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BULBOBACULITES ATTASHENSIS SP. NOV., A NEW AGGLUTINATED FORAMINIFERA FROM THE MIDDLE JURASSIC D7 ATTASH MEMBER OF THE DHRUMA FORMATION, CENTRAL SAUDI ARABIA

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Abstract: The new species *Bulbobaculites attashensis* sp. nov. is described from the rhythmite limestone and marl sediments of the D7 Attash Member of the Middle Jurassic (lower Callovian) Dhruma Formation in Central Saudi Arabia. This species is characterized by its coarsely agglutinated wall, streptospiral initial coiling, and a distinct bulbous initial coil. The occurrence of this species in limestone-marl rhythmite deposits suggests its adaptation to fluctuating environmental conditions, including changes in water depth, salinity, and nutrient flux, associated with rhythmic sedimentation.

Keywords: Taxonomy, new species, Mesozoic, Middle East.

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INTRODUCTION

The genus *Bulbobaculites* is characterized by its streptospirally enrolled globular and inflated chambers (Maync, 1952), in contrast to the genus *Ammobaculites* with an early planispirally coiled portion and a coarsely agglutinated wall (Cushman, 1910). It is also recognized to be distinct from the alveolar-walled *Haplophragmium* (Maync, 1952; Loeblich and Tappan, 1987). Its type species, *Ammobaculites lueckei*, identified from the Upper Cretaceous Colon Shale of Colombia, exhibits irregular early coiling, similar to the streptospiral coil of *Bulbophragmium* (Cushman and Hedberg, 1941). Most species belonging to this genus have been identified from Triassic to Upper Cretaceous sediments (Neagu, 1962, 2011; Kuhnt and Kaminski, 1990; Kaminski *et al*., 1992; Holbourn and Kaminski, 1995; Nagy *et al*., 2011; Holbourn *et al*., 2013; Hess *et al*., 2014). However, another species, *Bulbobaculites gorlicensis*, recently was reported from Paleogene sediments (Waśkowska, 2014).

Various authors (e.g., Cushman and Hedberg, 1941; Neagu, 1990; Hedinger, 1993; Holbourn and Kaminski, 1995; Waśkowska, 2014) have described different species of *Bulbobaculites* from deep-water settings, such as flysch-type shale deposits. However, the identification of *B. felixi* from the shallow-water carbonates of the Lower Cretaceous (upper Aptian) in the Subpiatra Quarry, western Romania, highlights its occurrence in different environmental settings (Pleş *et al.,* 2016). Unlike the previously reported species *B. problematicus*, identified from Upper Cretaceous marl-limestone alternations with assumed water depths of 30–100 m (Besen *et al*., 2021, 2023), the new species *B. attashensis* sp. nov., is identified in rhythmite limestone and marl sediments of the Atash Member of the D7 unit of the Middle Jurassic Dhruma Formation, in Central Saudi Arabia. It occurs in an epeiric carbonate ramp deposit, with a water-depth range of approximately 5–10 m, highlighting a different palaeoenvironmental setting. Its unique morphological characteristics, including a varied coiling mode and specific palaeoenvironmental conditions, justify its description as a new species, previously unreported in the Middle Jurassic of the Gulf region. The occurrence of this species in these rhythmite deposits possibly suggests its adaptation to fluctuating environmental conditions, including changes in water depth, salinity, and nutrient availability.

The Jurassic Central Basin of Saudi Arabia is known in the palaeontological literature for its remarkable assemblages of endemic species of ammonites (Arkell, 1952), echinoids (Kier, 1972), brachiopods (Cooper, 1989), and benthic foraminifera. Redmond (1964) recognized the endemic nature of the agglutinated benthic foraminifera and described eight new species of lituolids from the Upper Jurassic and Lower Cretaceous of Saudi Arabia. These genera, *Pseudomarssonella, Riyadhella*, and *Dhrumella* were also reported by Redmond (1965). Two identified late Bajocian species, *Haurania amiji* and *H. deserta*, led to the establishment of the Haurania Zone in the Middle Jurassic Dhruma Formation's lower section (Powers *et al.,* 1966). Extensive studies by Hughes (2004, 2006, 2009, 2018) have documented numerous species of benthic foraminifera and established biozones for the Dhruma Formation. Al-Dhubaib (2010) reported the occurrence of *Riyadhella elongata*, *Pseudomarssonella bipartita*, *Trocholina aptiensis*, *Meyendorffina bathonica*, and various *Neotrocholina* and *Andersenolina* species in the upper section (D7 unit) of the Middle Jurassic Dhruma Formation. The foraminiferal content of the formation's subsurface reservoirs has been described by Al-Dhubaib (2010), Lindsay *et al*. (2006), and Hughes (2009, 2018). All these studies were based on the traditional thin-section method.

Recent studies through disaggregation methods have reported diverse foraminiferal assemblages from the formation's older and intermediate units (Malik *et al*., 2020; Bu Khamsin, 2021, unpublished master's thesis). An important point made in Malik's study is the fact that disaggregation techniques reveal a much higher species diversity in the Dhruma Formation than traditional thin-section studies. Kaminski *et al.* (2018a, b, 2020) reported the occurrence of planktonic and shallow-water agglutinated benthic species: *Globuligerina* sp., *Conoglobigerina* sp., and *Ammobaculoides dhrumaensis,* from the basal marls of the marly D5 unit and lower shaley units (D1–D2), respectively. These discoveries highlight the critical need for detailed micropalaeontological studies in the upper section (D7 unit) of the Dhruma Formation to enhance biostratigraphic correlation and improve high-resolution sequence stratigraphy in the region. The aim of this study is to describe a common, but previously unidentified lituolid foraminifer belonging to the genus *Bulbobaculites*, found in the rhythmite sediments of limestone and marl in the D7 unit (Attash Member) of the Dhruma Formation, using the acetic acid disaggregation method. This study advances our geological understanding of the Middle Jurassic foraminiferal profile in the region, contributing to the identification of maximum flooding surfaces in the upper section of the formation. The abundance of *Bulbobaculites attashensis* sp. nov., along with its occurrence within marl-limestone rhythmites and association with finer-grained sediments, reflects periods of reduced sediment input and relatively deeper, more stable marine conditions. These conditions are indicative of maximum flooding events, characterized by peak transgression and low-energy depositional environments (Zecchin *et al.*, 2021, 2023).

STUDY AREA

The Middle Jurassic Dhruma Formation is well-exposed in the Riyadh region of Central Saudi Arabia in the Shaqra Group (Fig. 1). It has been subdivided into lower, middle, and upper sections at Khashm adh Dhibi (Powers *et al.*, 1966). Samples for this study were collected from the youngest section (D7-Attash Member). This member is dominated by golden-brown marl and packstone limestone (Fig. 2), with an outcrop thickness of 14.1 m and 12.2 m in the subsurface (Al-Dhubaib, 2010).

The geographic focus is the Darma quadrangle, located west of Riyadh (Fig. 3b). The studied outcrop section is along Highway 5395, near Ajaj Village (N24°10.779′, E46°26.853′), approximately 82 km from Riyadh (Fig. 3A). The reference section of the Dhruma Formation, measured at 375 m by Powers *et al*. (1966) and later revised to 447 m by Vaslet *et al*. (1985), is well exposed near Riyadh, particularly at Khashm al ‘Atash (N24°10′50″, E46°27′53″).

MATERIALS AND METHODS

Field work and sample collection

This study analyzed thirty-three samples of indurated limestone and marl, collected from the D7-Attash Member of the Dhruma Formation. The outcrop has irregular exposure, with some areas well-exposed and others more challenging to access. This variability hindered regular spacing in sample collection; as a result, the sampling interval varied along the entire outcrop section.

Foraminifera Extraction

The study used the modified acetic acid (CH_3COOH) leaching method (Malik *et al.*, 2022) to disintegrate and recover the foraminiferal species from well-indurated limestone and lithified marl samples. The samples were broken to a size of about 2–5 mm to increase surface area and weighed into 100 g portions to facilitate efficient dissolution and microfossil recovery. A diluted solution of 60% acetic acid was used to dissolve the samples for 8–10 hours. The dissolved samples were thoroughly washed through a 63 µm sieve to extract the foraminifera. Cleaned samples were dried in an electric oven at 100°C for 8 h. Residue from the >125 µm sieve was selected and mounted on cardboard microslides. The foraminiferal content was sorted under a binocular microscope, on the basis of shell morphology. Selected specimens of the genus *Bulbobaculites* were imaged, using a Gemini 450 Scanning Electron Microscope (SEM) and light microscope at the College of Petroleum and Geosciences, King Fahd University of Petroleum and Minerals, Saudi Arabia, for detailed analysis.

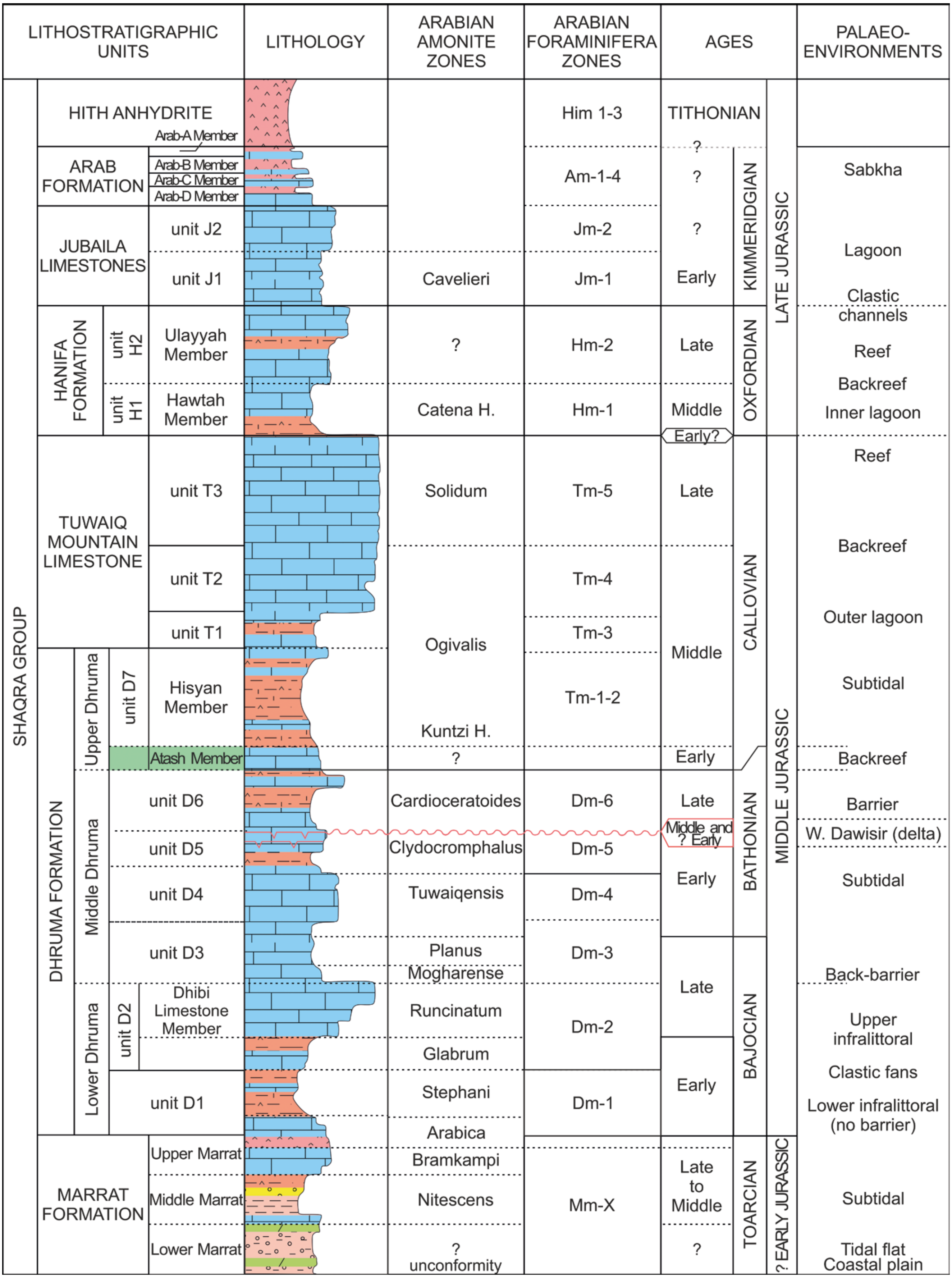

Fig. 1. Lithostratigraphy, biostratigraphy, chronostratigraphy, and palaeoenvironment of the Shaqra Group. Modified from Énay and Mangold (2021) and Hughes (2018). The studied D7 unit (Attash Member) of the Dhruma Formation is highlighted in green (for greater detail, see Figure 4).

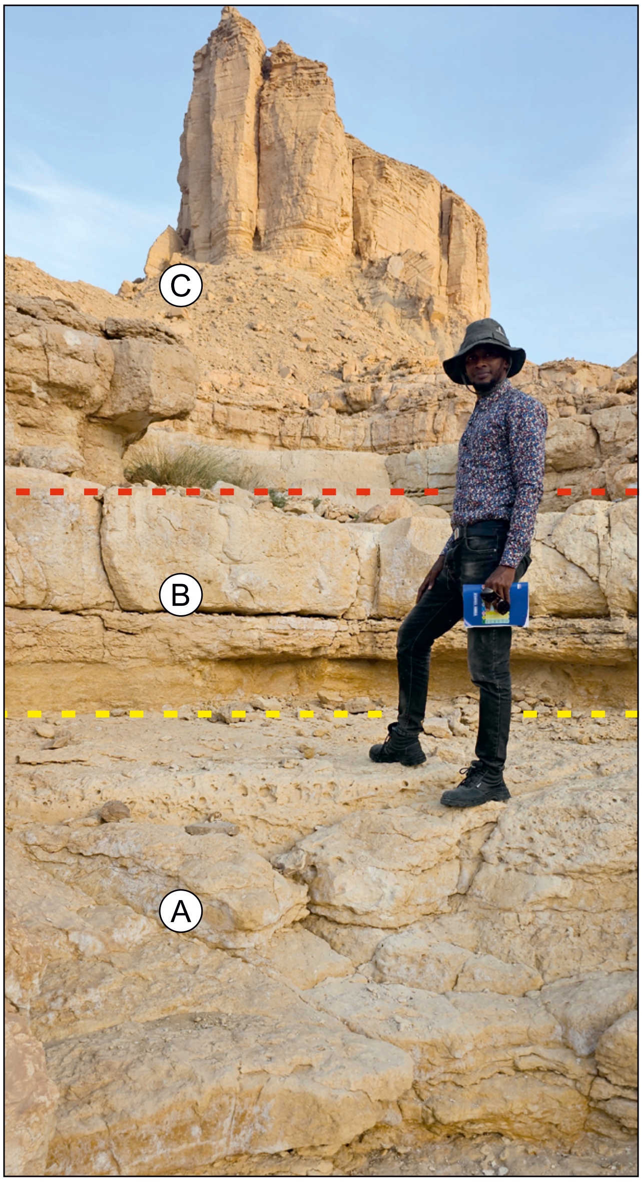

Fig. 2. Field photograph, showing the irregular base of the studied Atash outcrop, featuring limestone and marly sediments. A distinct contact is observed between the upper Hisyan (B) and underlying Atash Member (A) of the Dhruma Formation, as well as the overlying Tuwaiq Mountain Formation (C).

RESULTS

A total of 93 specimens were extracted from the 33 analyzed samples of the Attash outcrop of the Dhruma Formation D7 unit. The identified species (*Bulbobaculites attashensis* sp. nov.), is notably absent in sections, dominated by massive limestone in the studied section. Marl-limestone alternations are more likely attributed to environmental fluctuations, such as changes in water depth, sediment supply, or nutrient availability (Hughes, 2004, 2006; Al-Mojel and Razin, 2022), rather than to diagenetic overprints. While diagenetic processes, such as dissolution or recrystallization, can influence the final lithology (e.g., Munnecke and Servais, 2008), sedimentary structures like cross-bedding and preserved fossil assemblages across marl and limestone layers in the studied section strongly suggest a primary depositional origin.

The new species is observed to be present in sections, where the lithology consists of alternating layers of limestone and marl (Fig. 4). These samples SH-7 to SH-11, SH-15 to SH-16, SH-21 to SH-24, and SH-27 to SH-31, indicate more favorable environmental conditions for *Bulbobaculites attashensis* sp. nov. Marl appears to be conducive to preservation and reflects former supportive ecological conditions, characterized by low energy and slow sedimentation rates.

SYSTEMATIC PALAEONTOLOGY

The systematics of agglutinated foraminifera follows Kaminski (2014).
Suborder LITUOLINA Lankester, 1885
Superfamily RECURVOIDOIDEA Alekseychik-Mitskevich, 1973
Family AMMOBACULINIDAE Saidova, 1975
Subfamily HAPLOPHRAGMIINAE Maync, 1952
Genus *Bulbobaculites* Maync, 1952

Type species: *Ammobaculites lueckei* Cushman and Hedberg, 1941, p. 83, by original designation.

Bulbobaculites attashensis Jalloh and Kaminski, sp. nov.
Fig. 5Aa–Fc

Material: 93 specimens.
Type specimens: The slides, containing the holotype and figured paratypes, have been deposited in the European Micropalaeontological Reference Centre in Kraków, Poland. Specimens are housed in Cabinet 7, drawer 12.
Locus typicus: An inselberg outcrop, capped by the Tuwaiq Mountain Limestone Formation, on the south side of Highway 5395, overlooking Ajaj Village (N24°10.779′; E46°26.853′), in the limestone and marl sediments of the lower Callovian D7-Attash Member of the Dhruma Formation, Darma Quadrangle, west of Riyadh, Central Saudi Arabia.
Stratum typicum: The holotype of *Bulbobaculites attashensis* sp. nov. was selected from Sample SH-27, at a stratigraphic height of 10.5 m from the top of the lower Callovian D7-Attash Member of the Middle Jurassic Dhruma Formation.
Etymology: The species name "*attashensis*" is derived from the Attash Member of the D7 unit in the Dhruma Formation, located in Central Saudi Arabia.
Diagnosis: A *Bulbobaculites* with an inflated streptospiral coil followed by a uniserial portion consisting of three chambers, with a coarsely agglutinated wall.
Dimensions of type specimens: The holotype has a horizontal diameter of 265–351 µm, width of 125–181 µm, thickness of approximately 110 µm. The paratypes have a length of 292–470 µm, width of 160–221 µm, thickness of 131–220 µm.
Description: Test medium-sized and elongate, with an early stage, characterized by streptospirally enrolled, globular, and inflated chambers, consisting of approximately six

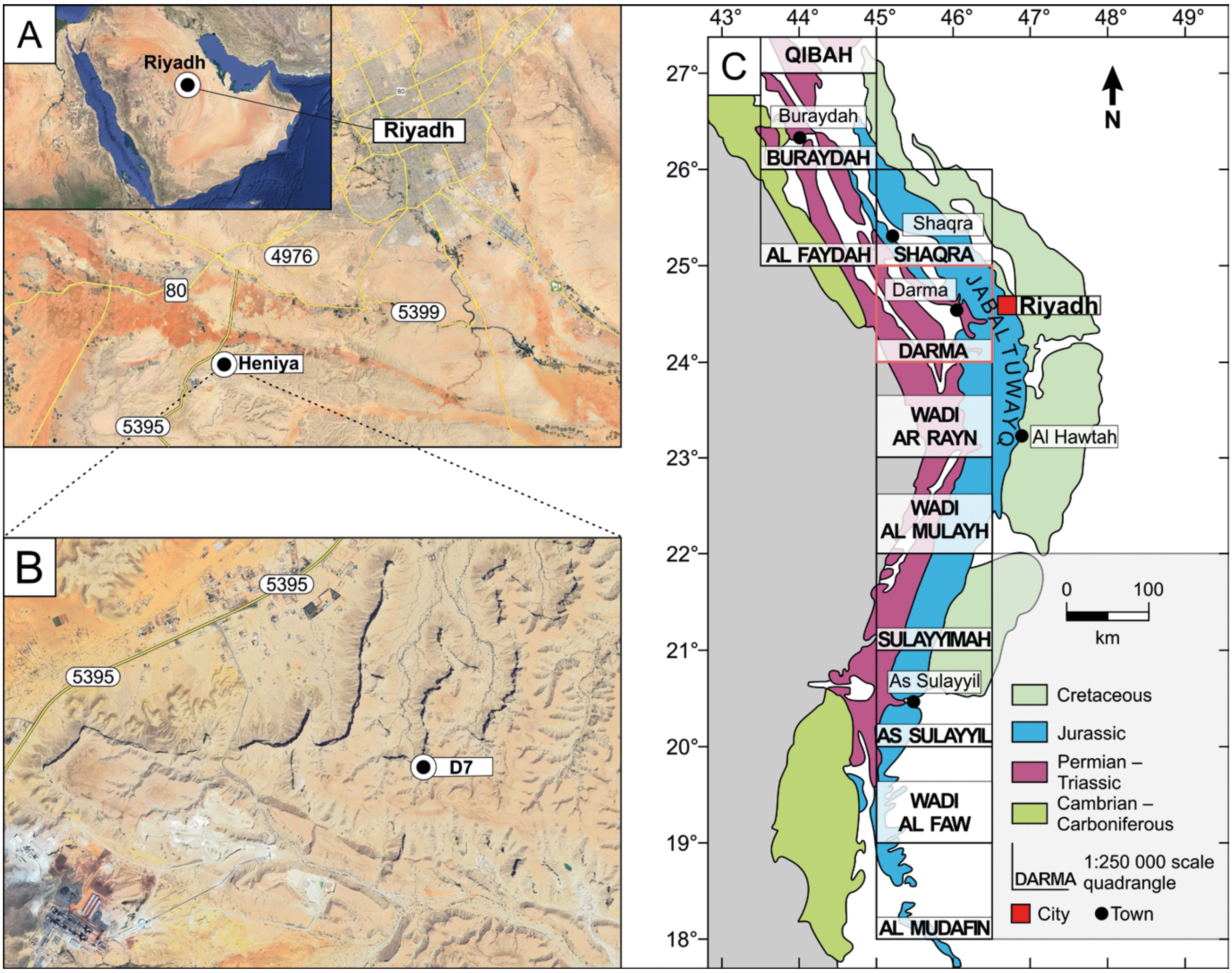

Fig. 3. Location of the studied site. **A.** Satellite image, showing the study localiy (from Google Earth). **B.** Enlarged satellite image, showing Road 5395, leading to the studied outcrop location (D7 unit; from Google Earth). **C**. The red square indicates the Darma Quadrangle and the Jurassic in Central Saudi Arabia (Fisher *et al.*, 2001).

chambers. Later chambers uncoiled and rectilinear, with up to three chambers: sutures distinct, depressed, and horizontal. The agglutinated wall is finely structured, smoothly finished, with a simple interior. The chambers maintain a constant shape without tapering towards a neck, ending in a terminal aperture with a small, rounded opening.

Remarks: *Bulbobaculites attashensis* sp. nov. is characterized by its coarsely agglutinated wall, streptospiral coiling, and a distinct bulbous initial portion. The species also exhibits an elongated test that may be slightly curved, with a small number of progressively enlarging chambers and a relatively large overall size, distinguishing it from other species within the genus. It differs from the type species *B. lueckei* (Cushman and Hedberg) in possessing a coarsely agglutinated wall and more elongated chambers in the uniserial portion.

Observed occurrence: *Bulbobaculites attashensis* sp. nov. is prevalent in the studied Attash Member outcrop at a stratigraphic height of 4.5 to 13.5 m above the base, specifically observed within the following samples: SH7 to SH11, SH15 to SH16, and SH21 to SH24, SH27 and SH31 (all composed of marl and limestone). The specific palaeoenvironmental conditions of the Dhruma Formation during the Middle Jurassic (its semi-isolated tropical setting and fluctuating salinity) probably facilitated the development and preservation of *B. attashensis* sp. nov. in this region.

DISCUSSION

Geographic Distribution of the Genus

Species of the genus *Bulbobaculites* have a broad stratigraphic and geographic distribution, ranging from the Triassic to the Upper Cretaceous and into the Paleogene, across both deep- and shallow-water environments. It has been identified from the Colon Shale of Colombia (Cushman and Hedberg, 1941), and from shallow-water carbonates of the Lower Cretaceous in Romania (Pleş *et al.*, 2016). It also was reported from Paleogene flysch deposits (Waśkowska, 2014). The genus is well-documented across multiple time periods and locations (Neagu, 1962, 2011; Kuhnt and Kaminski, 1990; Kaminski *et al.*, 1992; Holbourn

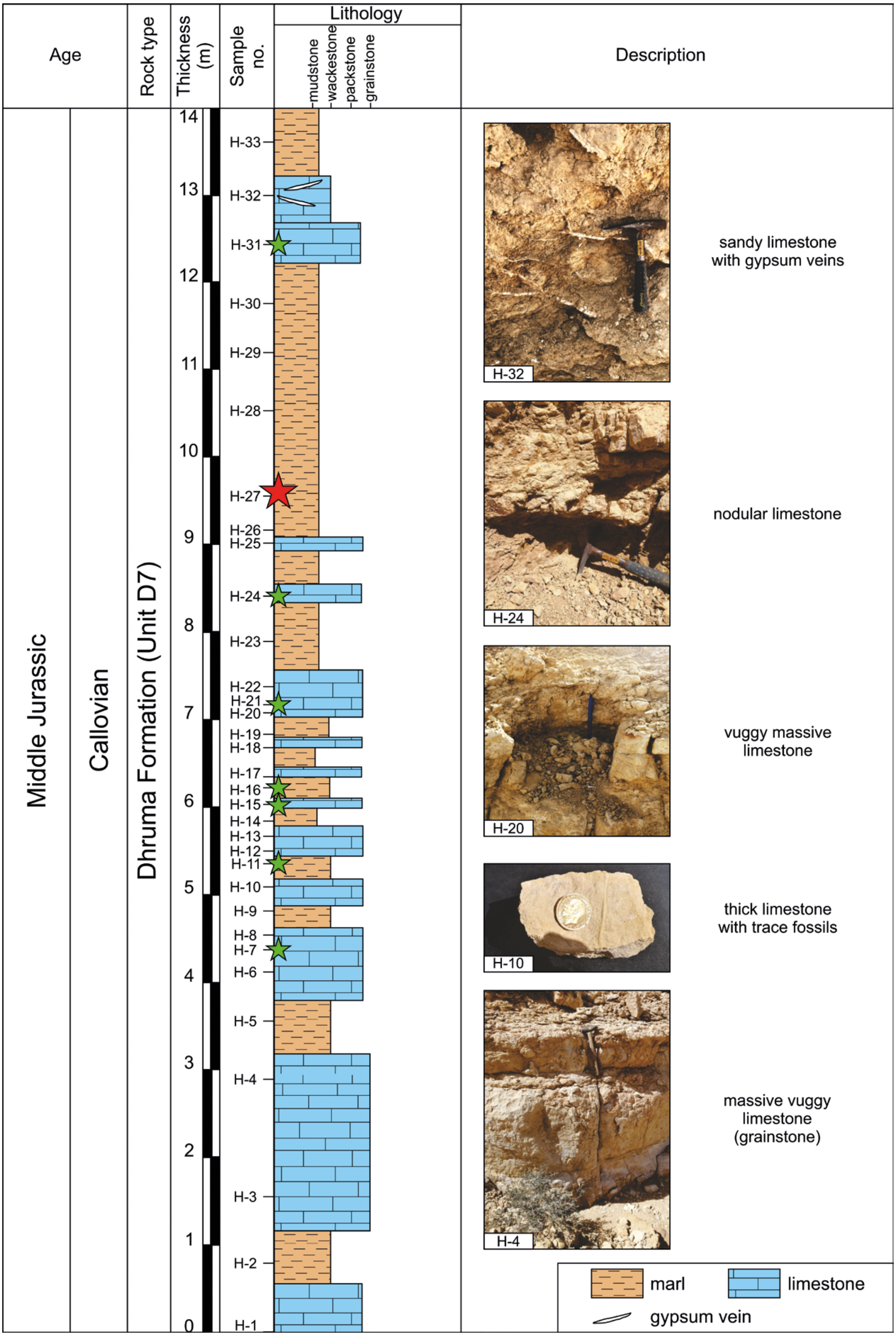

Fig. 4. Stratigraphic log of the Atash Member (D7 unit) of the Upper Dhruma Formation. The red star indicates the position of the identified holotype (HT), while the green stars represent the paratypes (PT).

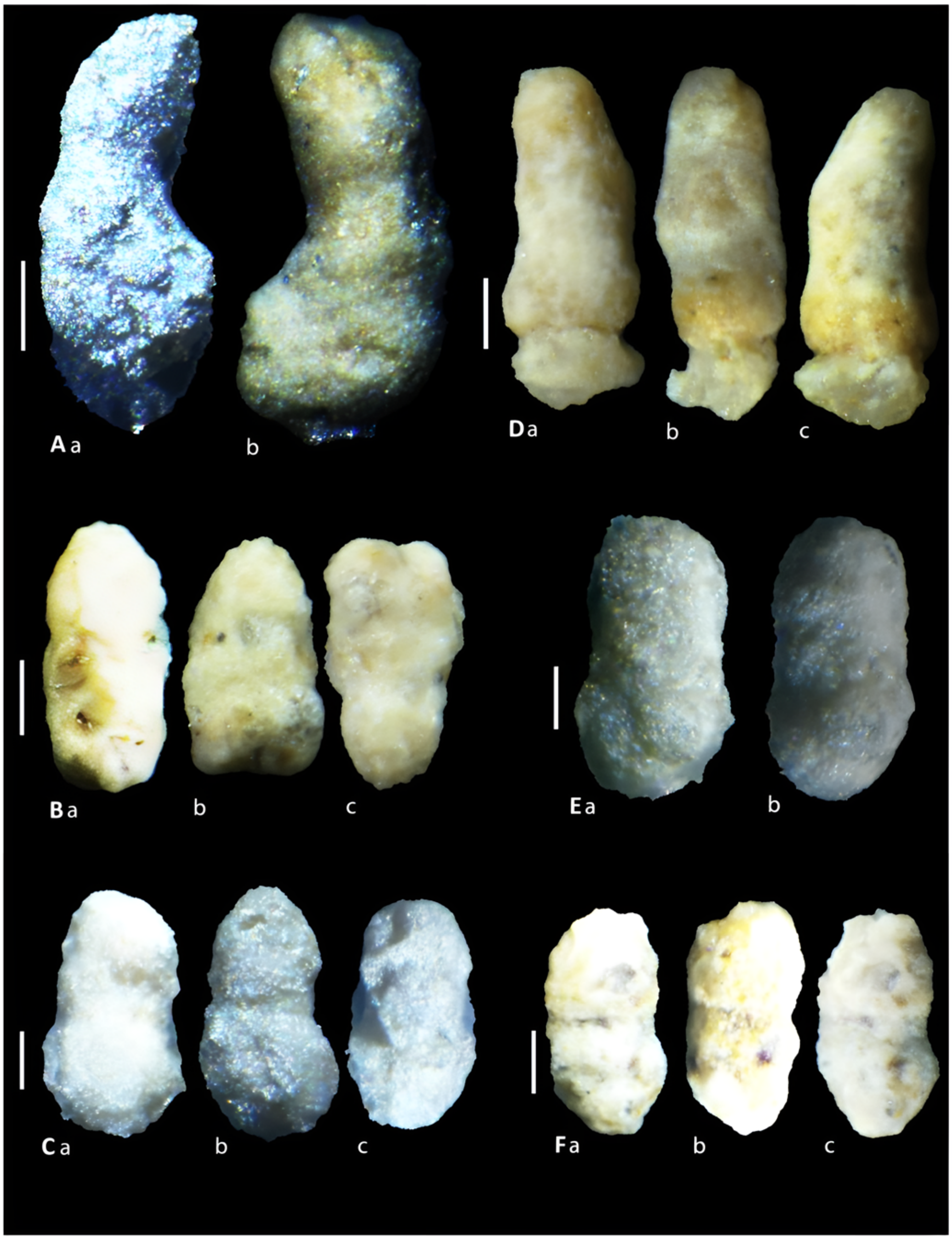

Fig. 5. *Bulbobaculites attashensis* sp. nov., from the D7-Attash Member, Middle Jurassic Dhruma Formation, Riyadh Region, Central Saudi Arabia. **Aa–b**. Holotype (EMRC 7/12a-1), Sample SH-27 at a stratigraphic height of 10.5 m (Fig. 4). **Ba–Fc**. Paratypes (EMRC 7/12a-2) from samples SH-7, SH-11, SH-15, SH-16, SH-21, SH-24, and SH-31, located at stratigraphic heights ranging from 4.5 to 13.5 m (Fig. 4). Specimen slides are registered in the EMRC as 7/12a, 1-2. All specimens were photographed, using a light microscope at the Micropaleontology Lab of the College of Petroleum Engineering and Geosciences, KFUPM. Scale bars 100 μm.

and Kaminski, 1995; Nagy *et al.*, 2011; Holbourn *et al.*, 2013; Hess *et al.*, 2014). *Bulbobaculites attashensis* sp. nov. is here recorded in the Middle Jurassic (lower Callovian) D7 unit of the Dhruma Formation in Central Saudi Arabia.

Paleoenvironmental implications of *Bulbobaculites attashensis* sp. nov.

The presence of *B. attashensis* sp. nov. in the alternating lithologies of marl and limestone at the Atash outcrop (D7 unit) indicates that these environments were favourable for proliferation of the species. The observed abundance of this agglutinated foraminifera suggests periods of relatively stable marine conditions during transgression. Early transgressive phases are often associated with unstable, high-energy conditions (Sharland *et al*., 2001).The rhythmic marl-limestone layers hosting *B. attashensis* sp. nov. reflect a shift to lower-energy, fine-grained sedimentation. The tests of *B. attashensis* sp. nov., appear robust, rather than particularly delicate. The species aids in identifying maximum flooding horizons in the upper section of the Dhruma Formation. The abundance of *B. attashensis* sp. nov. within specific marly intervals is consistent with fine-grained, low-energy depositional environments, which are characteristic markers of maximum flooding events (Al-Mojel and Razin, 2022). The peaks in the abundance and diversity of benthic foraminifera, widely recognized as primary tools for identifying maximum flooding surfaces (Fillon, 2007; Gutiérrez Paredes *et al*., 2017; Zecchin *et al*., 2021, 2023), are observed in the studied section.

The absence of the new species in the massive limestone suggests that it avoided a high-energy depositional environment. This is evidenced in the D7 Unit by the presence of cross-bedding, coarse-grained textures, scoured surfaces, and coral fragments. These conditions, characterized by strong water agitation and currents, are indicative of marine regression, where falling sea levels exposed marine areas (Ruban *et al.,* 2007). Such dynamic environments are less conducive to the preservation of delicate agglutinated foraminifera. This contrast between lithologies highlights the significant impact of environmental energy levels on the preservation potential of marine species.

The observed trend of *B. attashensis* sp. nov., with its intermittent presence in the lower sections and continued abundance in the middle sections of the D7-Attash outcrop, suggest a deepening-upward sequence. This trend indicates a transition from the fluctuating, higher-energy conditions of the massive limestone lithology to a more stable, low-energy environment, such as that represented by the marly sediments, supporting the interpretation of a deepening marine environment over time in the studied section.

B. attashensis sp. nov., like other agglutinated foraminifera, was sensitive to salinity variations, crucial to its distribution and abundance. This species was probably associated with stable marine environments. The widespread distribution of *B. attashensis* in the upper Dhruma Formation suggests a stable marine salinity. This stability contrasts with other Jurassic formations, such as the Arab Formation, where the presence of evaporites and the deposition of the Hith Anhydrite indicate periods of hypersalinity (Fischer *et al*., 2001; Énay and Mangold, 2021). The adaptation of endemic species to ‘restrictive’ conditions on wide, shallow platforms during the Middle Jurassic suggests they were subjected to environmental stress, including fluctuating salinity levels (Énay *et al*., 1987; Al-Husseini, 1997, 2009). In contrast, *B. attashensis* sp. nov. appears to have preferred a more stable marine environment.

CONCLUSIONS

The recorded abundance of *B. attashensis* sp. nov., is observed predominantly in marl intervals, with occasional occurrences in limestone beds, indicating adaptability to varying depositional settings. The discovery of this species in the Middle Jurassic D7 Atash Member of the Dhruma Formation in Central Saudi Arabia contributes to the understanding of foraminiferal diversity in shallow-marine environments. Characterized by a streptospiral initial coil and a uniserial portion with three chambers, it thrived in an epeiric carbonate-ramp setting at assumed water depths of 5–10 m.

These findings introduce a new marker species for the Middle Jurassic, enhancing the biostratigraphic framework of the Dhruma Formation. The species also provides a new tool for identifying maximum flooding events, refining our understanding of depositional dynamics and aiding regional stratigraphic correlations.

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