGRAF and NIEMEYER 1996, p. 30, figs 47–49; non fig. 50.

Material: 30 specimens from four samples (Table 1).

Dimensions: Length 225–750 μm , width 143–343 μm .

Description: Test similar to *T. sphaeroidalis*, but oval in outline. Test wall is made of quartz and other mineral grains.

TABLE 1
Counts of benthic foraminifera in samples from the Ra'an Member.

Sample	<i>T. spirooidalis</i>	<i>Stegannina</i> sp. (thin)	<i>Stegannina</i> sp. (thick)	<i>Psammospaera cava</i>	<i>Amphitremoida</i> sp. 1	<i>Bathysiphon</i> sp. 1	<i>Bathysiphon</i> sp. 2	<i>Rhabdammina trifurcata</i>	<i>Saccamminita galinae</i>	<i>Reophax</i> sp. 2	<i>Hyperammina</i> sp.	<i>Amphitremoida citroniforma</i>	<i>Amphitremoida cf. asperella</i>	<i>Kechenotiske</i> sp.	<i>Subreophax</i> sp.	<i>Reophax</i> sp. 1	<i>Areniconulus</i> sp.	<i>Thuraminoides</i> sp. 1
R21																		
R20	2	1			1													1
R19	4		2															
R18	2																	
R17																		
R16	7	3																
R15	7																	
R14																		
R13	177		1	5	1		1						1					6
R12	164																	
R11	164		2	2									11					6
R10	192		5		1								1				2	17
R9	20	1		1														
R8	19		1											1			2	
R7	103		2		1	1	1	2	1			1	7					
R6	93	41	2		5	10	4	4	3		2	4	2	5	3	1		
R5	18	1		2			1		1									
R4	74	13		5		4	4	1	4	1								
R3	3																	
R2	26			2	2													
R1	22	1	1															
SUM	1097	61	16	17	11	15	11	7	9	1	2	5	23	5	3	1	4	30

Remarks: Our specimens are similar to a species reported by Riegaf and Niemeyer (1996, figs 47–49, but not fig. 50) as *Amphitremoida elongata* Eisenack 1969 from the Ordovician of Germany. Riegaf and Niemeyer described it as *Reophax*-like, but three of the four illustrated specimens consist of large single oval chambers. Their fourth specimen may belong to a different species. Our specimens are restricted to the upper part of the studied section.

Family SACCAMMINIDAE Brady 1884

Subfamily SACCAMMININAE Brady 1884

Genus *Saccamminita* Kaminski and Perdana 2017

Saccamminita galinae Kaminski and Perdana 2017

Plate 2, figure 4

Saccamminita galinae KAMINSKI and PERDANA 2017, p. 60, pl. 1, figs. 1–3

Material: Nine specimens from four samples (Table 1).

Dimensions: Length 237–350 µm, width 82–125 µm.

Description: An elongated thin-walled saccamminid with a protruding aperture. Wall is solid, medium to finely agglutinated.

Remarks: Our specimens compare well with the Silurian ones from the Qusaiba Shale of Saudi Arabia.

Stratigraphic range: Upper Ordovician, Katian (this study) to Lower Silurian, Aeronian (Kaminski and Perdana 2017).

Geographic distribution: This species has been previously reported from the Lower Silurian Qusaiba Formation of Saudi Arabia (Kaminski and Perdana 2017).

Family PSAMMOSPHAERIDAE Haeckel 1894

Genus *Psammospaera* Schulze 1875

Psammospaera cava Moreman 1930

Plate 2, figure 5

Psammospaera cava MOREMAN 1930, 48, pl. 6, fig. 12. – IRELAND 1966, p. 225, pl. 1, fig. 16. – WATKINS et al. 1999, p. 543, fig. 5: 8–9. – KAMINSKI et al. 2016, p. 118, pl. 1, figs 9–12.

Material: 17 specimens from six samples (Table 1).

Dimensions: Diameter 160–187 µm.

Remarks: Our specimens compare well to the type specimens illustrated by Moreman (1930). However, our specimens have a smaller test diameter.

Stratigraphic range: Upper Ordovician (Mound 1968) to Upper Pennsylvanian (Conkin and Conkin 1982).

Geographic distribution: First described from the Silurian of Oklahoma (USA) by Moreman (1930); it has also been reported from the Silurian of England (Mabillard and Aldridge 1982), Ireland (Kaminski et al. 2016), Sardinia (Gnoli and Serpagli 1984), Australia (Bell et al. 2000) and Lower-Middle Devonian of the Czech Republic (Holcová 2004), and the Upper Devonian of central Poland (Olempska 1983). Conkin and Conkin (1982) reported a questionable occurrence of *P. cava*(?) from the Upper Pennsylvanian.

Subclass TUBOTHALAMANA Pawlowski, Holzmann and Tyszk 2013

Order AMMODISCIDA Mikhalevich 1980

Suborder HIPPOCREPININA Saidova 1981

Subfamily JACULLELINAE Mikhalevich 1995

Genus *Kechenotiske* Loeblich and Tappan 1984

Kechenotiske sp.

Plate 2, figure 6

Material. Five specimens from sample R6 (Table 1).

Dimensions: Length 310–412 µm, maximum width 275 µm.

Description: Test conical, flaring. Wall made of medium agglutinated grains, sugary in appearance. Aperture large, at the open end of the tube.

Remarks: Our specimens are smaller than the type species *K. expansus* (Plummer 1945), and the tubular chamber expands less rapidly with growth. *Kechenotiske expansus* was described by Plummer (1945) from the Pennsylvanian of Texas. The Early Permian species *Kechenotiske hadzeli* (Crespin 1958) differs in its thick finely agglutinated wall and larger sizes of the test (see Dixon and Haig 2004, pl. 1, figs 19–20). Our finding in the Ra'an Shale Member represents the oldest known report of the genus.

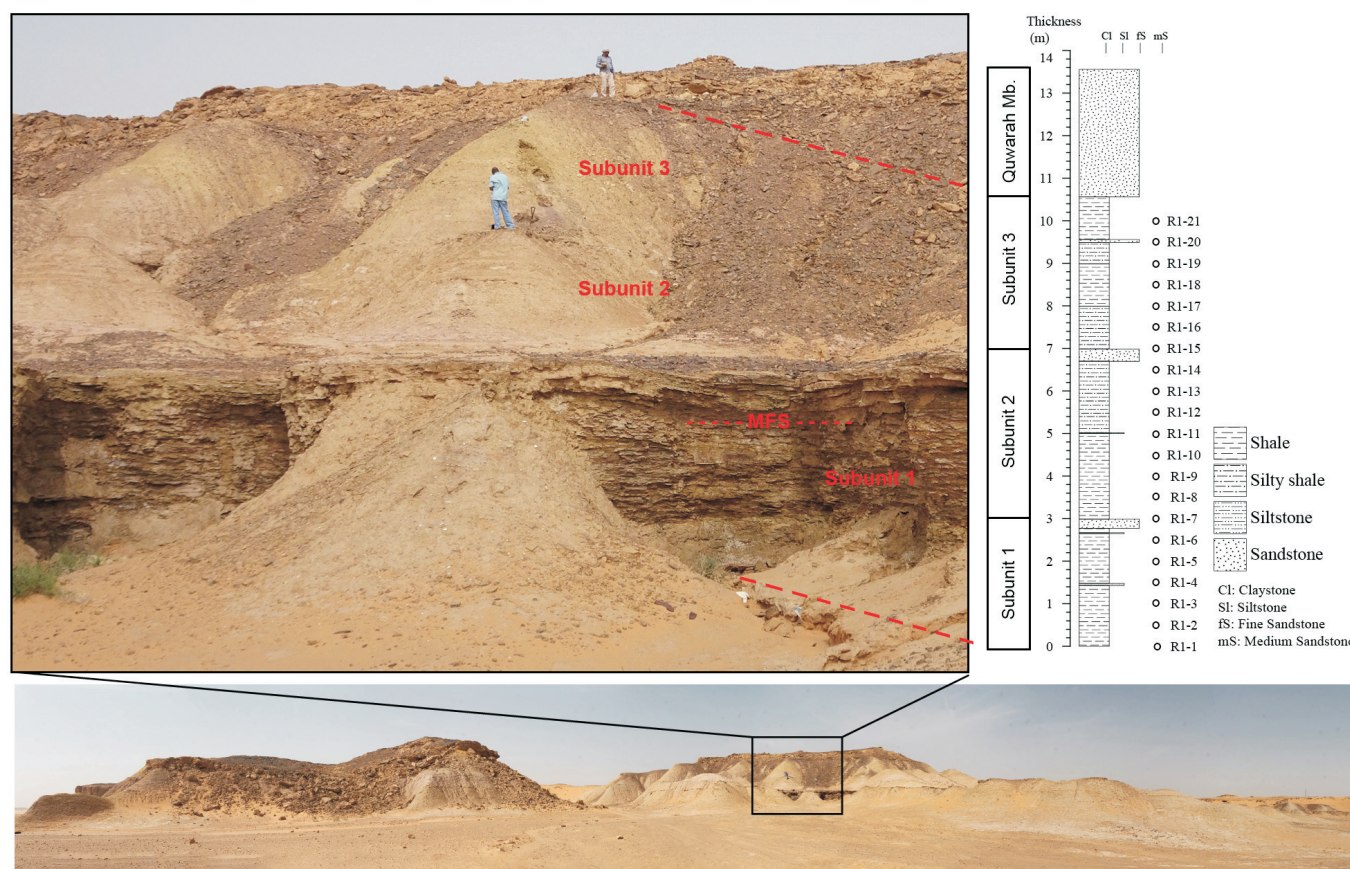
Family HYPERAMMINIDAE Eimer and Fickert 1899

Subfamily HYPERAMMININAE Eimer and Fickert 1899

Genus *Areniconulus* Eisenack 1969

Areniconulus sp.

Plate 2, figure 8



TEST-FIGURE 3

View of the Ra'an Shale Member cuesta near Al-Qaraa, looking north. The positions of the studied samples and the O40 maximum flooding surface (MFS) are indicated.

Material: Four specimens from two samples (Table 1).

Dimensions: Length 335–440 μm .

Description: Test robust, a thick-walled deformed tube made of medium to coarsely agglutinated quartz grains, expanding in diameter distally.

Remarks: Our specimens most closely resemble the species *Areniconulus bykovae* described by Eisenack (1969) from the Baltic Silurian.

Genus *Hyperammina* Brady 1878

***Hyperammina* sp. 1**

Plate 2, figure 7

Material: Two specimens from sample R6 (Table 1).

Dimensions: Length 185–315 μm .

Description: Test bilocular, with an expanded elongated proloculus and short tubular second chamber of fairly constant diameter. Wall is medium to coarse, comprised of quartz grains, sugary in appearance.

Superfamily HORMOSINELLOIDEA Rauser and Reitlinger 1986

Family HORMOSINELLIDAE Rauser and Reitlinger 1986

Genus *Subreophax* Saidova 1975

***Subreophax* sp. 1**

Plate 2, figure 9

Material: Three specimens from sample R6 (Table 1).

Dimensions: Length 858 μm , maximum width across last chamber 151 μm .

Description: Test meandering, comprised of three somewhat pyriform chambers. The initial chamber is flask-shaped, and the aperture is at the end of a produced and tapered neck.

Remarks: Our specimens are deformed, but display the typical features of the genus. With its slightly elongated and pyriform chambers, the species can be best compared with *Subreophax splendidus* (Grzybowski). This finding represents the oldest reported occurrence of the genus. The genus *Subreophax* was described by Saidova 1975 as possessing an agglutinated wall with carbonate cement. However, the representatives belonging to this genus are common in acid residue samples from the Cretaceous of Italy (Kaminski et al. 2011). The cement of the type species *Reophax aduncus* Brady was originally organic, not calcareous.

Subclass GLOBOTHALAMANA Pawlowski, Holzmann and Tyska 2013
 Order LITUOLIDA Lankester 1885
 Suborder HORMOSININA Mikhalevich 1980
 Superfamily HORMOSINOIDEA Haeckel 1894
 Family REOPHACIDAE Cushman 1927
 Genus *Reophax* Montfort 1808

***Reophax* sp. 1**

Plate 2, figure 10

Material: A single specimen from sample R6 (Table 1).

Dimensions: Length 467 µm, maximum width across last chamber 172 µm.

Description: Test elongated, slightly arched, comprised of four elongate chambers with an oblique suture between them. The ultimate chamber is pyriform. Aperture produced, on a neck.

Remarks: The oldest known representative of the genus *Reophax* is the Late Ordovician (Sandbian) species *Reophax blackriveranus* described by Gutschick (1986) from the Mifflin Formation of Illinois (USA). Our specimen differs in possessing more elongated chambers.

***Reophax* sp. 2**

Plate 2, figure 11

Material: A single specimen from sample R4 (Table 1).

Dimensions: Length 467 µm, maximum width 275 µm.

Description: Test comprised of three robust globular chambers, increasing in size slowly, separated by horizontal sutures.

Remarks: Our specimen is characterized by its three nearly equidimensional chambers. It differs from *Reophax* sp. 1 in being more *Hormosina*-like, with large overlapping chambers.

DISCUSSION

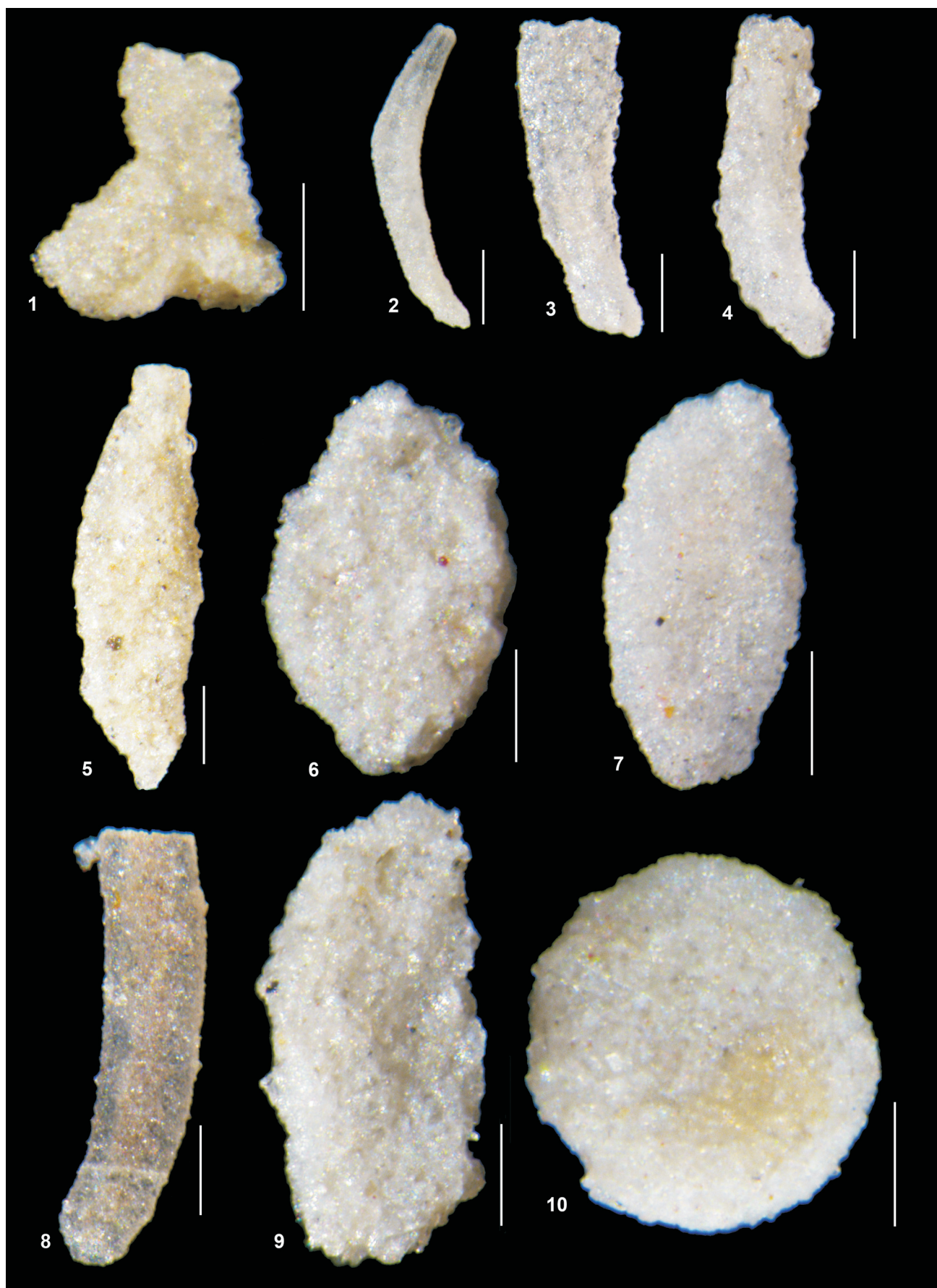
Our discovery of an assemblage of agglutinated foraminifera in the Ra'an Shale Member of the Qasim region of Saudi Arabia constitutes the first report of the foraminifera in the Upper Ordovician of the Middle East. The only previous report of Ordovician foraminifera in the Middle East is the finding of Middle Ordovician (Darriwillian) agglutinated assemblages in the Lashkarak Formation of Iran by Nestell et al. (2016). The Middle Ordovician assemblages from Iran consist entirely of monothalamous forms, mostly *Amphitremoida*, *Damghanites*, *Psammospaera* and *Sorosphaera*, whereas our Upper Ordovician (Katian) assemblages from the Ra'an Shale contain a small proportion (ca. 1%) of two-chambered (*Hyperammina*, *Keckenotiske*, *Areniconulus*), multichambered (*Reophax*), and pseudo-multichambered forms, *Subreophax*) in addition to the monothalamids. The multichambered genus *Reophax* is known from the Ordovician (Blackriverian regional stage) Mifflin Formation of Illinois (Gutschick 1986), which is now correlated with the Sandbian stage of the Late Ordovician in the global time scale (www.stratigraphy.org/bak/geowhen/geolist). However, the pseudochambered genus *Subreophax* has not been previously reported from the Ordovician. The oldest previous report of the genus is from the Upper Triassic according to Haig and McCartain (2010). The genus *Keckenotiske* is previously known from the Upper Devonian (Vdovenko et al. 1993) to Late Triassic (Haig and McCartain 2010).

A regional Late Ordovician marine flooding surface in the Ra'an Member of Saudi Arabia and the laterally equivalent Hasirah Formation in Oman was first identified by Droste (1997). In the studied section the O40 maximum flooding horizon (sensu Sharland et al. 2001) is identified near the top of the lowermost subunit of the Ra'an Member in the vicinity of our Sample R6 (text-fig. 3), which displays the highest species diversity and foraminiferal abundance. This level is characterized by the maximum abundance of tubular forms and *Amphitremoida* spp., and also contains rare *Hyperammina*, *Keckenotiske*, *Reophax* and *Subreophax* spp. From this point in the

PLATE 1

Foraminifera from the Ra'an Shale Member at Al-Qaraa, scale bars = 100 µm.

- | | |
|---|---|
| 1 <i>Rhabdammina trifurcata</i> Moreman, sample R4 | 7 <i>Amphitremoida</i> cf. <i>asperella</i> Nestell and Tolmacheva, sample R6 |
| 2 <i>Bathysiphon</i> sp. 1, sample R4 | 8 <i>Stegnammina</i> sp. 1 (thin), sample R4 |
| 3-4 <i>Bathysiphon</i> sp. 2, sample R6 | 9 <i>Stegnammina</i> sp. 2 (thick), sample R4 |
| 5 <i>Lakites</i> sp. 1, sample R20 | 10 <i>Thuramminoides sphaeroidalis</i> Plummer, sample R1. |
| 6 <i>Amphitremoida citroniforma</i> Eisenack, sample R6 | |



studied outcrop, values of foraminiferal abundance and diversity decline markedly upsection (Table 1). In the uppermost subunit of the Ra'an Shale Member, the foraminiferal assemblage is poor (three samples were barren), and consists mainly of few specimens of *Thuramminoides* with rare tubular forms. Our placement of the MFS near the top of the lowermost subunit of the Ra'an Shale Member is based on the observations that the species diversity of modern benthic foraminifera on the continental shelf increases in the offshore direction (Buzas and Gibson, 1969), and the recent finding that agglutinated foraminiferal biofacies are just as accurate in predicting gradients in water depth as are the calcareous benthic foraminifera (Frontalini et al. 2018).

CONCLUSIONS

The Ra'an Shale Member of the Qasim Formation at Al-Qaraa (Qassim District, Saudi Arabia) contains a foraminiferal assemblage consisting entirely of agglutinated forms. A total of 18 species belonging to 12 genera were found in the current study. Simple monothalamous genera such as *Thurammina*, *Psammosphaera*, *Stegnammina*, *Amphitremoida*, *Bathysiphon*, and *Saccamminita* comprise 99% of the assemblage, whereas the remainder consists of two-chambered (*Hyperammina*, *Ketchenotiske*, *Areniconulus*), pseudomultilocular (*Subreophax*), and multilocular (*Reophax*) forms. We note the oldest worldwide stratigraphic occurrence of the genera *Subreophax* and *Ketchenotiske* in the Ra'an Shale Member.

The O40 maximum flooding horizon is identified at ca. 2 m above the base of the studied section based on the maximum abundance and diversity of agglutinated foraminifera. Small tubular forms (*Stegnammina*, *Bathysiphon*), globular forms (*Amphitremoida*), and tubothalamids (*Hyperammina*, *Ketchenotiske*, *Subreophax*) show maximum relative abundance values at this level.

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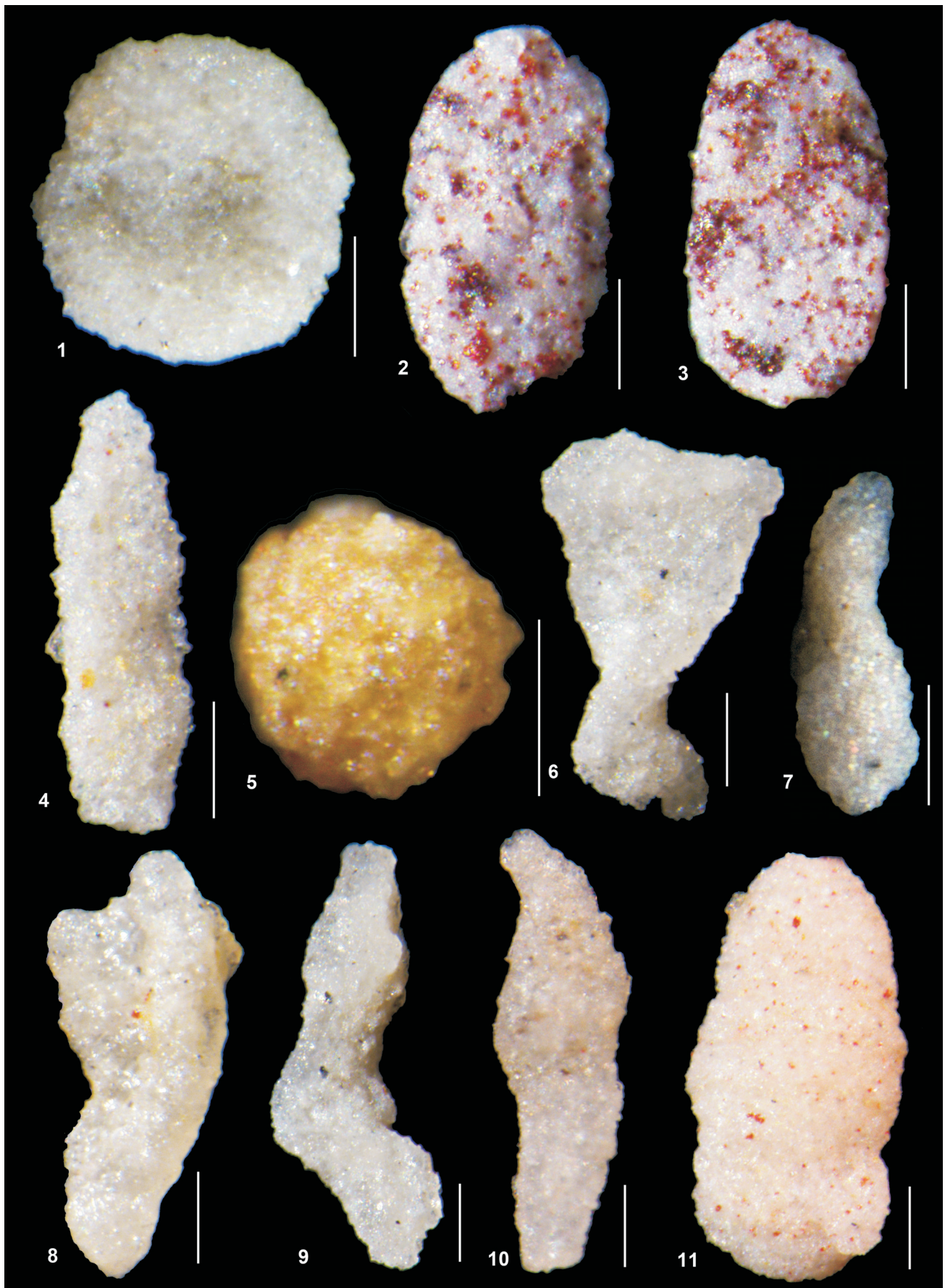
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PLATE 2

Foraminifera from the Ra'an Shale Member at Al-Qaraa, scale bars = 100 µm.

- | | |
|---|---------------------------------------|
| 1 <i>Thuramminoides sphaeroidalis</i> Plummer, sample R1 | 7 <i>Hyperammina</i> sp. 1, sample R6 |
| 2–3 <i>Thuramminoides</i> sp. 1, sample R10 | 8 <i>Areniconulus</i> , sample R10 |
| 4 <i>Saccamminita galinae</i> Kaminski and Perdana, sample R4 | 9 <i>Subreophax</i> sp. 1, sample R6 |
| 5 <i>Psammosphaera cava</i> Moreman, sample R2 | 10 <i>Reophax</i> sp. 1, sample R6. |
| 6 <i>Ketchenotiske</i> cf. <i>expansa</i> , sample R6 | 11 <i>Reophax</i> sp. 2, sample R4. |



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