New Foraminifera from the Lower Silurian Qusaiba Shale Formation of Saudi Arabia

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ABSTRACT: Eight new species of agglutinated foraminifera are described from the Lower Silurian Qusaiba Shale Formation of the Qalibah Group in central Saudi Arabia. The new species are found in an assemblage consisting entirely of agglutinated foraminifera dominated by monothalamids. The following genus and species are here described as new: *Saccamminita galinae* n. gen., n. sp., *Hyperammina sinuosa*, n. sp., *Thuramminoides plummerae*, n. sp., *Thurammina holcovae*, n. sp., *Thurammina pentagona*, n. sp., *Ceratammina* sp. 1., *Ammobaculites qusaibaensis*, n. sp. and *Simobaculites* sp. 1. Our finding of rare multichambered forms (*Ammobaculites* and *Simobaculites*) in the Qusaiba Shale Formation revises the early evolutionary history of these genera.

INTRODUCTION

During the Early Silurian, Arabia was situated on the northern passive margin of the Gondwanan Continent, located below 45° south latitude (Golonka et al. 2006). Owing to the melting of ice after the Hirnantian glaciation, much of Arabia and North Africa was flooded and covered by an epicontinental sea, resulting in the deposition of a fine-grained Lower Silurian succession rich in organic matter (Mahmoud et al. 1992). Anoxic conditions in intra-shelf basins led to the formation of organic-rich "hot shales". Consequently, the Lower Silurian Qusaiba Shale and its lateral equivalents in Gondwana play an essential role in the Paleozoic petroleum systems as a prolific source rock (Lüning et al. 2000).

Paleontological studies of graptolites and palynomorphs have been extensively conducted on the Lower Silurian in Saudi Arabia (Al-Hajri and Paris 1998; Miller and Melvin 2005, Zalasiewicz et al. 2007, Hayton et al. 2017). Graptolites studied from the nearby Qusaiba-1 core yielded an Aeronian age (Lituigraptus convolutus zone) for the greater part of the Qusaiba shale (Zalasiewicz et al. 2007), whereas the contact between the Qusaiba and Sharawra formations is correlated with the Telychian stage based on the occurrence of the Angochitina macclurei chitinozoan zone in Central Saudi Arabia (Miller and Melvin 2005). As this is the case, the contact between the Qusaiba and Sharawra formations is likely to be diachronous. Our investigation of these units in outcrop yielded the first discovery of Early Silurian agglutinated foraminiferal assemblages in the Arabian Peninsula (Kaminski and Perdana 2017).

The purpose of this paper is to describe and illustrate new species of foraminifera from the Qusaiba shale from the original type section of the formation exposed near old Qusaiba village, Qassim District, Saudi Arabia. The studied outcrop sections and the lithofacies and sedimentology of the overlying Sharawra Formation have been recently described by Abbas et al. (2017). Both lithological units are here regarded as having formation status in accordance with the scheme published by the Saudi Stratigraphic Committee in 2012.

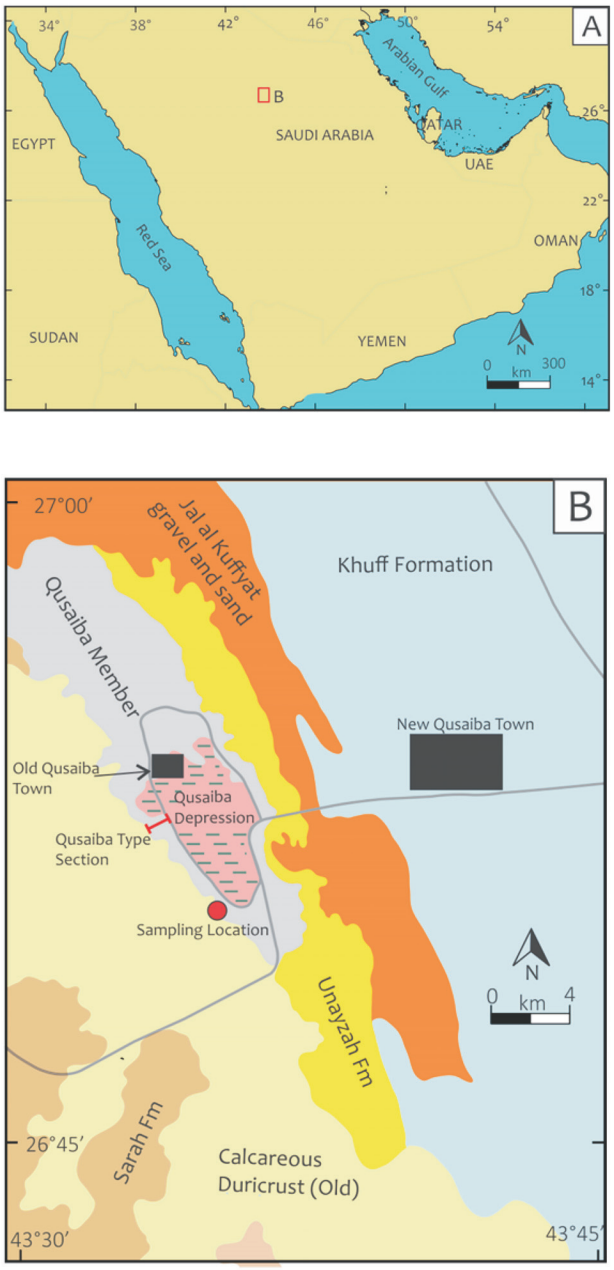
METHODS

Samples were collected from the shale to silty shale of the upper part of the Qusaiba Formation and interbedded shales from the lower part of the Sharawra Formation from the type section exposed along an unpaved road that leads up the face of the cuesta from Old Qusaiba Village (N 26° 50' 2.8", E 43°, 36' 00"), Qasim District, Saudi Arabia (text-fig. 1). The outcrop exposure consists of a 14.5 m-thick succession of Qusaiba shale in the lower part of the outcrop, overlain by alternating clay, silt, and sandstones of the Sharawra Formation in the upper part (text-figs. 2, 3). During our initial reconnaissance field work, we observed that the thin sandstone beds at the transition between the Qusaiba and Sharawra formations show evidence of bioturbation, indicating oxygenated conditions. We therefore focussed our efforts on sampling this transitional lithofacies in the uppermost part of the Qusaiba Formation (corresponding to the "Gray shale facies" of Hayton et al. 2017) with the aim of recovering foraminiferal assemblages. Samples were collected at half-meter spacing from the upper part of the Qusaiba shale, whereas in the lower Sharawra Formation the shale interbeds were sampled at irregular but more closely-spaced intervals.

Microfossil assemblages were studied from 25 shale samples disaggregated without special chemical treatment. Samples were prepared from 400–500 gram samples to standardize recoverable foraminiferal residue, and washed under running water using a standard stainless steel 63 μm sieve. Approximately 300 foraminifera were picked from each sample, separated into faunal slides, and photographed using a Nikon-1500 photomicroscope. The type specimens are deposited in the collections of the European Micropalaeontological Reference Centre, Micropress Europe, located at the AGU University of Science and Technology in Kraków, Poland.

RESULTS

Eight new species and one new genus of agglutinated foraminifera have been recovered from the Lower Silurian (Aeronian) Qusaiba Shale Formation in Saudi Arabia. The foraminiferal assemblage in the upper part of the Qusaiba shale



TEXT-FIGURE 1
A. Location of Qusaiba village in Saudi Arabia, with square showing the position of the insert map; B. Studied section showing sampling location (modified after Zalasiewicz et al. 2007)

is taxonomically diverse and well preserved, and consists entirely of agglutinated taxa (Kaminski and Perdana 2017). The full taxonomic inventory of this assemblage will be the subject of a further study. The assemblage is dominated by monothalamids, but also contains rare multichambered globothalamid species belonging to the genera *Ammobaculites* and *Simobaculites*. The new species are described below.

SYSTEMATICS

In this study the higher-order systematics of Kaminski (2014) are used.

Class FORAMINIFERA d'Orbigny 1826
Order ASTRORHIZIDA Lankester 1885
Family SACCAMMINIDAE Brady 1884

Genus ***Saccamminita*** Kaminski and Perdana, **n. gen.**
Type species: Saccamminita galinae n.sp.

Description: Test free, unilocular, elongated, with a uniform undivided elongated chamber, laterally compressed, widest near the center and tapering at both ends. Wall agglutinated, of fine quartz grains. Aperture situated on a short neck at one end of the test.

Remarks: This genus can be best compared with the modern genus *Nellya* Gooday, Anikeeva and Pawlowski, 2010, which has a tapering, elongated test with an aspect ratio of about 1:3. However, *Nellya* is only known from modern sediments of the Black Sea, and has a flexible organic wall with an agglutinated outer layer. This type of wall is unlikely to be reserved in the fossil record. Moreover, the test of *Nellya* is somewhat asymmetrical, gradually increasing in diameter toward the apertural end before tapering abruptly toward the aperture. Our specimens differ in tapering equally at both ends of the test, such that the test is widest approximately at the center. The genus *Pseudosacculinella* Yasini and Jones, 1995 has an elongated test shape, but is reported to have a wall with a "calcareous matrix" and a slit-like aperture. Additional monothalamid foraminifera with elongated test shapes that were formerly classified as allogromids are known from the modern ocean (e.g., *Bowseria* Sinniger, Lecroq, Majewski and Pawłowski 2008, *Gloiogullmia* Nyholm 1974, *Goodayia* Sergeeva and Anikeeva 2008; *Krymia* Anikeeva, Sergeeva, and Gooday 2013). To our knowledge this is the first report of an elongated saccamminid from the Silurian.

Saccamminita galinae Kaminski and Perdana, **n. sp.**
Plate 1, figures 1–3

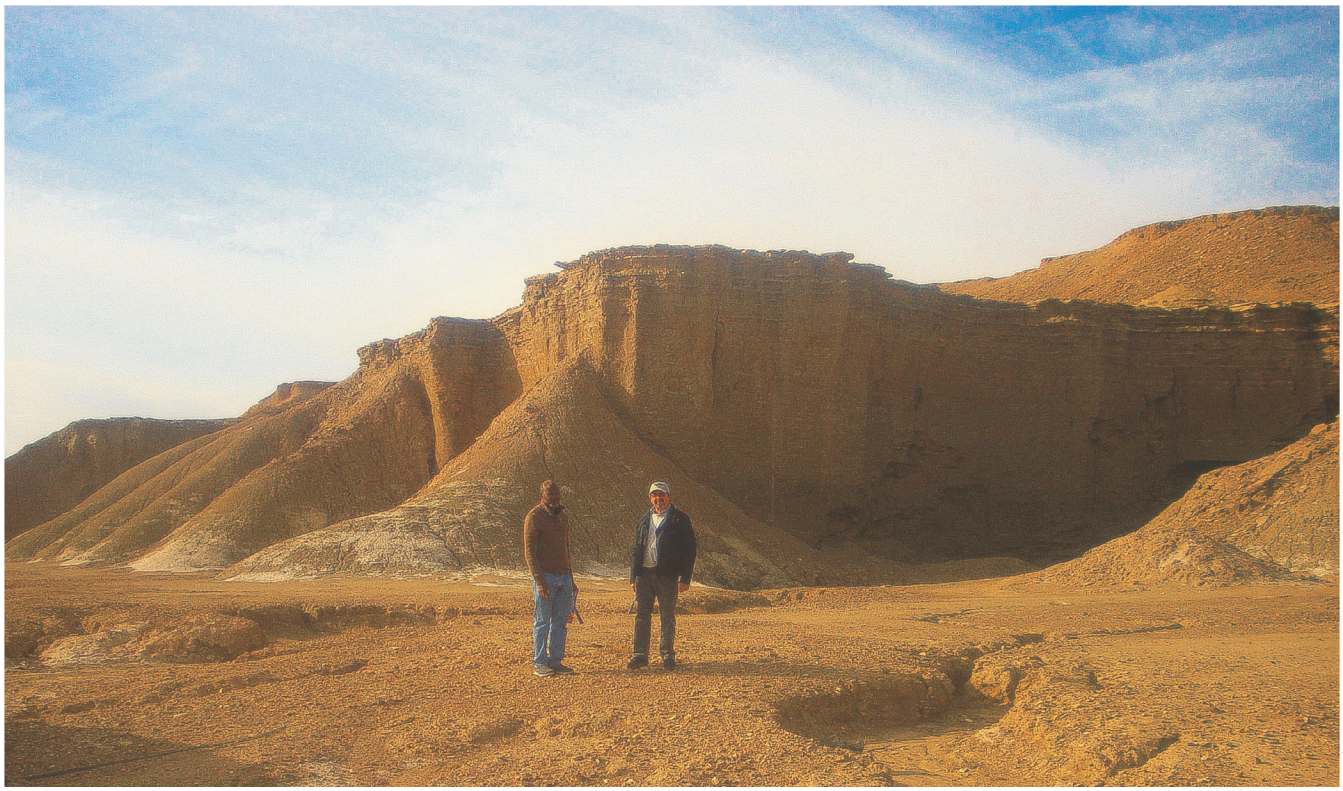
Etymology: In honor of Galina Nestell, in recognition of her valuable work on the taxonomy and stratigraphy of early Paleozoic foraminifera.

Material: Three specimens from one sample.

Dimensions: Specimens range from 312.5 µm to 375 µm in length, and 112 µm to 156 µm in width across the tubular chamber.

Description: Test free, elongated, with a uniform undivided elongated chamber, laterally compressed, tapering slightly at both ends. Width to length ratio is approximately 1:3, with maximum width approximately in the central part of the test. Wall agglutinated, of fine quartz grains. A single short apertural neck at one end of the test.

Remarks: The shape of the test resembles *Amphitremoida simehkuhensis* Nestell and Ghobadi Pour (in press) from the Ordovician of Iran, but it differs in possessing only a single aperture.



TEXT-FIGURE 2
View of the studied outcrop section south of Old Qusaiba village. Sandstones of the Sharawra Formation are visible at the top of the questa. Vertical height of the section is 14.5 m.

Type Level: Early Silurian (Aeronian), uppermost part of the Qusaiba Formation.

Type Locality: Old Qusaiba Village, Qasim District, Saudi Arabia.

Type Specimens: Deposited in the collections of the European Micropalaeontological Reference Centre (EMRC), Kraków, Poland, in cabinet 7, drawer 8.

Genus *Thurammina* Brady 1879
Thurammina pentagona Kaminski and Perdana, **n. sp.**
Plate 1, figures 8–9

Etymology: From its rounded-pentagonal test shape.

Material: Five specimens from three samples.

Dimensions: Specimens range from 175 µm to 250 µm in diameter.

Description: Test free, unilocular, rounded-pentagonal in outline, slightly inflated, with five small neck-like projections situated at the corners of the pentagon. Apertures circular, at the end of the projections. Wall finely agglutinated, translucent, with fine to medium-size grains.

Remarks: Our species most closely resembles *Thurammina hexagona* Dunn 1942, which differs in having an extra aperture located at the periphery of the test and its hexagonal rather than pentagonal outline. A similar form with longer necks has been observed in the Devonian (Emsian) in the Czech Republic (K. Holcová, personal communication to MAK, 2017).

Type Level: Early Silurian (Aeronian), uppermost part of the Qusaiba Formation.

Type Locality: Old Qusaiba Village, Qasim District, Saudi Arabia.

Type Specimens: Holotype (fig. 8a,b) and paratypes are deposited in the EMRC, Kraków, Poland, in cabinet 7, drawer 8.

Thurammina holcovae Kaminski and Perdana, **n. sp.**
Plate 1, figure 14

Thurammina triradiata Gutschick and Treckman 1959. – HOLCOVÁ 2002, p. 97, text-fig. 15g, pl. 4, fig. 3, pl. 16, fig. 4.
non *Thurammina triradiata* GUTSCHICK and TRECKMAN 1959, p. 233, pl. 33, figs 16, 17.

Etymology: The species name is in honor of Dr. Katarina Holcová, who first illustrated this species in the Lower Devonian of the Czech Republic.

Material: Seven specimens from five samples.

Dimensions: Specimens range from 156 μm to 200 μm in diameter.

Description: Test free, rounded-triangular in outline, with three tapering neck-like projections situated at the corners of the triangle. Apertures circular, at the end of the projections. Wall finely agglutinated, translucent, with a medium-size grains.

Remarks: These specimens differ from the holotype and paratypes described by Gutschick and Treckman (1959), and emended by Conkin et al. (1968) in its more triangular outline, and having apertures situated at the apex of the triangle. Our specimens are most similar to those illustrated by Holocová (2002) as *Thurammina triradiata*. Holcová's specimen has an inflated chamber, with short tubes serving as apertures located at each corner. The specimen illustrated by Holcová was recovered from the Pragian (Lower Devonian) in the Czech Republic.

Type Level: Early Silurian (Aeronian), uppermost part of the Qusaiba Formation. Holcová (2002) reported the species from the Lower Devonian (Lochkovian to Pragian) of the Czech Republic.

Type Locality: Old Qusaiba Village, Qasim District, Saudi Arabia.

Type specimens: Housed in the collections of the EMRC, Kraków, Poland in cabinet 7, drawer 8.

Family STEGNAMMINIDAE Moreman 1930
Genus *Ceratammina* Ireland 1939

Ceratammina sp. 1
Plate 1, figures 10, 13

Material: Three specimens from two samples.

Dimensions: Specimens range from 350 μm to 687.5 μm in length, and 175 μm to 350 μm in diameter across the tubular chamber.

Description: Test free, elongated, with undivided chamber, uniform test size, somewhat bent, exhibits a nipple-like shape in the early portion of the test. Aperture terminal located on the end of the extended portion. Wall constructed of medium to coarse siliceous particles.

Remarks: This species is similar to *Ceratammina cornucopia* Ireland 1939, which differs in having a horn-like shape in the early portion.

Type Level: Early Silurian (Aeronian), uppermost part of the Qusaiba Formation.

Type Locality: Old Qusaiba Village, Qasim District, Saudi Arabia.

Type Specimens: Housed in the collections of the EMRC, Kraków, Poland in cabinet 7, drawer 8.

Genus *Thuramminoides* Plummer 1945

Thuramminoides plummerae Kaminski and Perdana, **n. sp.**
Plate 1, figures 17–18

pars *Thuramminoides sphaeroidalis* PLUMMER 1945, p. 218, pl. 15, fig. 8.

Etymology: After Dr. Helen Plummer, who first illustrated a specimen.

Material: 24 specimens from three samples.

Dimensions: Specimens range from 187.5 μm to 600 μm in diameter.

Description: Test free, unilocular, spheroidal and strongly compressed, bearing several protuberances at the edge of its periphery. The protuberances exhibit a rounded terminal short tube-like opening.

Remarks: These specimens are similar to one of the paratypes of *Thuramminoides sphaeroidalis* Plummer 1945, which is here assigned to a new species owing to the distinctive protuberances at the margin of the test.

Type Level: Early Silurian (Aeronian), uppermost part of the Qusaiba Formation.

Type Locality: Old Qusaiba Village, Qasim District, Saudi Arabia.

Type Specimens: Deposited in the EMRC, Kraków, Poland, in cabinet 7, drawer 8.

Order AMMODISCIDA Mikhalevich 1980
Suborder HIPPOCREPININA Saidova 1981
Family HYPERAMMINIDAE Eimer and Fickert 1899
Genus *Hyperammina* Brady 1878

Hyperammina sinuosa Kaminski and Perdana, **n. sp**.
Plate 1, figures 4–6

Etymology: From the sinuous aspect of the tubular chamber.

Material: Three specimens from one sample.

Dimensions: Specimens range from 275 μm to 437 μm in length, and 100 μm to 112 μm in diameter across the tubular chamber.

Description: Test free, bilocular, elongated, with a rounded proloculus and an undivided short bent or sinuous tubular second chamber. Proloculus may be slightly wider than the tubular chamber. Aperture terminal, situated at the open end of the tube. Wall thin, constructed of medium to coarse siliceous particles.

Remarks: The species is characterized by its globular proloculus, which is visible in immersion oil, and its short tubular chamber which may be bent or slightly sinuous. The specimens are laterally compressed. Our species differs from the Ordovician species *Hyperammina minuta* Moreman 1930 in possessing a thinner more coarsely agglutinated wall and short tubular section.

Type Level: Early Silurian (Aeronian), uppermost part of the Qusaiba Formation.

Type Locality: Old Qusaiba Village, Qasim District, Saudi Arabia.

Type Specimens: Deposited in the EMRC, Kraków, Poland, in cabinet 7, drawer 8.

Order LITUOLIDA Lankester 1885
Suborder LITUOLINA Lankester 1885
Superfamily LITUOLOIDEA de Blainville 1827
Family LITUOLIDAE de Blainville 1827
Genus *Ammobaculites* Cushman 1910

Ammobaculites qusaibaensis Kaminski and Perdana, **n. sp.**
Plate 1, figures 11–12.

Etymology: From the name of Qusaiba village, Saudi Arabia.

Material: Three specimens.

Dimensions: Specimens range from 219 µm to 350 µm in length, and 93 µm to 156 µm in diameter across the uniserial portion.

Description: Test free, small, elongated, early portion close coiled, comprised of only four visible chambers, separated by straight radial sutures, with a depressed umbilicus; later uncoiling and rectilinear, rounded in cross-section, comprised of three irregular, uniserial, slightly inflated chambers. Sutures in the uniserial portion depressed. Wall medium to coarsely agglutinated. Aperture terminal, rounded, at the end of a broad neck.

Remarks: A small, somewhat irregular *Ammobaculites* species with few chambers. Compared with the Early Devonian specimen illustrated by Holcová (2002), our specimens have a smaller coiled portion and somewhat more inflated uniserial chambers. Holcová's specimen of "*Ammobaculites* sp. 1" has five chambers in the uniserial part, and the aperture is shifted toward the dorsal margin of the test as in the genus *Ammomarginulina*. The specimen illustrated by Holcová (2002) as *Ammobaculites* aff. *leptos* Gutschick and Treckman 1959 possesses a uniserial portion that is much narrower than the coiled portion.

Our finding of typical specimens of *Ammobaculites* in the Qusaiba Formation of Saudi Arabia pushes back the known stratigraphic range of the genus from the late early Devonian (Dalejan Třebotov Limestone of the Czech Republic) to the Early Silurian (Aeronian). *Ammobaculites gutschicki* Conkin 1961 differs in having a coiled portion that is generally broader than the uniserial part, and in possessing chambers that are more inflated in the uniserial part.

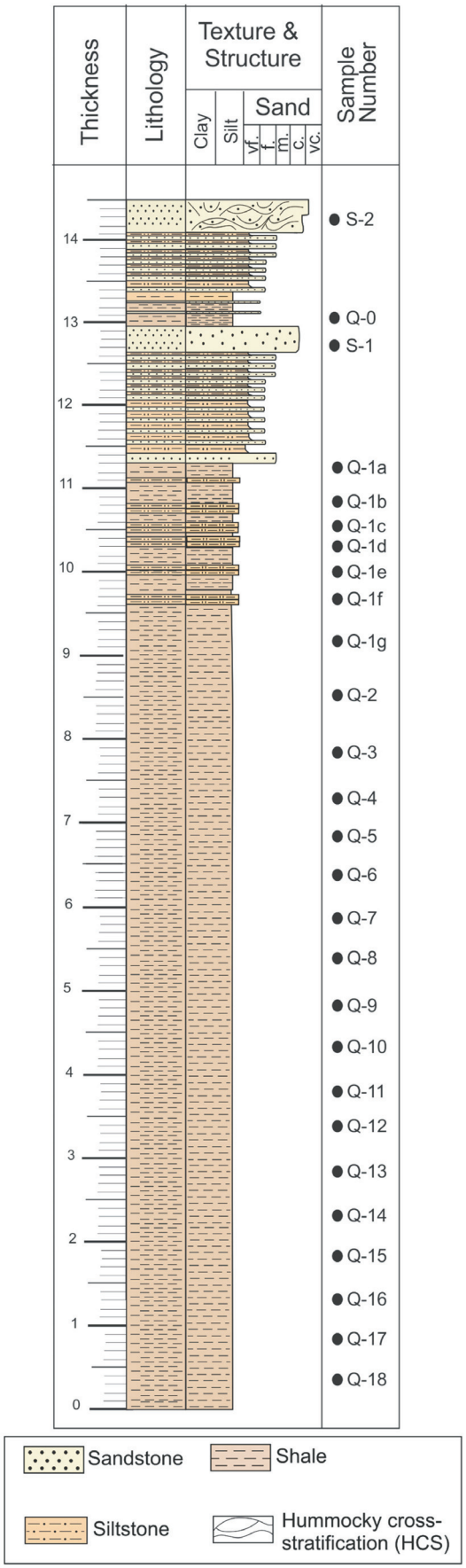
Type Level: Early Silurian (Aeronian), uppermost part of the Qusaiba Formation.

Type Locality: Old Qusaiba Village, Qasim District, Saudi Arabia.

Type Specimens: Deposited in the EMRC, Kraków, Poland, in cabinet 7, drawer 8.

Genus *Simobaculites* Loeblich and Tappan 1984

Simobaculites sp. 1
Plate 1, figures 15–16



TEXT-FIGURE 3 →
Lithological log of the studied section, showing the positions of micropaleontological samples.

Material: Three specimens.

Dimensions: Specimens range from 237 µm to 575 µm in length, and 112 µm to 200 µm in diameter across the uniserial portion.

Description: Test free, coiled in the early stage, uncoiling tangentially and straight in the final uniserial portion. The initial coil is comprised of six to seven irregular rounded chambers in the final whorl, separated by straight depressed radial sutures, with a distinct coil suture and depressed umbilicus. Uncoiled portion consists of three irregular chambers, broader than high, rounded to ellipsoidal in cross section, separated by depressed sutures. Wall consists of fine siliceous material. Aperture terminal, with an ellipsoidal shape.

Remarks: Our specimens bear superficial resemblance with the early Mississippian species *Ammobaculites leptos* Gutschick and Treckman, which was regarded by Loeblich and Tappan to be the oldest known representative of the genus. However, the *Ammobaculites leptos* type specimens possess an undivided early portion and a later portion consisting of pseudochambers – these features are clearly visible in text-fig 3 of Gutschick and Treckman (1959). They therefore do not belong in the genus *Ammobaculites*, which has true (overlapping) chambers. Our specimens from the Qusaiba Shale appear to have clearly defined sutures in the uncoiled part and therefore true chambers, even though these are somewhat irregular. Our finding revises the known stratigraphic range of the genus, which was previously reported to range upward from the upper Pennsylvanian (Loeblich and Tappan 1987).

Type Level: Early Silurian (Aeronian), uppermost part of the Qusaiba Formation.

Type Locality: Old Qusaiba Village, Qasim District, Saudi Arabia.

Type Specimens: Deposited in the EMRC, Kraków, Poland, in cabinet 7, drawer 8.

CONCLUDING REMARKS

An Early Silurian foraminiferal assemblage has been found in the Qusaiba shale and in shale interbeds within the lower part of the overlying Sharawra sandstone Formation of the Qalibah Group in the type section near Old Qusaiba Village, Qasim Region of Saudi Arabia. Foraminifera-bearing samples were recovered from silty shale of the uppermost part of the Qusaiba Formation, corresponding to the "Gray shale facies" of Hayton et al. (2017) of which was deposited in an offshore to lower shoreface palaeoenvironment (Abbas et al. 2017). In this transitional facies near the gradational contact between the Qusaiba and Sharawra formations, interbedded thinly bedded sandstones show signs of bioturbation, indicating that oxygenated conditions existed at the sea floor. Palynomorphs from the Sharawra Formation suggest deposition in a shallow marine environment, close to emerged land with primitive plants (Al-Hajri and Paris 1998). The recovered foraminiferal assemblage is diverse compared with coeval assemblages described from Europe and North America. The assemblage is comprised mostly of monothalamid genera such as *Saccammina, Thuramminoides, Thurammina, Amphitremoida, Tolypammina, Hyperammina, Bathysiphon, Rhizammina, Rhabdammina, Psammosphaera, Glomospira, Lituotuba,* and *Lagenammina.* The assemblage displays some affinity to the Silurian–Devonian agglutinated assemblages of the Barrandian area of the Czech Republic, where at least one of our new species has been illustrated previously. Other foraminiferal species from the Qusaiba Shale Formation are apparently new to science and are described here for the first time.

Unexpectedly, the assemblage from the Qusaiba shale also contains rare multichambered agglutinated foraminifera, including new species belonging to the genera *Ammobaculites* and *Simobaculites* that until now were thought to originate in the Devonian and Carboniferous, respectively. Holcová (2002, 2004) reported species of *Ammobaculites* from the Lower-Middle Devonian transition (Třebotov Limestone) of the Barrandian area in the Czech Republic, whereas Loeblich and Tappan (1987) reported *Simobaculites* as ranging upward from the upper Pennsylvanian. Our finding of multichambered lituolids in the Lower Silurian (Aeronian) of Saudi Arabia therefore provides an important new observation for the revision of the early evolutionary history of the multichambered globothalamid foraminifera.

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PLATE 1

Scale bars = 100 µm

1-3 *Saccamminita galinae* n.sp., sample Q-12.

4-6 *Hyperammina sinuosa* n.sp, sample Q-12.

7 *Simobaculites* sp. 1, sample Q-4.

8-9 *Thurammina pentagona* n.sp, sample Q-11.

10 *Ceratammina* sp. 1, sample Q-12.

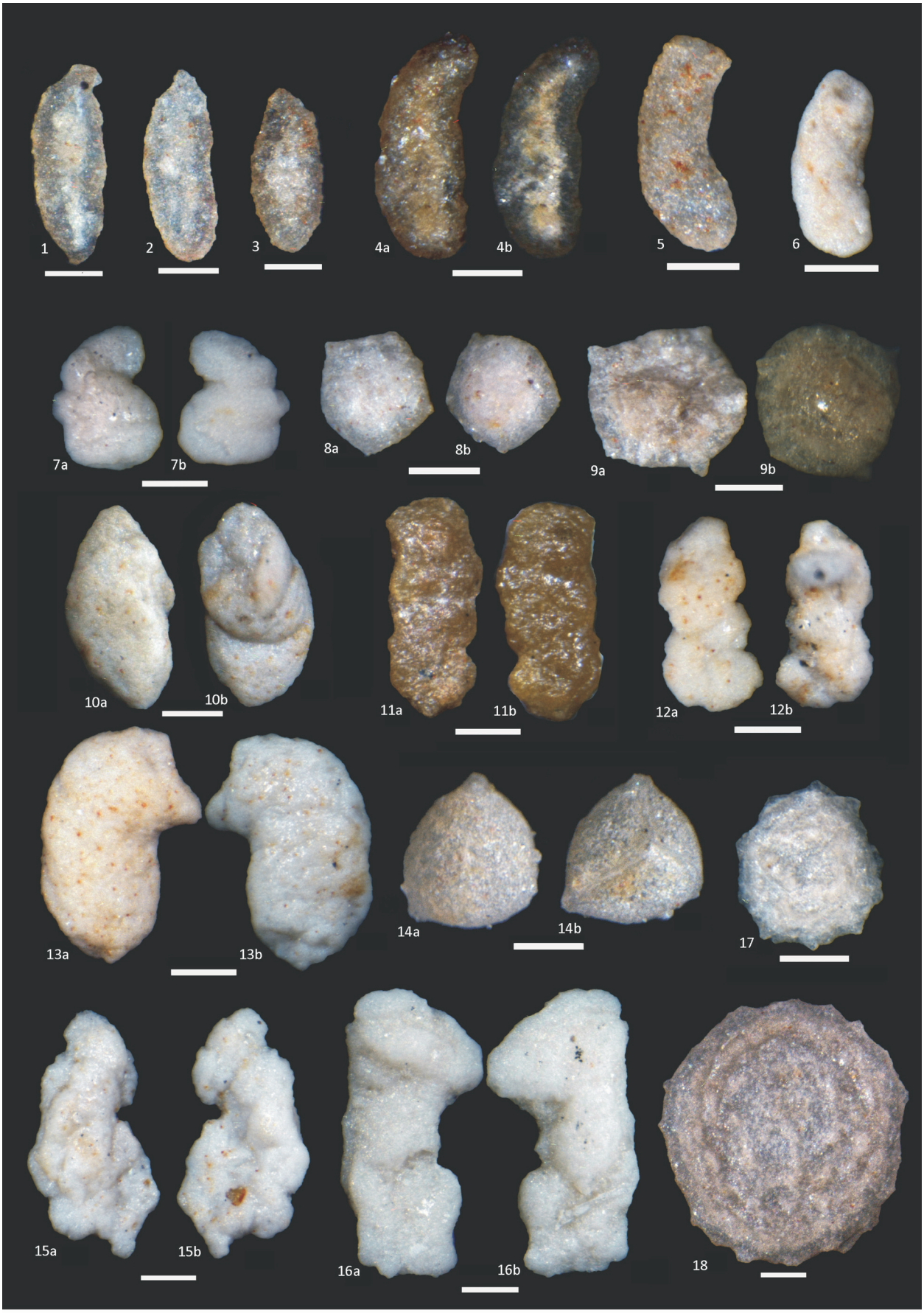
11-12 *Ammobaculites qusaibaensis* n.sp, 11. Sample Q-4; 12. Sample Q-12.

13 *Ceratammina* sp. 1, sample Q-4.

14 *Thurammina holcovae* n.sp, sample Q-7.

15-16 *Simobaculites* sp. 1, sample Q-4.

17-18 *Thuramminoides plummerae* n.sp, sample Q-10.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