

**TAXONOMY, BIOSTRATIGRAPHY AND
MORPHOGROUPS OF BENTHIC FORAMINIFERA IN
THE D1–D2 UNITS OF THE DHRUMA FORMATION,
CENTRAL REGION OF SAUDI ARABIA**

BY

ALI HUSSAIN BU KHAMSIN

A Thesis Presented to the
DEANSHIP OF GRADUATE STUDIES

KING FAHD UNIVERSITY OF PETROLEUM & MINERALS

DHAHRAN, SAUDI ARABIA

In Partial Fulfillment of the
Requirements for the Degree of

MASTER OF SCIENCE

In
GEOLOGY

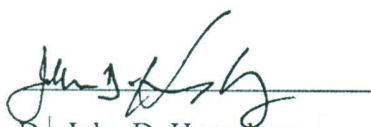
NOVEMBER, 2021

KING FAHD UNIVERSITY OF PETROLEUM & MINERALS

DHAHRAN- 31261, SAUDI ARABIA

DEANSHIP OF GRADUATE STUDIES

This thesis, written by **ALI HUSSAIN BU KHAMSIN** under the direction of his thesis advisor and approved by his thesis committee, has been presented and accepted by the Dean of Graduate Studies, in partial fulfillment of the requirements for the degree of **MASTER OF SCIENCE IN GEOLOGY**.



Dr. John D. Humphrey
Department Chairman



Prof. Suliman Saleh Al-Homidan

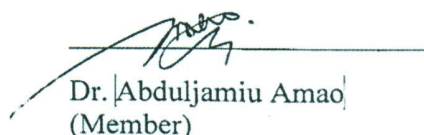
Dean of Graduate Studies



Prof. Michael A. Kaminski
(Advisor)



Dr. Khalid Al-Ramadan
(Member)



Dr. Abduljamiu Amao
(Member)

Date _____



©Ali Hussain Bu Khamsin

2021

Dedication

To my family

ACKNOWLEDGMENTS

I would like to express my deep gratitude and sincere thanks to my advisor Prof. Michael A. Kaminski for his knowledge, encouragement, guidance, patience and continuous support during all stages of this work. I would also like to thank my thesis committee members; Dr. Khalid Al-Ramadan and Dr. Abduljamiu Amao for their support and constructive feedback on my work.

TABLE OF CONTENTS

ACKNOWLEDGMENTS	IV
TABLE OF CONTENTS	V
LIST OF TABLES	VII
LIST OF FIGURES	VIII
ABSTRACT.....	VIII
ملخص الرسالة	X
CHAPTER 1	1
INTRODUCTION.....	1
1.1 Geological setting	1
1.2. Lithostratigraphy and biostratigraphy of the Shaqra Group	4
1.3. Lithostratigraphy and biostratigraphy of the Dhruma Formation	7
1.4. Foraminiferal Studies on the Dhruma Formation	10
1.5. Study Area	12
1.6. Problem Statement and Objectives	20
CHAPTER 2	22
METHODOLOGY	22
2.1 Sample Collection.....	22
2.2 Sample Processing.....	23

2.3 Foraminiferal Identification	25
2.4 Morphogroup Analysis.....	25
CHAPTER 3	27
RESULTS	27
3.1 Paleoecological analysis	36
3.2 Morphogroup analysis.....	46
3.3 Taxonomy	57
CHAPTER 4.....	174
DISCUSSION AND CONCLUSION	174
4.1 Discussion.....	174
4.2 Conclusions & Recommendations	179
REFERENCES.....	180
VITAE.....	191

LIST OF TABLES

TABLE 1. Taxonomic Summary of reported taxa.....	30
TABLE 2. Paleoecological analysis results.....	41
TABLE 3. Morphogroup percentages in the three sections.....	53

LIST OF FIGURES

Figure 1: Geology of central Saudi Arabia (modified after Ismanto, 2018).....	3
Figure 2: Lithostratigraphic column of the Shaqra Group and the ammonite zones (Fisher et al. 2001)	6
Figure 3: The lithology and age of the Dhurma formation units (Vaslet et al., 1983, modified by Al-Dhubaib, 2010).....	9
Figure 4: Stratigraphical range of important species observed in thin sections of Jurassic carbonates of Saudi Arabia (Hughes 2018).....	11
Figure 5: Location of the study area	13
Figure 6: Stop D2W, massive creamy limestone of Dhibi, D2 unit	14
Figure 7: Stop D1A, 6.4 m thick unit of shale and carbonate.....	15
Figure 8: Stop D1B, limestone interbedded with shale at the top of D1 unit.	16
Figure 9: Sedimentological log of stop D1A	17
Figure 10: Sedimentological log of stop D1B	18
Figure 11: Sedimentological log of stop D2W	19
Figure 12: Rarefaction curve of the taxa.....	40
Figure 13: Genera percentages in location D1A.....	43
Figure 14: Genera percentages in location D1	44
Figure 15: Genera percentages in location D2W	45
Figure 16: Agglutinated vs Calcareous percentages in the three locations	54
Figure 17: Agglutinated morphogroups modified after Reolid et al. (2008).	55
Figure 18: Calcareous morphogroups modified after Reolid et al. (2008).	56

ABSTRACT

Full Name : [Ali Hussain Bu Khamsin]

Thesis Title : [Taxonomy, biostratigraphy and morphogroups of benthic foraminifera in (D1-D2) units of the Dhurma Formation, Central region of Saudi Arabia]

Major Field : [Geology]

Date of Degree : [November 2021]

The Dhurma formation is part of the middle Jurassic succession in Saudi Arabia and is of Bajocian to Bathonian age. It consists of mixed carbonates and siliciclastic beds that are deposited over an extensive shallow marine carbonate platform. The siliciclastic beds are more dominant in the lower part of the formation. The knowledge of foraminifera of the middle and upper part of the Dhurma Formation is well known and based mainly on thin section analysis. The aim of this research is to study the foraminiferal content of the lower part of the formation in terms of taxonomy, distribution, morphogroups, and paleoenvironment by using disaggregation techniques. Following high resolution sampling, a total of 50 samples were collected and analyzed from three outcrops near the reference section of the Dhurma Formation. A total of 63 foraminiferal species were retrieved from the samples, among which are ten species reported for the first time. The results suggest that lower Dhurma has a high diversity of smaller benthic foraminifera, with several endemic species, and its paleoenvironment is interpreted as marine with normal environmental conditions.

ملخص الرسالة

الاسم الكامل	: علي حسين بو خمسين
عنوان الرسالة	: التصنيف والتطبيق الحيوي والمجموعات المورفولوجية للمنخريات القاعية في الودعتين ض ١ - ض ٢ من متكون ضرما ، في المنطقة الوسطى من المملكة العربية السعودية
التخصص	: جيولوجيا
تاريخ الدرجة العلمية	: نوفمبر ٢٠٢١

يعد متكون ضرما جزء من التعاقب الجوراسي الأوسط في المملكة العربية السعودية، ويمتد عمره بين المرحلتين الباجوسية والباثونية. وهو عبارة عن خليط من الصخور الكربوناتها والمتراصفات السيليسية التي ترسبت على نطاق شاسع في منصة كربوناتها ذات بيئة بحرية ضحلة. تسود المتراصفات السيليسية بشكل أكبر في الجزء السفلي من المتكون. هناك كم هائل من الابحاث حول المنخريات الموجودة في الجزئين الأوسط والعلوي من متكون ضرما، والمبنية بشكل رئيسي على تحليل عينات المقاطع الرقاعية. يهدف هذا البحث إلى دراسة المحتوى المنخري في الجزء السفلي من متكون ضرما من ناحية التصنيف والتوزيع والمجموعات المورفولوجية والبيئات الباليوية، وذلك من خلال مقارنة تقانية تجزيئية. باتباع خطة جمع عينات ذات دقة عالية، تم جمع وتحليل ٥٠ عينة من ثلاث بروزات صخرية بالقرب من القطع المرجعي لمتكون ضرما. تم استخلاص ٦٣ نوع منخري من العينات، عشر منها لم تُكتشف مسبقاً. تشير النتائج إلى احتواء الجزء السفلي من متكون ضرما على تنوع عالي للمنخريات القاعية، والعديد منها من الأنواع المستوطنة الحصرية في مكان وجودها. كما تشير النتائج إلى أن الجزء السفلي من المتكون ذو بيئة باليوية بحرية.

CHAPTER 1

INTRODUCTION

1.1 Geological setting

The Shaqra Group is the name given to the Jurassic succession of Saudi Arabia and is comprised of seven formations. In ascending stratigraphic order these are: the Marrat (Lower Jurassic), Dhruma and Tuwaiq Mountain (Middle Jurassic), Hanifa, Jubaila, Arab and Hith formations (Upper Jurassic) (Vaslet 1987). The reference section for the Dhruma Formation is located in Central Saudi Arabia in a well-developed outcrop (**Figure 1**). Several authors reviewed and summarized the tectonic evolution of the Arabian Plate (Powers et al., 1966; Al-Husseini, 2000; Konert et al., 2001; Sharland et al., 2001; Al-Qahtani et al., 2004 and Haq & Al-Qahtani, 2005). Haq & Al-Qahtani (2005) presented 14 major Phanerozoic tectonic events that influenced sedimentary patterns on the Arabian platform. In the early Late Permian, the Neo-Tethys Ocean started to open as a result of rifting along the Arabian plate's eastern margin where a passive margin was created along the northeast boundary of the plate. This setting was maintained until the Late Cretaceous (Konert et al. 2001; Haq & Al-Qahtani, 2005). Based on review of plate tectonic and sediments accumulation events, Sharland et al. (2001) subdivided the tectonostratigraphic

framework on the Arabian Plate (AP) into eleven tectonic mega-sequences (TMS). The entire Jurassic succession was placed between AP6 and AP8. AP6 is associated with the opening of the Neo-Tethys Ocean (Mid-Permian to Early Jurassic). AP7 spanned over 33 million years from (Early to Late Jurassic) where the Arabian plate maintained an equatorial position and its passive margin slowly subsided and was covered by epeiric shallow water shelf deposits. Lastly, AP8 which is associated with the southern extension of the plate and the opening of the Indian Ocean (Late Jurassic to Late Cretaceous). The authors further, marked the tectonic unconformity between the Marrat and Dhruma formations as the boundary between the AP6-AP7 mega-sequences. Subsequently, the Marrat Formation is assigned to AP6 and Dhruma formation to AP7 (Al-Mojel, 2017).

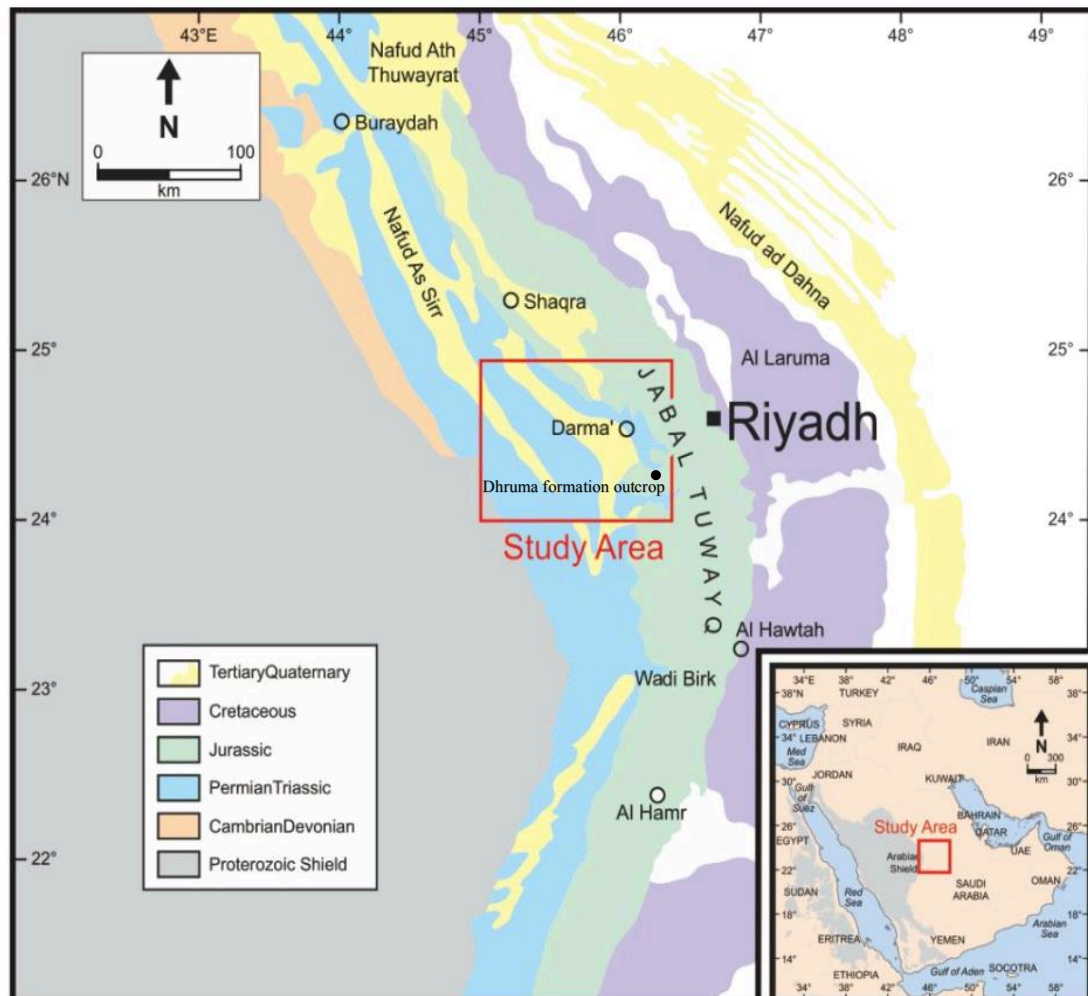


Figure 1: Geology of central Saudi Arabia (the red square is the location of the study area where the Dhruma Formation crops out on the surface) (modified after Ismanto, 2018)

1.2. Lithostratigraphy and biostratigraphy of the Shaqra Group

Powers et al. (1966) and Powers (1968) published the Jurassic lithostratigraphic nomenclature of Saudi Arabia describing seven formations, from older to younger these are: Marrat, Dhurma, Tuwaiq Mountain, Hanifa, Jubaila, Arab and Hith. Vaslet (1987) combined the Jurassic succession into one group called the Shaqra Group. The group is well exposed in 1130 m thick outcrop belts in central Saudi Arabia and dominantly consists of shale and carbonate with smaller amounts of sandstone and anhydrites and is bounded by two regional unconformities. Early Jurassic unconformity below the Marrat Formation and the early Cretaceous unconformity above the Hith Formation (Fischer et al., 2001).

The ammonite species is the main reference group used for the biostratigraphic zonation of the whole Jurassic in Saudi Arabia (**Figure 2**). Arkell (1952, 1957) identified nine ammonite faunas for the Marrat, Dhurma and lower Tuwaiq Mountain formations based on the standard European stages. In a later study, Imlay (1970) introduced eleven ammonite zones for the same formations. The Bureau de Recherches Geologiques et Minières (BRGM) conducted a series of ammonite studies to identify the Jurassic ammonite stratigraphy framework (e.g., Enay et al., 1986, 1987, 2009). Enay et al. (1987) identified seventeen ammonite species for the Jurassic succession in central of Saudi Arabia and twelve out of seventeen species, were from the Dhuma Formation (six in the Lower Dhurma, five in the Middle Dhurma and one in the Upper Dhurma). Beside ammonites, other macro- and microfaunas were the scope of biostratigraphic studies of the Jurassic of Saudi Arabia e.g., nautiloids (Tintant 1987), brachiopods (Almérás 1987), ostracods

(Dépêche et al., 1987), calcareous nannofossils (Manivit 1987), dasycladacean algae (Bernier 1987), gastropods (Fischer 2001), foraminifera (Hughes, 2004 a-c, 2008, 2009, 2018, Al-Dhubaib, 2010, Malik, 2016; Malik et al. (2020); Kaminski et al., 2018a,b, 2020). Hughes (2018) subdivided the Jurassic of Saudi Arabia into twenty-three micropaleontological biozones using foraminifera and other microfossils bioevents based on thin-section analysis of outcrops and sub-surface samples.

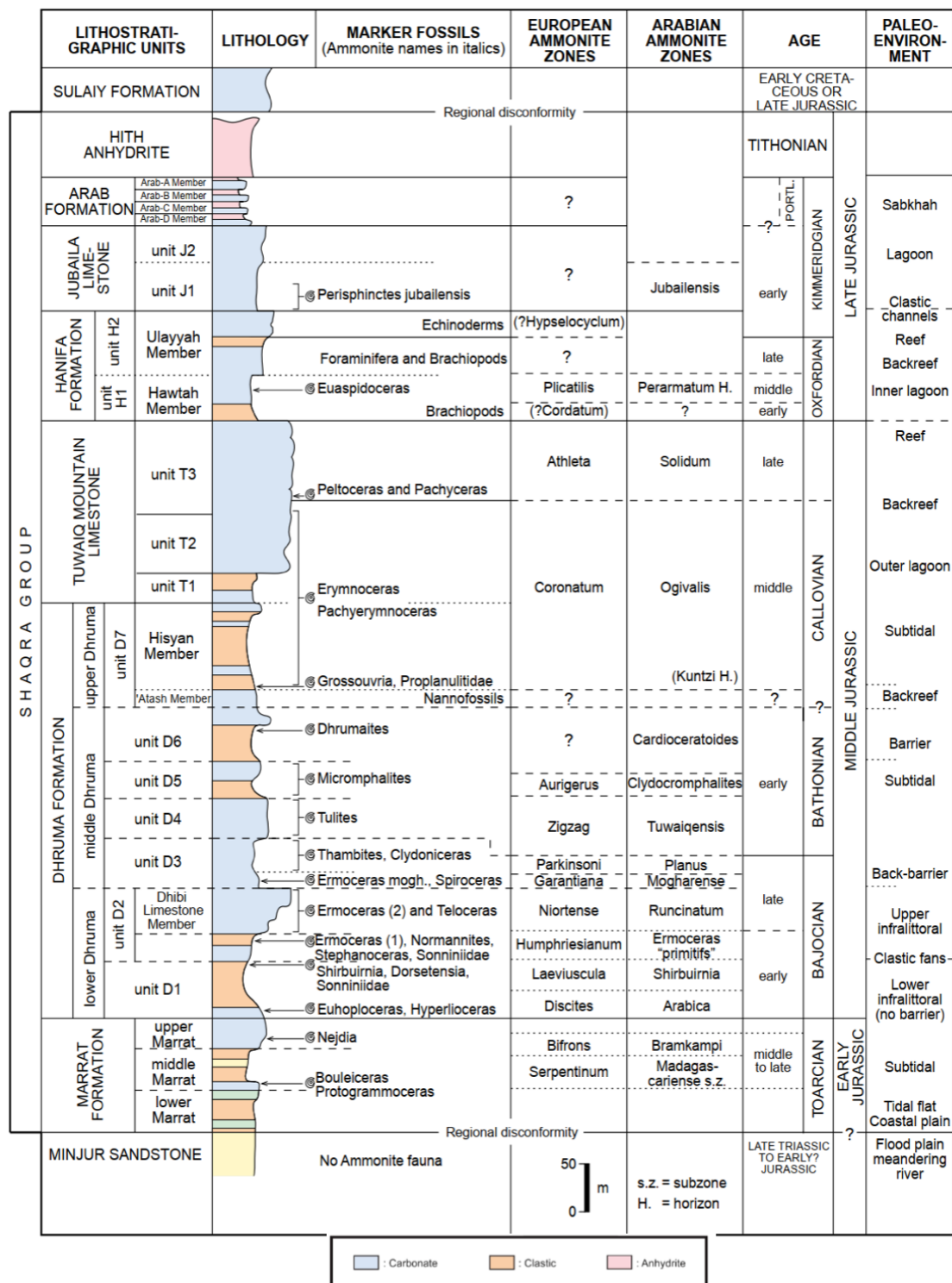


Figure 2: Lithostratigraphic column of the Shaqra Group and the ammonite zones (Fisher et al. 2001)

1.3. Lithostratigraphy and biostratigraphy of the Dhurma Formation

Bramkamp and Steineke (1952) subdivided the Dhurma Formation in Central Saudi Arabia into three units: lower, middle and upper. Powers et al. (1966) measured 375 m from Khashm ash Dhibi outcrop (24° 12' 24'' N, 46° 07' 30'' E) as a reference section and subdivided the formation into three members. From bottom to top these are: the Dhibi limestone member, Atash member and Hisyan member. During the 1980s, the French Geological Survey (BRGM) conducted comprehensive studies on the Jurassic succession of Saudi Arabia and subdivided the Dhurma formation into 7 informal units (**Figure 3**), based on the biostratigraphy and lithology with total thickness in the outcrops of 447 m. The proposed units are D1- D2 corresponding to lower Dhurma, D3-D6 corresponding to the middle Dhurma, while D7 corresponds to upper Dhurma (Vaslet et al., 1991).

The lithology of the Dhurma Formation is summarized by Powers et al. (1966) as 120.8 m of green and purple shale interbedded with thin beds of calcarenite and gypsum as the Lower Dhurma. The upper 35.4 m from this section which consists of cliff forming creamy limestone (mudstone to packstone) interbedded with olive green shale is recognized as the Dhibi Limestone (D2 member). Followed by 164.7 m of calcarenitie and calcarenitic limestone interbedded with pellet-molluscan-algal and oolite-foraminiferal-molluscan calcarenite as the Middle Dhurma. Finally, the upper 89 m part of the formation as the Upper Dhurma consisting of two intervals. A calcarenitic limestone, 25 m thick and overlain by 64 m of tan to olive-tan calcareous shale.

The age of each member of the formation was assigned based on the presence of ammonite species and calibrated in some cases by subordinate faunas of brachiopods, nautiloids, and calcareous nannofossils. The D1 unit is of early Bajocian age based on two European ammonite biozones, *Discites* and *Laeviuscula* which are equivalent to the *Arabica* and *Shirbuirnia* Arabian ammonite zones. The D2 unit is assigned an early late Bajocian age based on another two European ammonite biozones, *Humphresinum* and *Nortense*, equivalent to the *Eremnoceras* and *Runcinatum* Arabian ammonite biozones. The presence of ammonite faunas of the *Garanatiana* and *Parkinsoni* European biozones along with their equivalent the *Mogharensen* and *Planus* Arabian biozones used to assign an age of late Bajocian to the middle Dhruma D3 unit. The (D4 and D5) units, middle Dhruma, are of early Bathonian age based on the Tuwaiqensis Arabian ammonite zone and its equivalent the Zigzag European ammonite biozone followed by the Clydocromphalites Arabian ammonite zone and its equivalent the Aurigerus European ammonite biozone respectively. The D6 unit is dated as late Bathonian based on the presence of an endemic fauna called *Dhrumaites* in the Cardioceratoides Arabian ammonites, without an equivalent European biozone, and two species of nautiloids. Lastly, the D7 unit is dated as middle Callovian based on the presence of the *Grossouvrei* and *Pachyerymnoceras* ammonite biozones (Fischer et al., 2001).

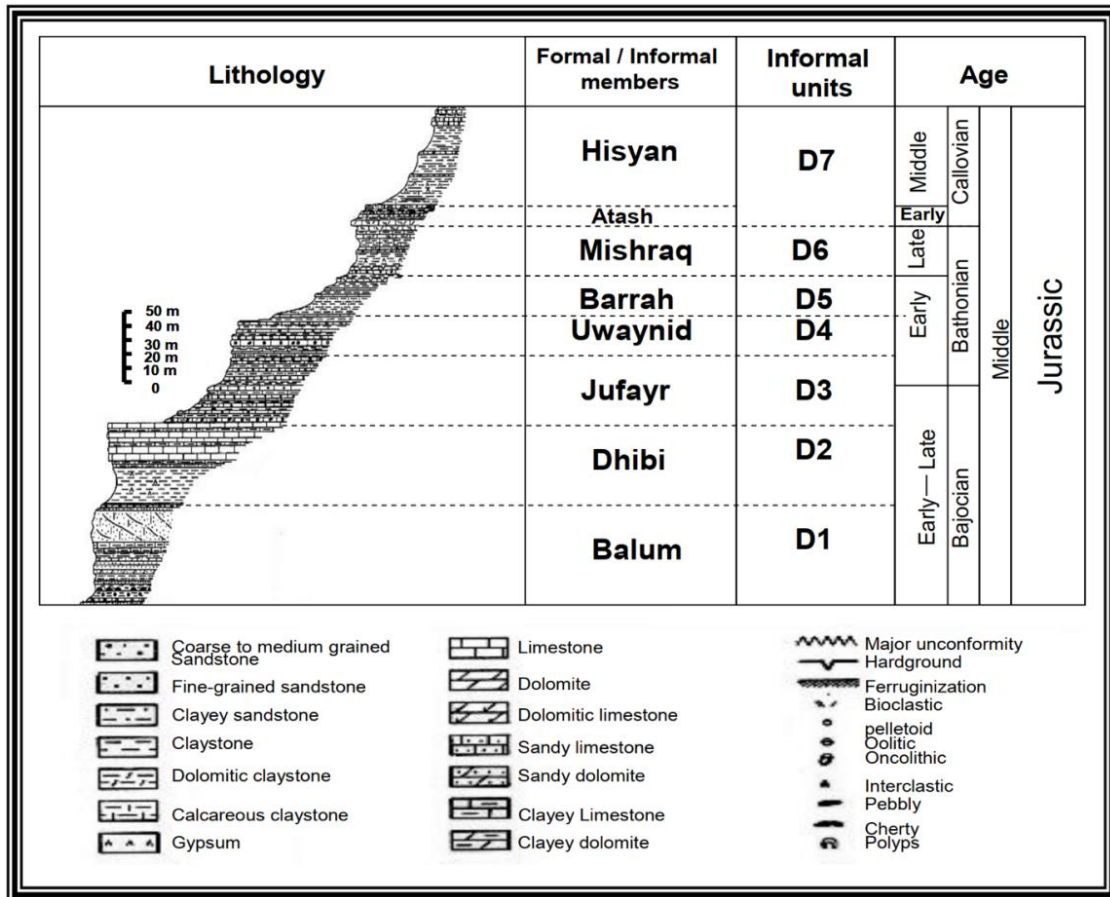


Figure 3: The lithology and age of the Dhruma formation units (Vaslet et al., 1983, modified by Al-Dhubaib, 2010)

1.4. Foraminiferal Studies on the Dhurma Formation

The foraminifera from the Dhurma formation in Saudi Arabia were the scope of several studies. Most of these studies utilized the thin-section technique (e.g., Hughes 2004 a, b, c, 2006, 2009b, 2018, Al-Dhubaib 2010 and Ismanto et al., 2019). Redmond (1965) identified three new genera (*Pseudomarssonella*, *Riyadhella* and *Dhrumella*). Powers et al. (1966) described eight foraminiferal zones and characterized the top of Dhibi limestone by the appearance of one of the following species: *Haurania amiji*, *Haurania deserta*, *Pfenderina inflata*, and '*Coskinolinopsis*' sp (Haurania zone). Hughes (1996, 2000b, 2004a, b, c, e, 2005a, 2009a, b, 2013 and 2018) through his extensive studies on the biostratigraphy and paleoenvironment of Jurassic succession reported thirteen species from the Dhurma Formation and subdivided the formation into six biozones (Dm1 – Dm6) based on first and last downhole occurrences of the microfaunas in subsurface drilling cuttings (**Figure 4**). By applying the disaggregation technique to retrieve calcareous microfossils, Malik et al., 2020 reported a total of thirty-five foraminifera species belonging to nineteen genera from the middle Dhurma (D5 unit) outcrop samples. Kaminski et al. (2018a, b) reported two new species from the Dhurma formation. The planktonic species *Globuligerina* sp., from middle Dhurma (D5 unit) and a new agglutinated benthic *Ammobaculoides* species (*Ammobaculoides dhrumaensis*) from the lower Dhurma shale (D1 unit).

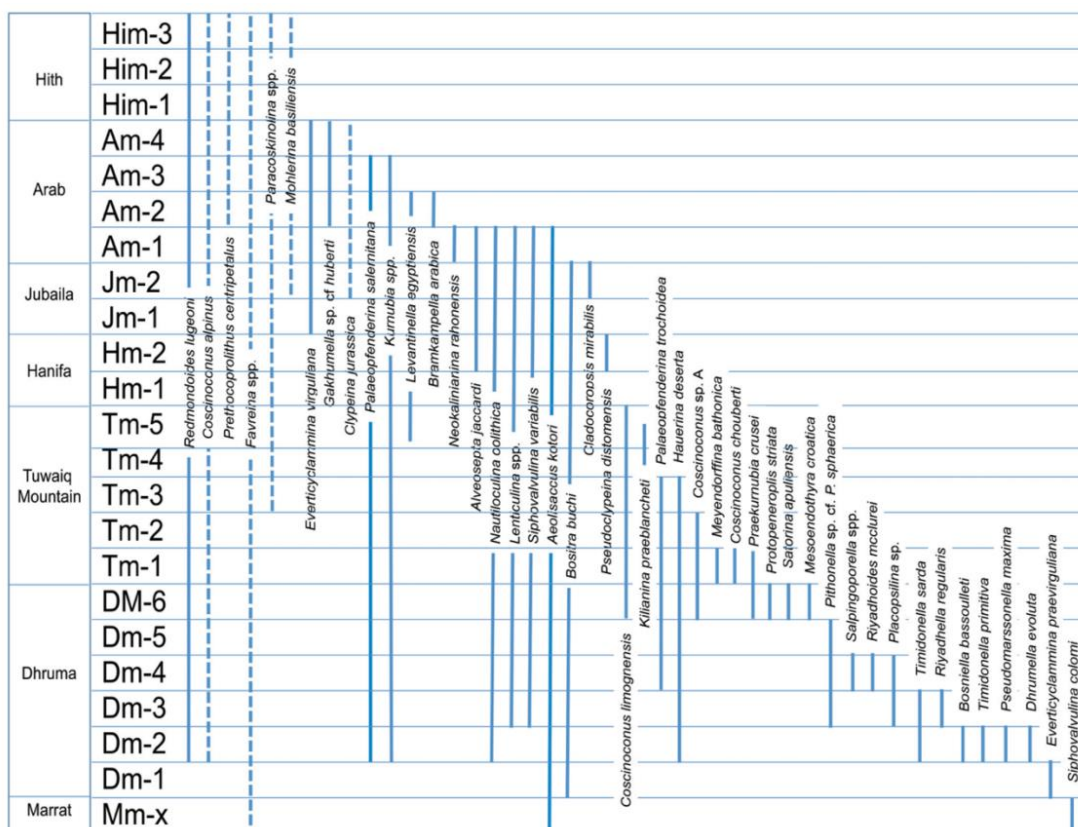


Figure 4: Stratigraphical range of important species observed in thin sections of Jurassic carbonates of Saudi Arabia (Hughes 2018)

1.5. Study Area

The study area is located around 60 kilometers southwest of Riyadh, central Saudi Arabia close to the reference section of the Dhurma formation at Khashm ad Dhibi ($24^{\circ} 12' 04''$ N, $46^{\circ} 07' 05''$ E) (**Figure 5**). Samples were collected from three stops (D1A, D1B and D2W) along the road between Saudi White Cement Factory and Hafirat Nisah. Stop D2W ($24^{\circ} 11' 59.2''$ N, $46^{\circ} 14' 28.11''$ E) is about 10 km to the east of Khashm ad Dhibi where a 6 m thick massive Dhibi limestone of lower Dhurma (D2 unit) is well presented (**Figure 6**). The other stops (D1A and D1B) are located 5 kilometers toward the southeast from stop D2W toward Hafirat Nisah village and comprised of around 6 m of thick green and purple shale interbedded with carbonate beds representing the uppermost part of the D1 unit. These stops are separated by approximately 200 m in distance ($24^{\circ} 10' 16''$ N, $46^{\circ} 16' 43''$ E) (**Figure 7**) (**Figure 8**).

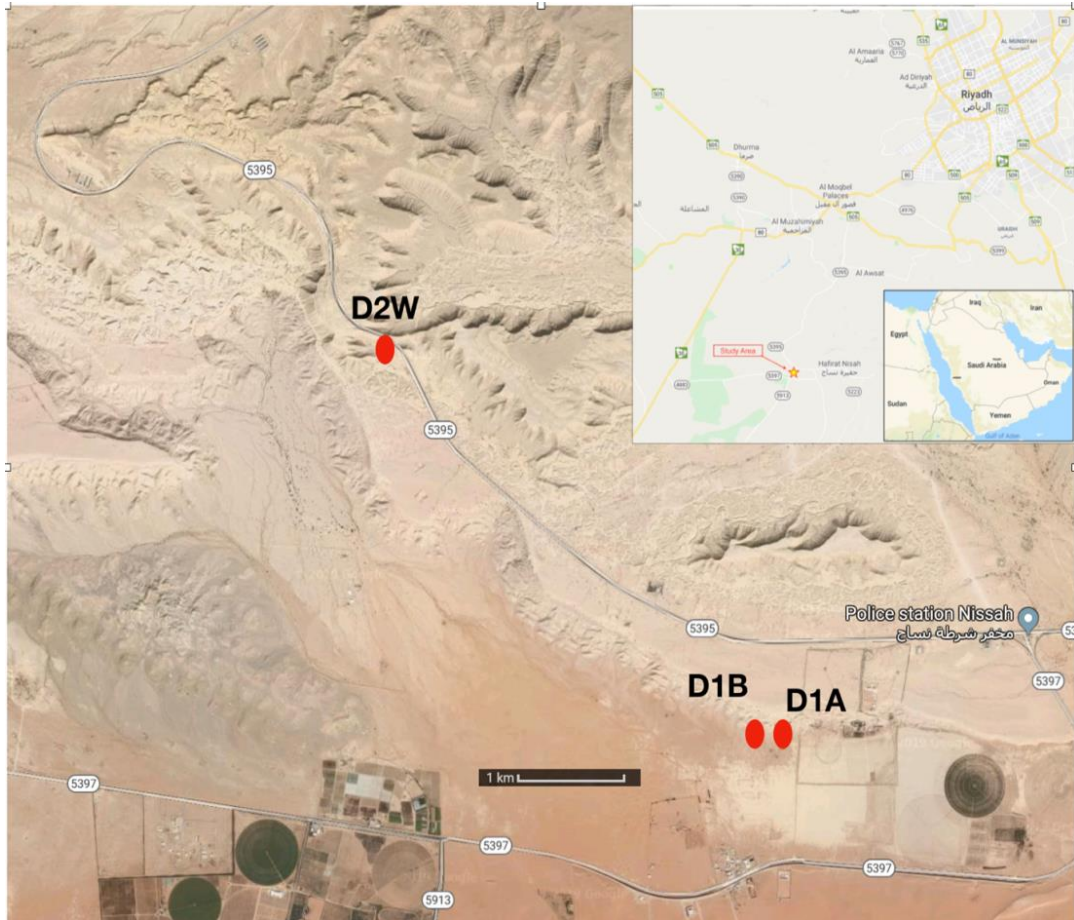


Figure 5: Location of the study area



Figure 6: Stop D2W, massive creamy limestone of Dhibi, D2 unit (photo courtesy of Dr. Babalola)



Figure 7: Stop D1A, 6.4 m thick unit of shale and carbonate



Figure 8: Stop D1B, 6.4 m thick beds of limestone interbedded with shale at the top of D1 unit.

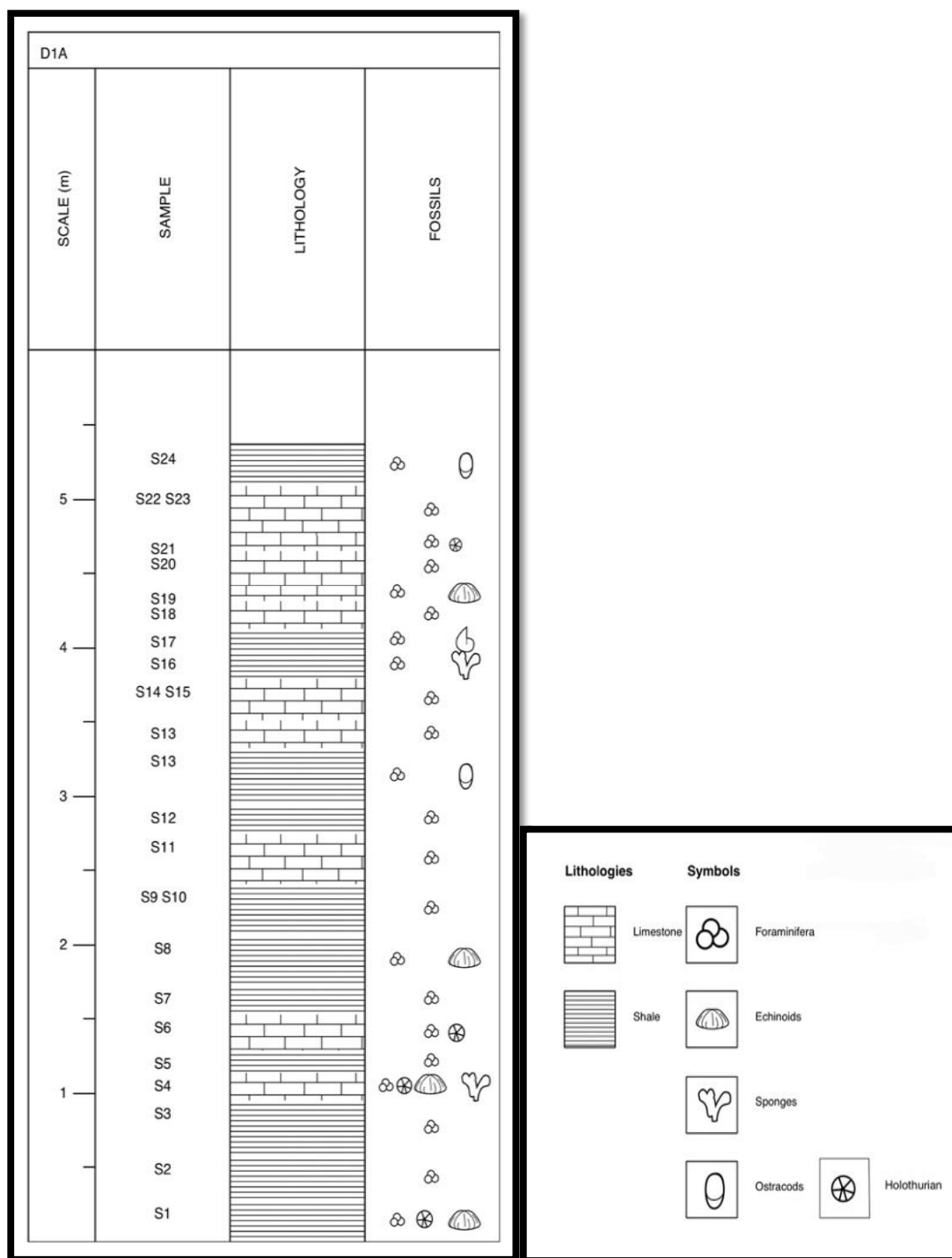


Figure 9: Sedimentological log of stop D1A

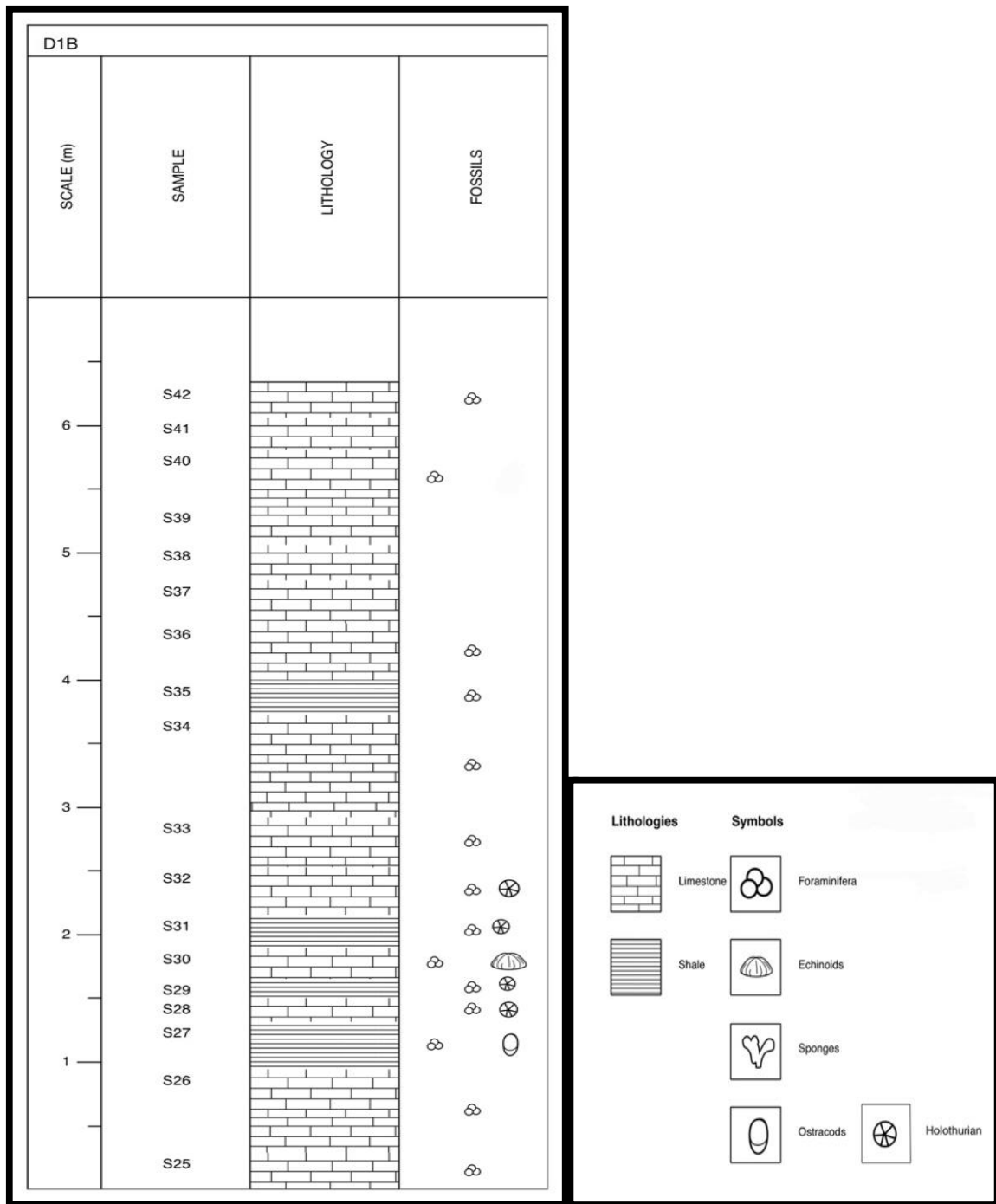


Figure 10: Sedimentological log of stop D1B

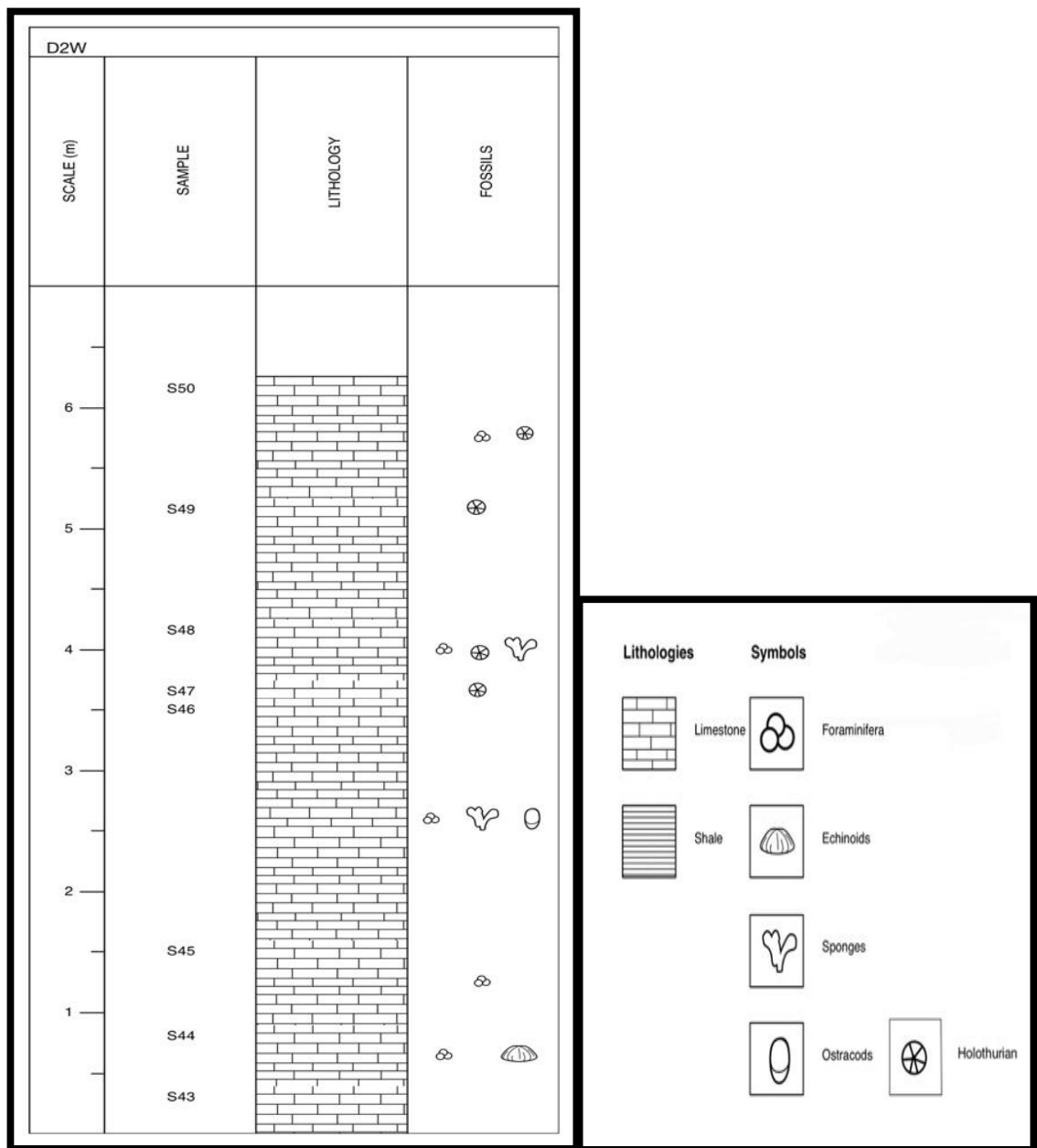


Figure 11: Sedimentological log of stop D2W

1.6. Problem Statement and Objectives

The majority of the micropaleontological studies of the Dhurma formation in Saudi Arabia focused on the carbonate beds of the formation and used thin-section technique only for the foraminiferal analysis (e.g., Hughes, 2004, 2006, 2009a, 2018; Al-Dhubaib, 2010). Moreover, these studies utilized mainly subsurface carbonate samples with little attention paid to outcrop samples. Thus, the current knowledge for the foraminiferal assemblages in the shale beds of lower Dhurma (D1 and D2 units) is very limited and no appropriate taxonomy was attempted on the assemblages of this part of the formation. Hughes (2018) described the foraminiferal taxa of D1 unit as: “dwarf agglutinated and calcareous benthic foraminiferal genera including *Reophax*, *Siphovalvulina*, *Ammodiscus*, *Textulariopsis*, *Ammobaculites*, *Valvulina* and *Glomospira*” without further details on the species level taxonomy.

The Jurassic assemblages in Saudi Arabia are like the assemblages reported from other Gulf States, Iran, Iraq, Syria, and southern Turkey (Clark & BouDagher-Fadel, 2001). Yet, several endemic species of foraminifera have been reported from Central Saudi Arabia (Redmond, 1965; Al-Saad, 2008). Additionally, a recent study utilized the disaggregation technique to extract foraminifera from a shale bed of the D1 unit of the Dhurma formation outcrop resulted in the discovery of a new small agglutinated species *Ammobaculoides dhurmaensis* n.sp. (Kaminski et al., 2018a).

The taxonomy, abundance, and distribution of the smaller benthic foraminifera from the lower Dhurma is not well established. Therefore, the main objectives of this thesis, are summarized as follows:

1. Taxonomic classification and documentation of the foraminiferal species from the lower Dhurma units utilizing disaggregation techniques.
2. Review and modify the stratigraphic range for the identified species.
3. Re-illustrate, describe and photograph the physically extracted key species from the lower Dhurma Formation.
4. Interpret the paleoenvironmental conditions using morphogroup analysis.

CHAPTER 2

METHODOLOGY

2.1 Sample Collection

In total, 50 samples were collected from three outcrops situated 60 km southwest of Riyadh, central Saudi Arabia, near the reference section of the Dhurma formation at Khashm ad Dhibi. To retrieve as many taxa as possible, the sampling strategy applied was to collect one sample per bed for beds that have a maximum thickness of 20 cm. For beds thicker than 20 cm, one sample every 20 cm was collected. The main lithologies of the samples are carbonate and shale. Two different methods were applied to disaggregate the samples based on the lithology and condition of the sample.

2.2 Sample Processing

For shale, mud dominated, or unconsolidated samples, the standard method to extract microfossils involves soaking the sample in water, then gentle boiling of the mixture, followed by washing and sieving through a 63-micron sieve mesh. The process was repeated until all the mud was removed. Industrial soap was added to the water to act as surfactant to help disperse the clay matrix. The final weight of the residue varies based on the clay content of the sample.

For well indurated carbonate samples, the acid leaching method was applied. Acetic acid (CH_3COOH) was used here. Bourdon (1962) first utilized the acetic acid to extract ostracods from limestone samples. Several researchers have modified this method with different acid concentrations and reaction time to extract foraminifera from well-indurated limestone samples (Notzold, 1965; Stouge et al., 1983; Reolid and Herrero, 2004; Malik et al., 2020). In this method the samples were treated with acetic acid by the following procedure:

1. Break 100 g of carbonate sample gently into small fragments of few millimeters in diameter. Smaller fragments yield better reaction with acetic acid.
2. Submerge the sample in a solution of 80% acetic acid mixed with 20% distilled water (the level of the solution should be at least 2 cm above the sample level). The

sample should be submerged in the solution for 10 to 15 hours to enhance the disaggregation process.

3. Wash the residue with abundant water through stainless steel standard sieves with mesh opening 250, 125 and 63 μm
4. Dry the residue at low temperature (40 – 50°C).
5. Transfer the residue to small, labelled vials and pick the microfossils under a binocular stereomicroscope.

The final weight of the residue of the sample after the acid leaching process decreased from 100 g to about 20 g. A weight of 3 g for each sample was used for picking 300 specimens, when possible, of microfossils under a binocular stereoscopic microscope for semi-quantitative analysis. The picked microfossils were sorted into cardboard micropaleontological slides and enumerated. The well-preserved specimens were photographed using a JEOL scanning electron microscope in the Geosciences Department at King Fahd University of Petroleum & Minerals.

2.3 Foraminiferal Identification

All picked foraminiferal specimens in this study were benthic. Two main references used for systematic analysis: Loeblich and Tappan (1987) “Foraminiferal Genera and Their Classification” of calcareous taxa and the Kaminski (2014) classification of agglutinated foraminiferal taxa. Identification of species was carried out using the classic Jurassic references and the Ellis & Messina (1940+) catalog of foraminifera.

2.4 Morphogroup Analysis

The concept of foraminiferal morphogroup analysis assumes that there is a relationship between the form of foraminiferal test and its function. So, different forms have different living habitats, feeding strategies and preferred environment. Consequently, the change in relative abundance of any group of similar morphogroup will reflect the environmental changes during that time (Jones & Charnock, 1985). It is used to evaluate and interpret the paleoenvironmental and its controlling parameters like oxygen level and nutrient availability based on the morphology and distribution of foraminiferal taxa only, without the need to identify the taxon to species level. Therefore, it can also be used to reliably compare assemblages of different ages since the taxonomic effect is reduced. Jones & Charnock (1985) developed two morphogroup schemes, one for the agglutinated foraminifera and the other one is for the calcareous benthic forms. The morphological categories of Jurassic genera were the subject of other notable studies (e.g., Nagy, 1992,

Tyszka, 1994, Nagy et al., 1995, Reolid et al., 2008a, 2012 and Farahani et al., 2018). The morphogroup scheme used in this study is modified after the Reolid (2008) scheme due to the high similarity in the reported taxa between the two studies.

CHAPTER 3

RESULTS

A total of 8209 foraminifera specimens were recovered from the 50 samples collected and studied from the three sections, corresponding to 14 suborders, 22 families, 32 genera (18 agglutinated and 14 calcareous) and 63 species. Identification to the species level was possible for 7383 specimens (89.93%), which indicates a good overall preservation of the obtained specimens. However, the identification of the species and genera belonging to the family Polymorphinidae is challenging due to the fragmentation of the shells plus the inconsistency of Polymorphinidae taxonomy in the literature. The reported taxa belong to the following suborders (from high to low occurrence): Lagenina (39.33%), Verneulinina (10.38%), Lituolina (9.18%), Hormosinina (7.70%), Trochamminina (7.36%), Textularina (7.28%), Nezzazatina (4.94%), Robertinina (2.47%), Spirillinina (2.26%), Orbitolinina (2.15%), Schlumbergerinina (2.11%), Saccamminina (1.13%), Ammodiscina (1.12%) and Spiroplectamminina (0.24%).

The taxa are distributed among 22 families: Polymorphinidae (33.95%), Haplophragmoididae (8.58%), Verneulinidae (7.78%), Reophacidae (7.70%), Trochamminidae (7.36%), Paravalvulinidae (7.28%), Nautiloculinidae (4.94%), Nodosariidae (3.30%), Vaginulinidae (2.80%), Prolixoplectidae (2.65%), Epistominidae (2.47%), Spirillinidae (2.26%), Pfenderinidae (2.15%), Miliamminidae (2.11%), Ichthyolaridae (1.57%), Saccamminidae (1.13%), Ammodiscidae (1.12%), Lituolidae (0.59%), Pseudobolivinidae (0.22%), Textulariopsidae (0.03) and Reophacellidae (0.01%).

In total, **32** genera are reported in this study, (**18** agglutinated): *Lagenammina*, *Glomospira*, *Miliammina*, *Reophax*, *Haplophragmoides*, *Ammobaculites*, *Plectinella*, *Pseudobolivina*, *Trochammina*, *Riyadhella*, *Gaudryinopsis*, *Verneulinoides*, *Pseudoreophax*, *Nautiloculina*, *Siphovalvulina*, *Pseudomarssonella* and *Redmondoides* and (**14** calcareous genera): *Spirillina*, *Paralingulina*, *Prodentalina*, *Dentalina*, *Nodosaria*, *Lingulina*, *Fronicularia*, *Lenticulina*, *Vaginulinopsis*, *Vaginulina*, *Lagena*, *Ramulina*, *Epistomina* and 7 species belonging to the family Polymorphinidae.

The four most abundant species are cf. *Reophax dentaliniformis*, *Nautiloculina oolithica*, *Haplophragmoides bartensteini*, and *Verneulinoides conoidalis*. Among the 63 recovered species, 10 new species described for the first time: *Haplophragmoides* sp. 1, *Pseudobolivina?* sp. 1, *Trochammina* sp. 1, *Trochammina* sp. 2, *Gaudryinopsis* sp. 1, *Gaudryinopsis* sp. 2, *Gaudryinopsis* sp. 3, *Gaudryinopsis* sp. 4, *Gaudryinopsis* sp. 5 and

Lenticulina sp. 1. (Detailed species descriptions are given in the Appendix). No larger benthic foraminifera were obtained from the samples.

Between the three sections (D1A, D1B and D2W), the number of specimens recovered, species abundance, species diversity and specimen preservation decreased ascendingly (D1A: 5990, D1B: 1914 and D2W: 304). On the other hand, the size of the foraminiferal tests noticeably increased in ascending order between the three sections. Other biocomponents present in the samples are sponge spicules (monaxon and triaxon, echinoid spines, ostracods, holothurian sclerites, and juvenile gastropods. Sections D1B and D2W yielded more biocomponents compared to section D1A.

Calcareous nannofossils were used to confirm the age of each section. Shale samples from D1A show good recovery with moderate to good preservation of *Carinolithus superbis*, *Carinolithus magharensis*, *Discorhabdus striatus*, *Axopodorhabdus cylindratus*, *Watznaueria fossacincta*, *Watznaueria barnesiae*, *Watznaueria manivitiae* and *Watznaueria britannica*. The assemblage indicates an early Bajocian age (D1 unit of the Dhruma Formation). The age is assigned to a range from the NJ9 to the NJ10a biozones. Samples from D1B and D2W were barren of nannofossils. The suborders, families, genera and species reported in this study are summarized in the following table.

TABLE 1. Taxonomic Summary of Reported Taxa

SUBORDER	FAMILY	GENUS	SPECIES
SACCAMMININA Lankester 1885	SACCAMMINIDAE Brady 1884	<i>Lagenammina</i> Rhumbler 1911	<i>Lagenammina difflugiformis</i> (Brady, 1879)
AMMODISCINA Mikhalevich 1980	AMMODISCIDAE Reuss 1862	<i>Glomospira</i> Rzehak 1885	<i>Glomospira gordialis</i> (Jones & Parker) var. <i>chodzica</i> Antonova, 1958
SCHLUMBERGERI NINA Mikhalevich 1980	MILIAMMINIDAE Saidova 1981	<i>Miliammina</i> Heron-Allen and Earland 1930	<i>Miliammina grana</i> Azbel', 1977
HORMOSININA Mikhalevich 1980	REOPHACIDAE Cushman 1927	<i>Reophax</i> De Montfort 1808	cf. <i>Reophax dentaliniformis</i> Brady, of Görög 1995
LITUOLINA Lankester 1885	HAPLOPHRAGMOI DIDAE Maync 1952	<i>Haplophragmo ides</i> Cushman 1910	<i>Haplophragmoides bartensteini</i> Kalantari, 1969 <i>Haplophragmoides barthouxi</i> Said & Barakat, 1958 Resembling to some extent: <i>Haplophragmoides canui</i> Cush man, 1930 <i>Haplophragmoides</i> cf. <i>planus</i> Antonova, 1958

			<i>Haplophragmoides</i> sp. 1
	LITUOLIDAE de Blainville 1827	<i>Ammobaculites</i> Cushman 1910	<i>Ammobaculites alaskensis</i> Tappan, 1955
SPIROPECTAMMININA Mikhalevich 1992	TEXTULARIOPSIDAE Loeblich and Tappan 1982	<i>Plectinella</i> Marie 1956	<i>Plectinella aegyptiaca</i> Said & Barakat, 1958
	PSEUDOBOLIVINIDAE Wiesner 1931	<i>Pseudobolivina</i> Wiesner 1931	<i>Pseudobolivina?</i> sp. 1
TROCHAMMININA Saidova 1981	TROCHAMMINIDA E Schwager 1877	<i>Trochammina</i> Parker and Jones 1859	<i>Trochammina elevata</i> Kosyrev in Dain, 1972 <i>Trochammina instabilis</i> Vassilenko, 1988 <i>Trochammina</i> cf. <i>numerosa</i> Akimets, 1966 <i>Trochammina squamataformis</i> Kaptarenko-Chernousova, 1959 <i>Trochammina</i> sp. 1 <i>Trochammina</i> sp. 2
	PROLIXOPLECTIDAE Loeblich and Tappan 1985	<i>Riyadhella</i> Redmond 1965	<i>Riyadhella arabica</i> Redmond, 1965

VERNEUILININA Mikhalevich and Kaminski 2004			<i>Riyadhella sibirica</i> Mjatiuk, 1939
	VERNEUILINIDAE Cushman 1911	<i>Gaudryinopsis</i> Podobina 1975	<i>Gaudryinopsis</i> sp. 1 <i>Gaudryinopsis</i> sp. 2 <i>Gaudryinopsis</i> sp. 3 <i>Gaudryinopsis</i> sp. 4 <i>Gaudryinopsis</i> sp. 5
		<i>Verneuilinoide</i> s Loeblich and Tappan 1949	<i>Verneulinoides</i> cf. <i>asperulus</i> Crespin, 1963 <i>Verneulinoides conoidalis</i> Azbel, 1977 <i>Verneulinoides kirillae</i> Dain, 1971 <i>Verneulinoides</i> aff. <i>minutus</i> Said and Barakat, 1958 <i>Verneulinoides</i> sp. 2 of Jenkins & Murray, 1989
		REOPHACELLIDAE Mikhalevich and Kaminski 2004	<i>Pseudoreopha</i> x Geroch, 1961 <i>Pseudoreopha</i> aff. <i>cisovnicensis</i> Geroch, 1961

NEZZAZATINA Kaminski 2004	NAUTILOCULINID AE Loeblich and Tappan 1985	<i>Nautiloculina</i> Mohler 1930	<i>Nautiloculina oolithica</i> Mohler, 1938
ORBITOLININA Kaminski 2004	PFENDERINIDAE Smout and Sugden 1962	<i>Siphovalvulina</i> Septfontaine 1988	<i>Siphovalvulina colomi</i> BouDagher-Fadel, Rose, Bosence & Lord, 2001 <i>Siphovalvulina gibraltarensis</i> BouDagher- Fadel, Rose, Bosence and Lord, 2001
TEXTULARIINA Delage and Héroutard 1896	PARAVALVULINID AE Banner, Simmons and Whittaker 1991	<i>Pseudomarssonella</i> Redmond, 1965	<i>Pseudomarssonella maxima</i> Red mond, 1965 <i>Pseudomarssonella reflexa</i> Redmond, 1965
		<i>Redmondoides</i> Banner, Simmons and Whittaker 1991	<i>Redmondoides medius</i> Redmond, 1965 <i>Redmondoides</i> primitivus Redmond, 1965
SPIRILLININA Hohenegger and Piller, 1975	SPIRILLINIDAE Reuss and Fritsch, 1861	<i>Spirillina</i> Ehrenberg, 1843	<i>Spirillina involuta</i> Antonova, 1958 <i>Spirillina trochoides</i> Berthelin, 1879

LAGENINA Delage and Herouard, 1896	ICHTHYOLARIDAE Loeblich and Tappan, 1986	<i>Paralingulina</i> Gerke, 1969	<i>Paralingulina cernua</i> spp. A Berthelin, 1879 of Copestake & Johnson (2014)
		<i>Prodentalina</i> Norling, 1968	<i>Prodentalina digitalis</i> Franke, 1913 of Copestake & Johnson (2014)
	NODOSARIIDAE Ehrenberg, 1838	<i>Dentalina</i> Risso, 1826	<i>Dentalina bicornis</i> Terquem, 1870 of Görög 1995
			<i>Dentalina botuliformis</i> Terquem, 1870
			<i>Dentalina digitata</i> Paalzow, 1932
			<i>Dentalina guembeli</i> Schwager, 1865 of Gordon 1966
		<i>Nodosaria</i> Lamarck, 1812	<i>Nodosaria</i> cf. <i>geniculata</i> Terquem & Berthelin, 1875
		<i>Lingulina</i> d'Orbigny, 1826	<i>Lingulina</i> cf. <i>ampliata</i> Loeblich & Tappan, 1950
			<i>Lingulina pregradniensis</i> Mamontova, 1957

		<i>Fronicularia</i> DeFrance, 1826	<i>Fronicularia longiscata</i> Terquem, 1870
	VAGINULINIDAE Reuss, 1860	<i>Lenticulina</i> Lamarck, 1804	<i>Lenticulina</i> cf. <i>papillaecostata</i> Bielecka & Styk, 1981 <i>Lenticulina</i> sp. 1
		<i>Vaginulinopsis</i> Silvestri, 1904	<i>Vaginulinopsis eritheles</i> Loeblich & Tappan, 1950
		<i>Vaginulina</i> d'Orbigny, 1826	<i>Vaginulina parva</i> Franke, 1936 of Copestake & Johnson 2014
	LAGENIDAE Reuss, 1862	<i>Lagena</i> Walker and Jacob, 1798	<i>Lagena haeusleri</i> Copestake & Johnson, 2014
	POLYMORPHINIDA E d'Orbigny, 1839	<i>Ramulina</i> T. R. Jones, 1875	<i>Ramulina</i> sp. 1 resembling <i>muricatina</i> Loeblich & Tappan, 1949
ROBERTININA Loeblich & Tappan, 1984	EPISTOMINIDAE Wedekind, 1937	<i>Epistomina</i> Terquem, 1883	<i>Epistomina</i> sp. 1

3.1 Paleoecological analysis

The quantity and quality of specimens recovered from the samples (89.93% determinable specimens) indicate good state of preservation. However, the number of specimens obtained in each sample is highly variable, from a maximum of 331 to a minimum of zero, always per 3 g of sediment sample. The number of species in each sample ranges between 23 and 1. To assess the palaeoecological conditions, PAST software (version 4.02) is used to evaluate (species diversity, richness, dominance, evenness and equitability) by calculating the following indices: Fisher's α , Margalef's richness and Simpson's index. Sample diversity is evaluated by Fisher's α index and Margalef's richness index. The mathematical expression ($S = \alpha \ln(1 + n/\alpha)$) is used in Fisher's α index, where S: number of species and n: sample size. In Margalef's richness index, the mathematical expression relates the total number of species with the number of specimens in each sample ($S = S - 1/\ln N$), where S: number of species and N: number of specimens.

The Simpson index is used to evaluate a species dominance over the total number of species. In other words, it estimates the probability that two randomly picked individuals are of the same species ($\lambda = \sum p_i^2 = \lambda = \sum p_i^2$), where $p_i = n_i/n$, being n_i : number of specimens of each species and n: total number of specimens (Hammer and Harper, 2005). So, when $\lambda=1$ it indicates there is only 1 species in that sample.

The relative abundance is calculated from the total number of specimens assigned to each of the taxonomic categories recognized, in relation to the total number of individuals and in it is expressed by percentage. The studied samples show a clear predominance of the Suborder Lagenina which represents (39.33%) for the whole interval. The family Polymorphinidae is the most abundant with a total of (33.95%). At the generic level, *Haplophragmoides* (7.72%), *Reophax* (6.93%) and *Trochammina* (6.62%) are the most abundant genera. On the species level, cf. *Reophax dentaliniformis* Brady (6.93%) is the most abundant species followed by *Nautiloculina oolithica* (4.44%). The polymorphinid genera and species are excluded due to their undeterminable status.

Fisher's α index values range between (6.025 and 0.342). Samples (D1B S29 and D1A S9) have the highest value at 6.025 and 5.745 respectively. Both samples have 23 taxa and similar facies (green shale with high percentage of Calcium). On the other hand, samples (D1B S40 and D1B S36) have the lowest values (0.342 and 0.42), 1 and 2 taxa in them respectively. In general, samples from section D1A tend to have higher values compared to the samples from section D1B and D2W ($\alpha > 2.61$).

Values from Margalef's richness index follow similar trend as well. They range between (3.93 and 0). Samples (D1B S29 and D1A S9) have the highest values at (3.935 and 3.837) respectively and samples (D1B S40, D2W S43) have the lowest value at 0 where only 1 taxon is present in each of these samples. Again, samples from D1A have higher values

compare to samples from the other section except for the sample D1B S29 which has the maximum value at 3.93. Generally, shale samples have higher richness and diversity, and it is reflected by their values using both indexes.

Values from Simpson's index indicate high diversity and no dominant species in samples with high number of specimens. Sample D1B S29 have the lowest λ value (0.0565) while all samples from location D2W have ($\lambda > 0.216$) and samples from D1A have ($0.17 > \lambda > 0.0582$) respectively.

The Shannon-Wiener index is used to evaluate the evenness of the species by the formula ($H' = -\sum p_i \ln p_i$), where $p_i = n_i/n$, n_i : number of specimens of each species and n : total number of specimens (Hammer and Harper, 2005). When ($H'=0$) it means a single taxon in the sample while higher value indicates a diverse sample. Equitability evaluates the distribution of specimens among the species of an assemblage by the mathematical expression ($J = H' / \ln S$), where H' : Shannon-Wiener index and S : total number of species. When $J=1$, no dominance of any species. The values range between (0.54 to 0.94) which means the diversity is high and no dominance of any species. All indices show high diversity which suggest no stressful environment conditions through the three sections.

In this study, the rarefaction curve has a value of 67.5% (95% PI) (figure 3.1). It means from about 45 samples analyzed, over 67.5 % of possible species were retrieved with a 95% statistical confidence.

The lithology and induration of the rock sample has a direct impact on the probability of retrieving specimens from the sample. As the induration increase, the chance of retrieving well preserved specimens decreased. This can explain why samples from section D2W shows very low number of specimens and none of the key larger foraminifera usually reported from thin section samples reported here.

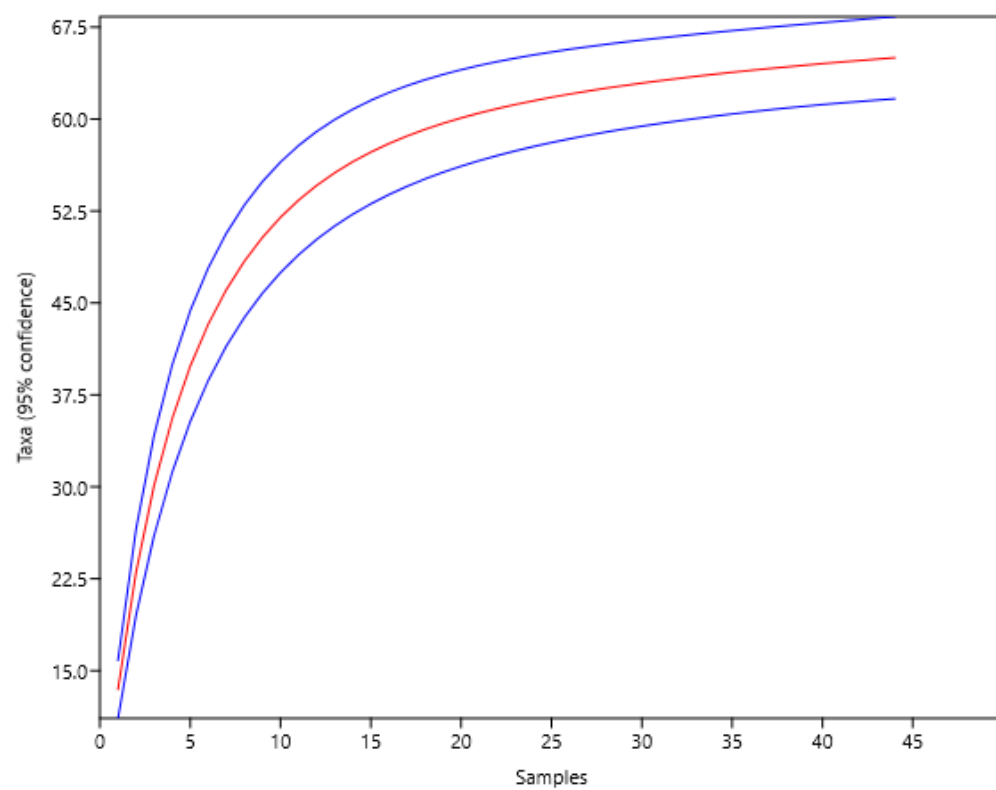


Figure 12: Rarefaction curve of the taxa

TABLE 2. Paleoecological Analysis Results

Sample	Taxa_S	Individuals	Dominance_D	Simpson_1-D	Shannon_H	Evenness_e^H/S	Margalef	Equitability_J	Fisher_alpha
D1B S42	1	2	1	0	0	1	0	0	0.7959
D2W S45	1	4	1	0	0	1	0	0	0.4279
D1B S40	1	6	1	0	0	1	0	0	0.3426
D1B S26	2	8	0.7813	0.2188	0.3768	0.7288	0.4809	0.5436	0.8559
D1B S31	3	24	0.3785	0.6215	1.033	0.9363	0.6293	0.94	0.905
D1B S33	2	28	0.7066	0.2934	0.4692	0.7994	0.3001	0.6769	0.493
D1B S35	3	29	0.6528	0.3472	0.6415	0.6331	0.5939	0.5839	0.8404
D2W S50	6	32	0.2695	0.7305	1.533	0.7721	1.443	0.8557	2.18
D2W S44	8	34	0.237	0.763	1.666	0.6612	1.985	0.801	3.298
D1B S36	2	48	0.6467	0.3533	0.5383	0.8565	0.2583	0.7766	0.4216
D2W S5	4	68	0.6254	0.3746	0.7579	0.5334	0.711	0.5467	0.9287
D2W S48	6	70	0.409	0.591	1.274	0.596	1.177	0.7112	1.571
D2W S46	9	94	0.2164	0.7836	1.767	0.6506	1.761	0.8044	2.45
D1A S16	10	117	0.151	0.849	2.076	0.7975	1.89	0.9017	2.616
D1A S4	16	170	0.0888	0.9112	2.566	0.8135	2.921	0.9255	4.33
D1A S3	15	183	0.1708	0.8292	2.183	0.5916	2.687	0.8062	3.868
D1B S34	15	191	0.0954	0.9046	2.512	0.8217	2.666	0.9275	3.813
D1A S21	14	195	0.0981	0.9019	2.46	0.8363	2.465	0.9322	3.457
D1A S22	17	210	0.0964	0.9036	2.534	0.7412	2.992	0.8943	4.366

D1A S2	16	220	0.1231	0.8769	2.283	0.6129	2.781	0.8234	3.967
D1A S15	16	228	0.0797	0.9203	2.641	0.877	2.763	0.9526	3.922
D1B S25	14	231	0.0991	0.9009	2.407	0.793	2.389	0.9121	3.28
D1A S7	19	233	0.0863	0.9137	2.62	0.7227	3.302	0.8897	4.891
D1A S19	14	236	0.0963	0.9037	2.479	0.852	2.379	0.9393	3.259
D1A S1	21	239	0.1224	0.8776	2.478	0.5676	3.652	0.814	5.546
D1A S5	21	239	0.1159	0.8841	2.553	0.6118	3.652	0.8386	5.546
D1B S30	11	241	0.1271	0.8729	2.158	0.7866	1.823	0.8999	2.376
D1A S10	15	244	0.0934	0.9066	2.501	0.8132	2.547	0.9236	3.529
D1A S20	18	245	0.0815	0.9185	2.665	0.7979	3.09	0.9219	4.477
D1A S24	14	256	0.1035	0.8965	2.403	0.7897	2.344	0.9105	3.182
D1A S17	19	256	0.0721	0.9279	2.741	0.816	3.246	0.9309	4.741
D1A S18	16	263	0.0922	0.9078	2.568	0.8152	2.692	0.9263	3.752
D1A S11	19	265	0.0809	0.9191	2.713	0.793	3.226	0.9212	4.689
D1B S29	23	268	0.0565	0.9435	2.975	0.8514	3.935	0.9487	6.025
D1B S27	17	272	0.086	0.914	2.601	0.7925	2.854	0.9179	4.02
D1B S32	15	277	0.0844	0.9156	2.563	0.8651	2.489	0.9465	3.399
D1B S28	21	289	0.0625	0.9375	2.903	0.8684	3.53	0.9536	5.205
D1A S8	22	292	0.071	0.929	2.808	0.7536	3.699	0.9085	5.517
D1A S14	19	304	0.0733	0.9267	2.756	0.8281	3.148	0.9359	4.492
D1A S6	18	306	0.0789	0.9211	2.679	0.8092	2.97	0.9268	4.179
D1A S9	23	309	0.0757	0.9243	2.79	0.7077	3.837	0.8897	5.745
D1A S13	21	323	0.0815	0.9185	2.736	0.7347	3.462	0.8987	5.026
D1A S23	23	326	0.0583	0.9417	2.962	0.8411	3.802	0.9448	5.647
D1A S12	23	331	0.0792	0.9208	2.746	0.6777	3.792	0.8759	5.62

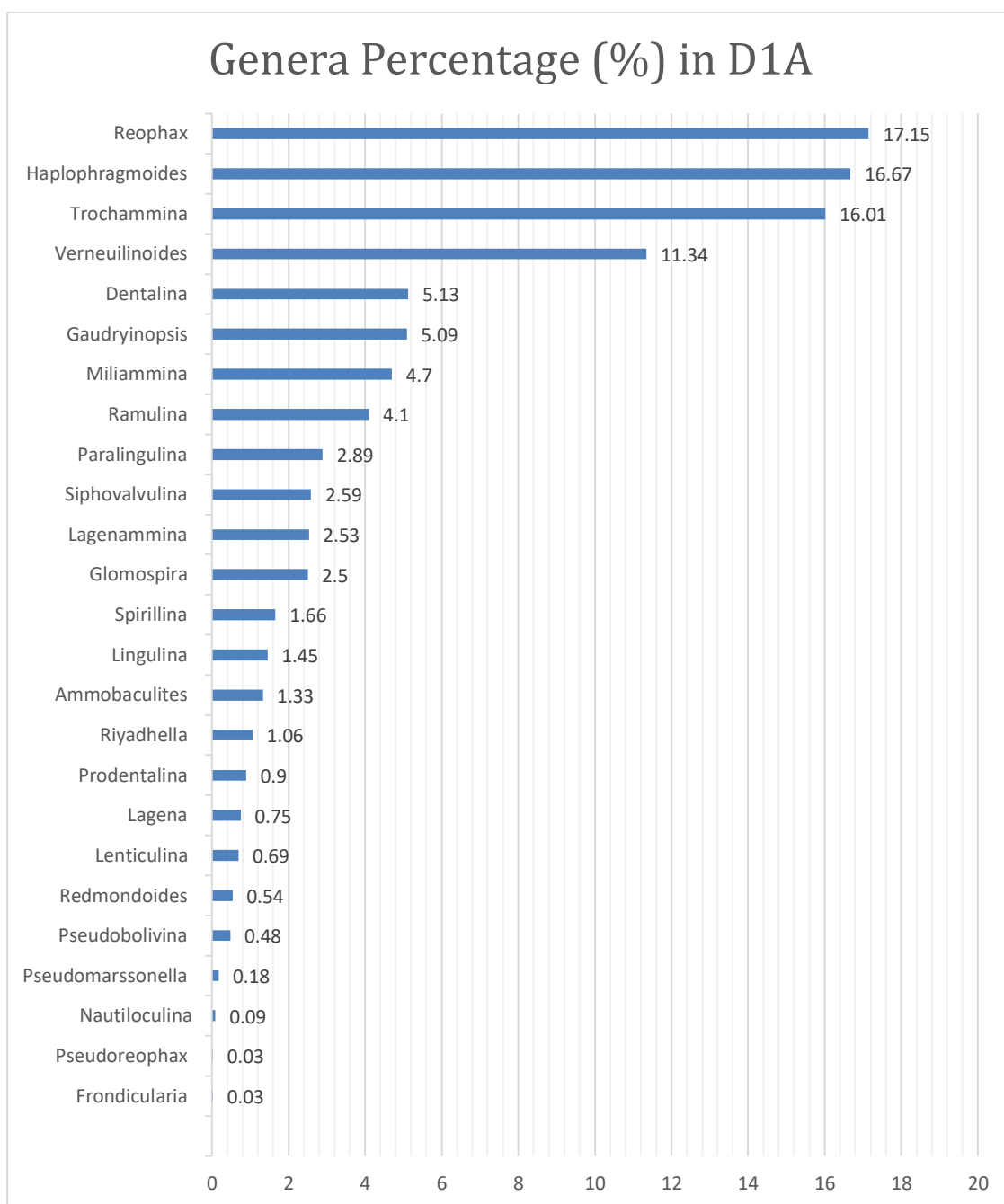


Figure 13: Genera percentages in location D1A

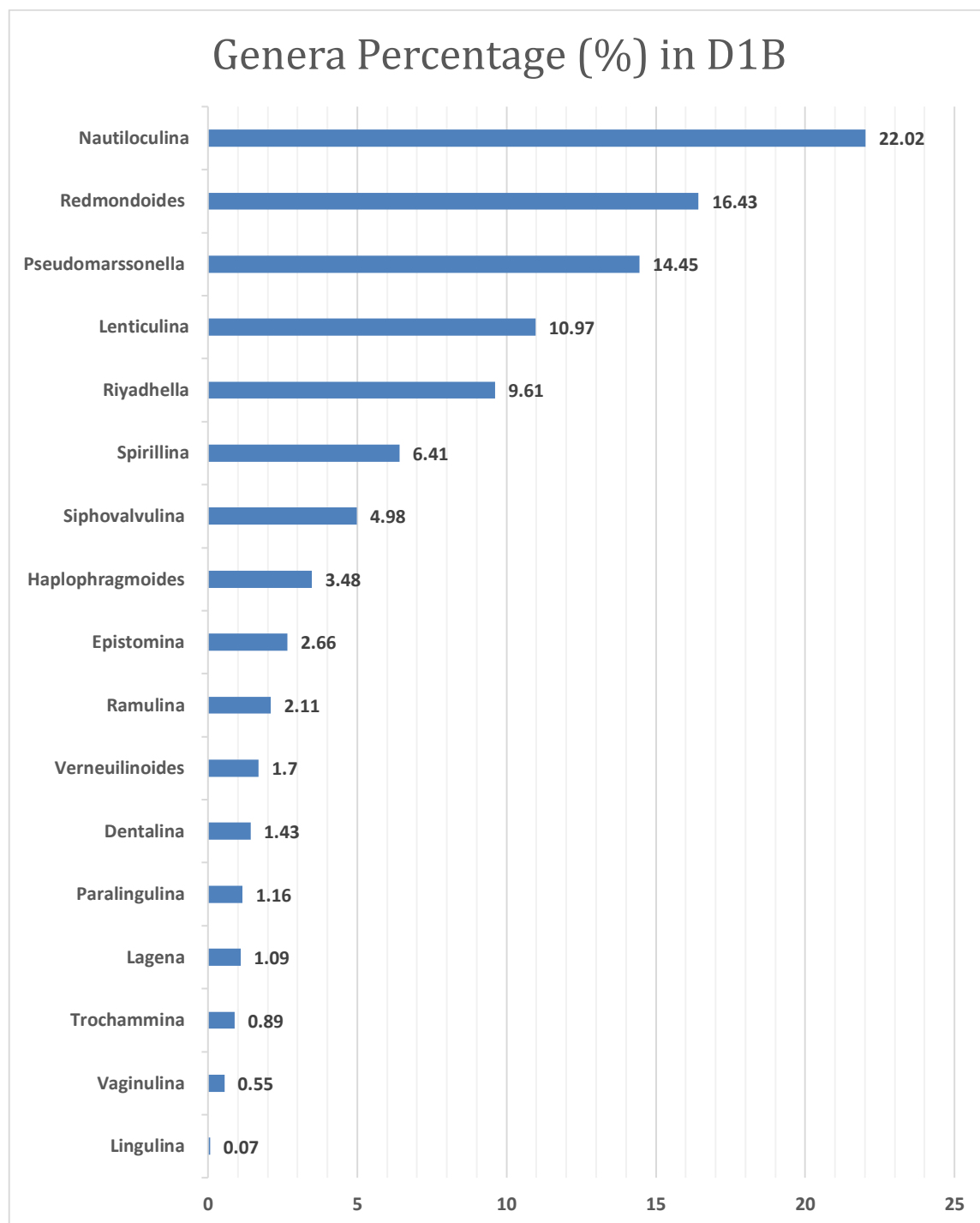


Figure 14: Genera percentages in location D1

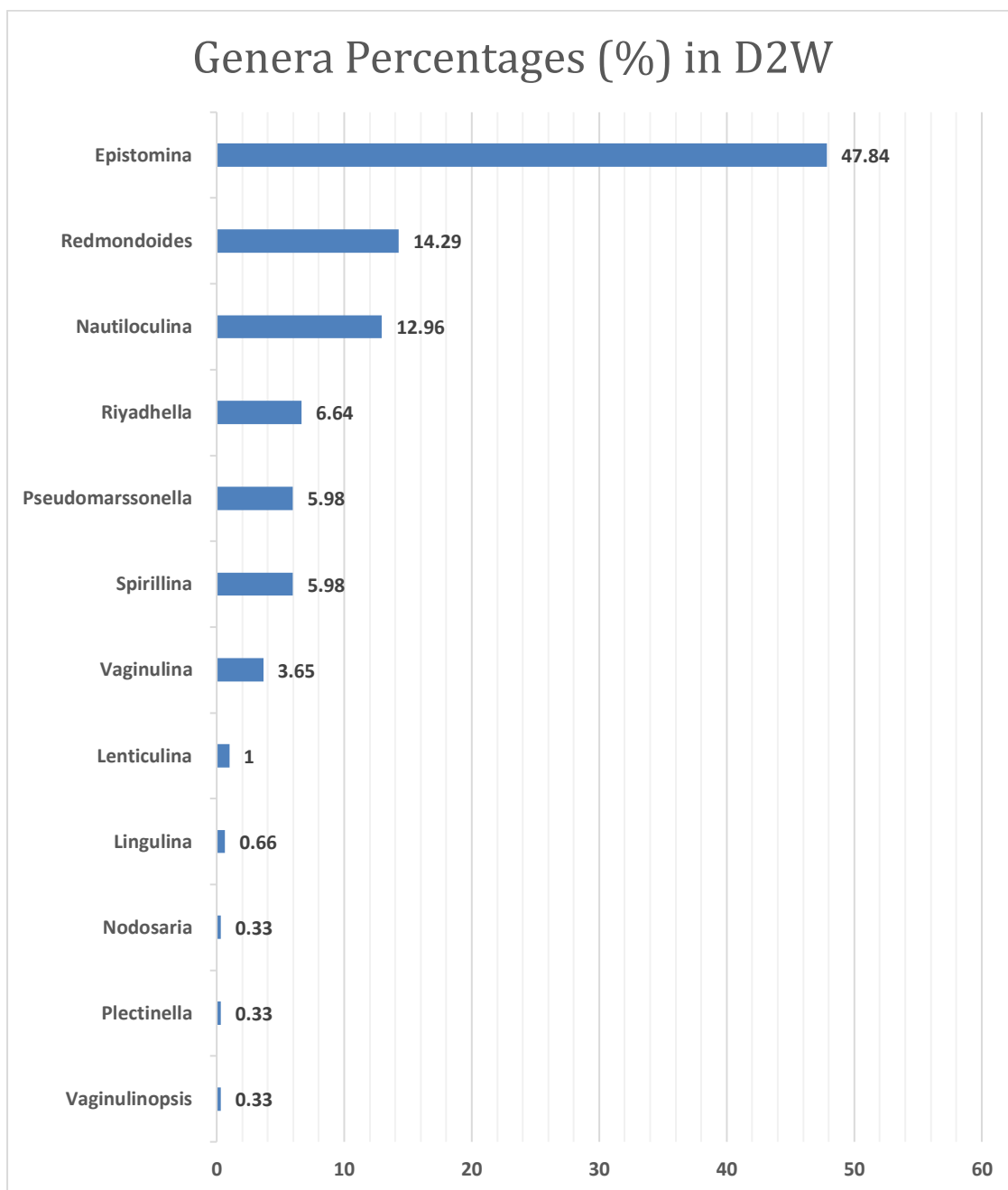


Figure 15: Genera percentages in location D2W

3.2 Morphogroup analysis

Foraminiferal morphogroup analysis is used to semi-quantitatively evaluate and interpret the paleoenvironment and its controlling parameters, i.e., nutrient availability, oxygenation, and paleobathymetry. The analysis hangs on the relationship between foraminiferal test characteristics (shape, chamber arrangement, mode of coiling, aperture features and position) and their feeding strategies and living habitat with the assumption that different forms have different functions (Nagy et al., 1995). Morphogroup analysis has been applied to modern and ancient environments, agglutinated and calcareous forms in both shallow and deep-water settings (e.g., Corliss, 1985; Jones and Charnock, 1985; Corliss and Chen, 1988; Nagy et al., 1992, 1995; Tyszka and Kaminski, 1995; Kaminski and Gradstein, 2005; Reolid et al., 2008, 2010, 2012; Cetaan et al. 2011; Farahani et al., 2018). The morphogroup scheme used here is modified after the morphogroup analysis scheme developed by Reolid et al. (2008a, 2012) and Farahani et al. (2018) on Jurassic samples due to the similarities in taxa and morphotypes to some extent. The 32 foraminiferal genera from the three sections are here differentiated into 10 different morphotypes, equally distributed between agglutinated named: B, C (with subtypes C1, C2 and C3), D, E plus one morphotype (M) that has not been reported in Reolid's morphogroup scheme, and calcareous named: H, J (with subtypes J1 and J3), K, F and G.

Based on inferred microhabitats (epifaunal, shallow infaunal and deep infaunal) and feeding strategies (suspension-feeder, herbivore, bacterivore, omnivore, etc.) the distinctive morphogroups are as follows:

Morphotype B: (*Lagenammina*) includes tubular and unilocular test shapes, epifaunal mode of life, suspension-feeders feeding strategy.

Morphotype C: have the highest number of genera among the agglutinated morphotypes and covers all the elongated agglutinated forms that share a similar feeding strategy and is subdivided into three subgroups:

C1: (*Reophax* and *Pseudoreophax*) is characterized by elongated uniserial forms, shallow to deep infaunal living habitat, detritivores and bacterial scavengers feeding strategy.

C2: (*Ammobaculites*) is characterized by elongated uniserial with an initial coiled phase, shallow to deep infaunal living habitat and detritivores and bacterial scavengers feeding strategy.

C3: (*Pseudobolivina*, *Riyadhella*, *Plectinella*, *Verneuilioides*, *Gaudryinopsis*, *Siphovalvulina*, *Pseudomarssonella* and *Redmondoides*) includes all elongated biserial, triserial, initially biserial or triserial and high trochospiral forms, shallow to deep infaunal living habitat and detritivores and bacterial scavengers feeding strategy.

Morphotype D: (*Haplophragmoides* and *Trochammina*) includes all elongated biserial, triserial, initially biserial or triserial and high trochospiral forms, shallow to deep infaunal living habitat and detritivores and bacterial scavengers feeding strategy.

Morphotype E: (*Glomospira*) consists of unilocular discoidal coiled forms with an epifaunal mode of life, and active herbivores or detritivores feeding strategy.

Morphotype M: (*Miliammina*) includes milioline shaped tests, shallow to deep infaunal living habitat and detritivores feeding strategy.

Morphotype F: (*Ramulina*) consist of calcareous tests that have a meandering initial phase, sessile epifaunal lifestyle and passive herbivores feeding strategy.

Morphotype G: (*Epistomina*) comprises plano-convex trochospiral calcareous forms, epifaunal living habitat and grazing herbivores feeding strategy.

Morphotype H: (*Spirillina*) consists of discoidal flattened planispiral and trochospiral calcareous form, epifaunal living habitat and grazing herbivores or phytodetritivores feeding strategy.

Morphotype J: has the highest number of genera among the calcareous morphotypes and covers all the elongated forms that share similar feeding strategies and subdivided into three subtypes:

J1: (*Nodosaria*, *Dentalina*, *Prodentalina*, *Lingulina*, *Paralingulina*, *Lagena*, *Virgulina* and *Fronidicularia*) comprises elongated uniserial calcareous forms, shallow infaunal living habitat, and active deposit feeders, herbivores, or bacterial scavengers feeding strategy.

J3: (polymorphinids) consists of elongated calcareous forms that have a straight periphery i.e., *Polymorphina* and *Eoguttulina*, shallow to deep infaunal living habitat, and active deposit feeders and grazing omnivores feeding strategy.

Morphotype K: (*Lenticulina*) includes bioconvex (lenticular) planispiral calcareous tests, infaunal living habitat, and active deposit feeders and grazing omnivores feeding strategy.

The most dominant morphotypes in the three sections are D, J3 and C3. However, the proportion and percentage of the morphogroups varies between the three sections, which suggests changes in paleoenvironmental settings.

Section D1A:

This section is dominated by the calcareous morphotype J3: (36.57%) and the agglutinated morphotype D (20.82%). Overall, the 5990 specimens from this section are spread into 8 morphotypes covering all the microhabitats of this study with almost an equal ratio between calcareous and agglutinated taxa (50.45% to 49.55%). The relatively high diversity and abundance of foraminiferal morphogroups in this section suggests a relatively well oxygenated environment with a flux of organic matter which was high enough for the survival of deep infaunal forms.

Section D1B:

A total of 1914 specimens were retrieved from this section and distributed into 7 morphotypes. The percentage of the agglutinated forms increased compared to the previous section and the ratio between calcareous to agglutinated taxa is (42.94% to 57.06%). The agglutinated morphotypes dominated this section; D (35.68%) followed by C3 (21.33%). Most of the groups in this section have an epifaunal living habitat, which might suggest an increase in the oxygen level and reduction in nutrient availability.

Section D2W:

A smaller number of specimens (309) and fewer morphotypes (6) are reported from this section. The distribution of the morphotypes changed significantly and are dominated by the calcareous morphotype G (36.55%), which accounts for only 2.52% in section D1B

and is nonexistent in section D1A, followed by the agglutinated morphotype C3 (24.14%). the ratio between calcareous to agglutinated taxa changed as well to (63.42% to 36.58%). The epifaunal and shallow infaunal taxa account for more than 95% of the assemblage, which suggests a shallow environment setting with an increase in the oxygen level and reduced nutrient availability.

TABLE 3. Morphogroup percentages in the three sections

Morphogroups in Section D1A	%	Morphogroups in Section D1B	%	Morphogroups In Section D2W	%
J3	36.57	D	35.68	G	36.55
D	20.82	C3	21.38	C3	24.14
C3	14.16	J1	20.02	J1	22.12
C1	10.85	J3	8.7	D	12.44
J1	7.17	K	7.83	H	3.19
M	3.21	H	2.98	K	1.56
E	1.63	G	2.52		
F	2.09	F	0.89		
B	1.64				
H	1.41				
C2	0.45				

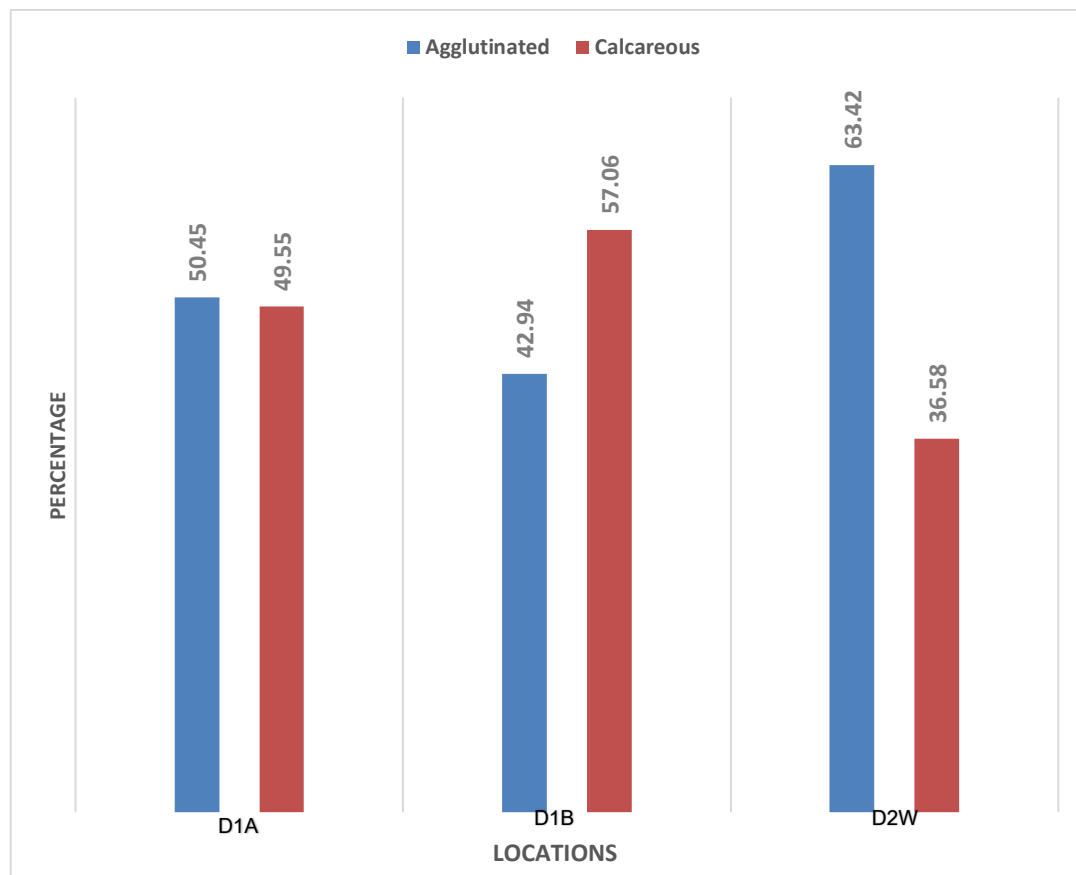


Figure 16: Agglutinated vs Calcareous percentages in the three locations

Morphogroup		Test form	Lifestyle	Feeding strategy	Examples
B		Globular, unilocular	Epifaunal	Passive depositivorous	 Lagenammina
C	C1	Elongated uniserial	Shallow to deep infaunal	Detritivores, bacterial scavengers	  Pseudoreophax Reophax
	C2	Elongated uniserial with an initial coiled phase	Shallow infaunal	Detritivores, bacterial scavengers	 Ammobaculites
	C3	Elongated biserial, triserial and high trochospiral	Shallow to deep infaunal	Detritivores, bacterial scavengers	  Siphovalvulina Pseudomarssonella    Riyadhella Verneuillinoidea Gaudryinopsis
D		Rounded, globular and plano-convex planispiral to trochospiral	Epifaunal	Active herbivores, omnivores, detritivores and bacterivores	  Haplophragmoides Trochammina
E		Discoidal coiled (unilocular)	epifaunal	Active herbivores, detritivores	 Glomospira
M		Milioline shaped test	Shallow to deep infaunal	detritivores	 Miliammina

Figure 17: Agglutinated morphogroups modified after Reolid et al. (2008).

Morphogroup	Test form	Lifestyle	Feeding strategy	Examples
F	Meandering initial phase coiled	Sessile epifaunal	Passive depositivorous	 Ramulina
G	Elongated uniserial	Shallow to deep infaunal	Detritivores, bacterial scavengers	 Epistomina
H	Elongated uniserial with an initial coiled phase	Shallow infaunal	Detritivores, bacterial scavengers	 Spirillina
J1	Elongated biserial, triserial and high trochospiral	Shallow to deep infaunal	Detritivores, bacterial scavengers	 Dentalina, Prodentalina, Lingulina, Paralingulina   Lagena Frondicularia
J3	Rounded, globular and plano-convex planispiral to trochospiral	Epifaunal	Active herbivores, omnivores, detritivores and bacterivores	 Eoguttulina, Polymorphina
K	Discoidal coiled (unilocular)	epifaunal	Active herbivores, detritivores	 Lenticulina

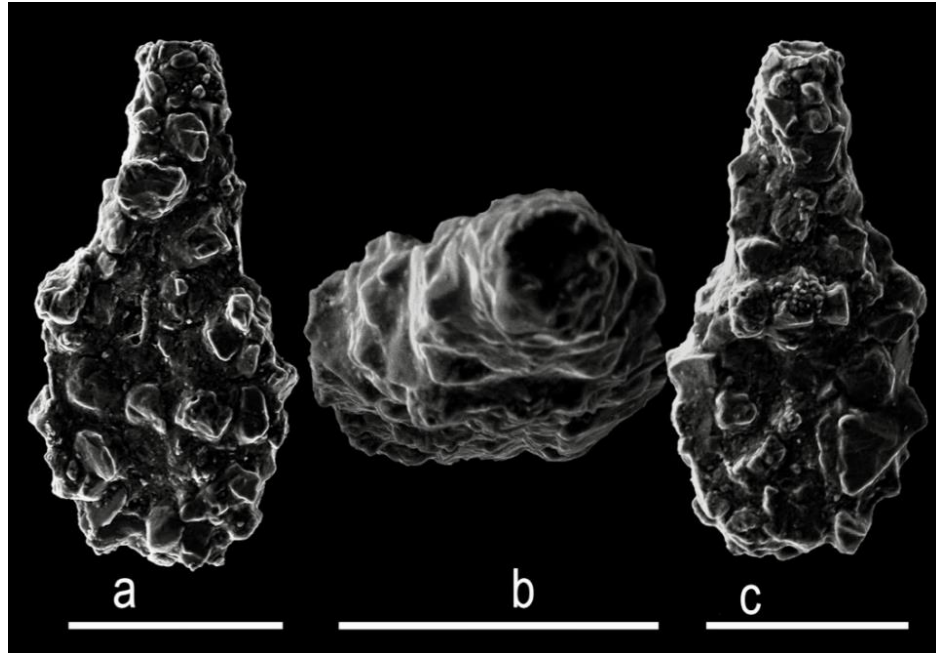
Figure 18: Calcareous morphogroups modified after Reolid et al. (2008).

3.3 Taxonomy

From the sixty-three benthic foraminiferal taxa identified in this study, fifty-seven have been described to species level. The agglutinated species were identified based on the generic criteria of Kaminski (2014) catalog and arranged similar to their order in the catalog. On the other hand, the calcareous taxa were identified based on the generic criteria of Loeblich and Tappan (1987) “Foraminiferal Genera and Their Classification” and arranged here alphabetically. Species-level identifications were carried out using the Ellis & Messina Catalog of Foraminifera and the classic references mentioned therein. The following format is used for each species: three SEM pictures (umbilical, spiral and apertural view) and a scale bar of 100 micrometer (μm), genus, original designation, synonyms, diagnosis, type level, remarks and occurrences.

Agglutinated Species

***Lagenammina difflugiformis* Brady, 1879**



Genus: *Lagenammina* Rhumbler, 1911

Original Designation: *Reophax difflugiformis* Brady, 1879 p. 51, pl. 4, fig 3a, b.

Synonyms: *Lagenammina difflugiformis* Brady, 1879 of Copestake & Johnson 2014, pl. 1, fig. 21

Diagnosis: Test small, ovate and flask shaped with tubular neck, approximately as long as chamber. Initial portion of test spherical to subconical. Wall coarsely agglutinated.

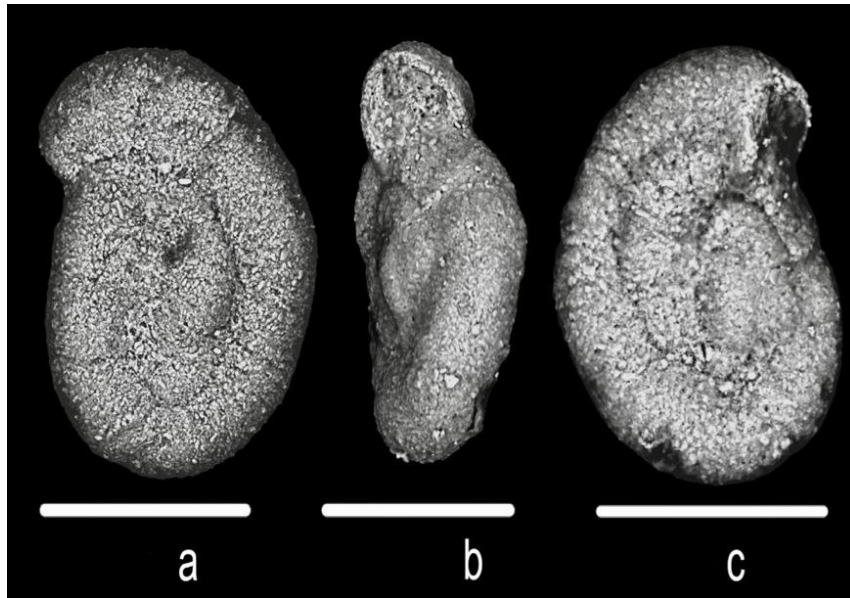
Aperture at the end of a neck.

Type Level: Recent

Remarks: *Reophax difflugiformis* was originally described by Brady from the Holocene. According to Copestake & Johnson (2014), there is a Lower Jurassic *Lagenammia* species that is identical to the Holocene *Lagenammia difflugiformis*. 41 specimens found on the marly beds of D1 unit of the Dhruma Formation (Bajocian) in this study.

Occurrences: Jurassic of Britain, France, Germany, Portugal, Spain, Sweden, Switzerland and offshore of Morocco. (Copestake & Johnson 2014).

***Glomospira gordialis* (Jones & Parker) var. *chodzica* Antonova, 1958**



Genus: *Glomospira* Rzehak, 1885

Original Designation: *Trochammina squamata* Jones & Parker var. *gordialis* Jones & Parker, 1860, p. 304 (pl & fig. not given), Berggren & Kaminski, 1990, pl. 1. fig. 1.

Synonyms: *Glomospira gordialis* (Jones & Parker) var. *chodzica* Antonova, 1958, p. 48, pl. 1, fig. 4a-c.

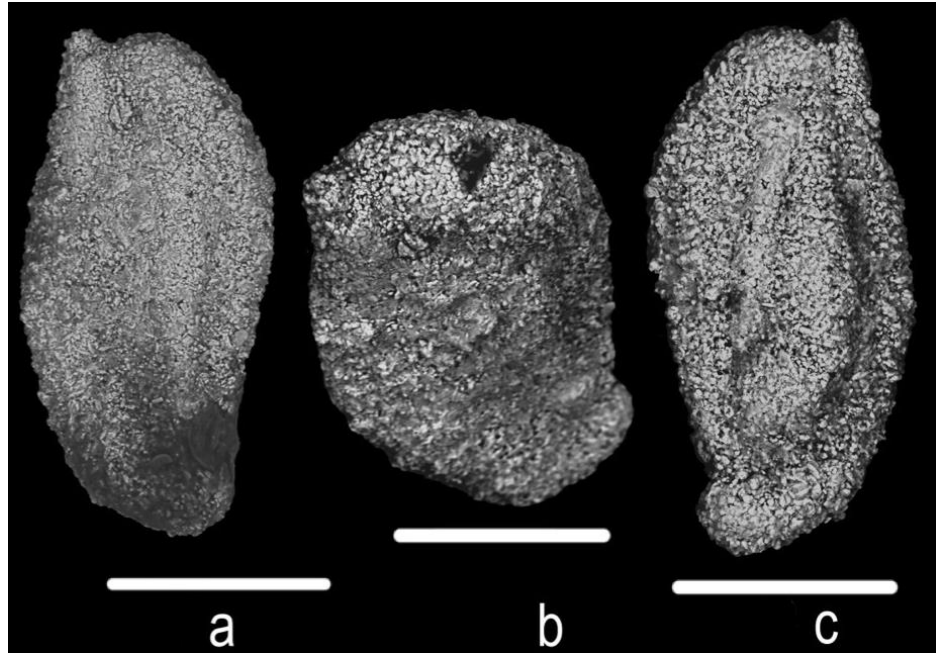
Diagnosis: Test discoidal, oval, streptospirally or irregularly coiled around the proloculus. Wall finely agglutinated. Aperture has a rounded-oval shape and located at the end of the tubular chamber.

Type Level: Middle Jurassic.

Remarks: *Glomospira gordialis* (Jones & Parker, 1860) has different synonyms and varieties. The synonyms include *Ammodiscus gordialis* (Jones & Parker, 1860), *Gordiammina gordialis* (Jones & Parker, 1860), *Trochammina squamata gordialis* (Jones & Parker, 1860) (Hayward et al., 2014). The varieties include *Glomospira gordialis* (Parker & Jones) var. *diffundens* Cushman & Renz, 1946 from the Paleocene, *Glomospira gordialis* (Parker & Jones) var. *irregularis* Rauser-Chernoussova, 1948 and *Glomospira gordialis* (Parker & Jones) var. *prisca* Rauser-Chernoussova, 1948 from the Lower Carboniferous. In this study 83 specimens were found in the beds of the D1 unit of the Dhruma Formation (Bajocian).

Occurrences: Bajocian of Pseba region of the Northern Caucasus (Antonova, 1958).

***Miliammina grana* Azbel', 1977**



Genus: *Miliammina* Heron-Allen and Earland, 1930

Original Designation: *Miliammina grana* Azbel' 1977, p. 22, pl. 2, fig. 16, 17.

Synonyms: none verified.

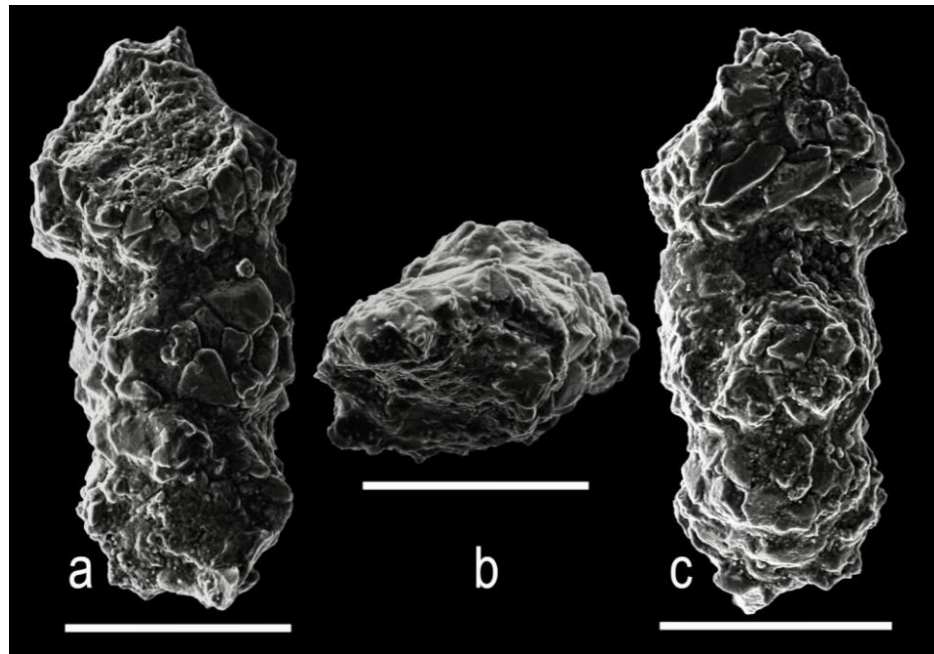
Diagnosis: Test milioline, elongate, slightly compressed and convex, with angularly rounded base and apertural end, about twice as long as greatest width, chamber arrangement quinqueloculine, sutures weakly depressed, wall finely agglutinated. Aperture semilunate, marginal and inclined.

Type Level: Middle Jurassic (Bathonian)

Remarks: The outline and degree of convexity of the test vary quite slightly. This species is similar to *Miliammina jurassica* (Hauesler) [synonym: *Trochammina jurassica*, 1882] but with a broader test and lack of an apertural neck (Azbel', 1977). In this study 83 specimens found in the beds of the D1 unit of the Dhruma Formation (Bajocian).

Occurrences: Mangyshlak, Kazakhstan (Azbel', 1977).

***Reophax* cf. *R. dentaliniformis* Brady, of Görög 1995**



Genus: *Reophax* de Montfort, 1808

Original Designation: *Reophax dentaliniformis* Brady – Görög, 1995, p. 27, pl. 1, fig. 4.

Synonyms: *Nodosaria agglutinanus* Terquem, 1886, p. 10, pl. 1, fig. 20.

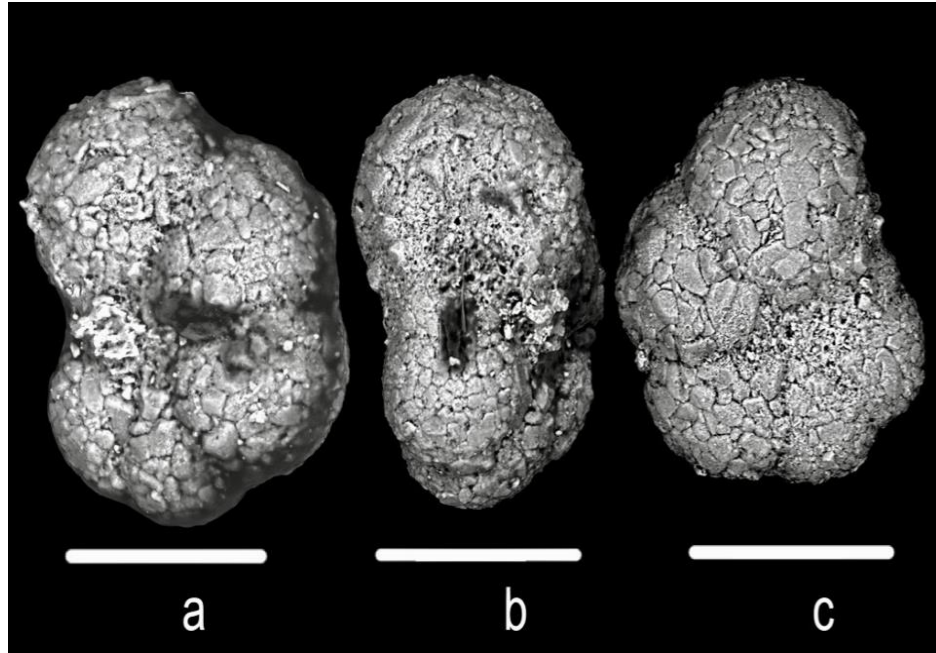
Diagnosis: Test elongated, straight, consists of 3 to 4 chambers, first chamber is slightly globular, the following chambers pyriform in shape and the last chamber is triangular. Sutures are depressed, wall coarsely agglutinated. Aperture terminal.

Type Level: Middle Jurassic (Bathonian).

Remarks: This species differs from *Reophax dentaliniformis* Brady, as illustrated by Görög (1995), in being smaller in size, the first chamber is not greatly globular, and the last chamber is shorter. A total of 569 specimens were found in the beds of the D1 unit of the Dhruma Formation (Bajocian) in this study with different degrees of preservation.

Occurrences: NW Germany (Bathonian), S Germany (Lower to Upper Jurassic), Russia (Bajocian), Ukraine (Upper Jurassic), southern Poland (Bathonian), Hungary (Bathonian) (Görög, 1995).

***Haplophragmoides bartensteini* Kalantari, 1969**



Genus: *Haplophragmoides* Cushman, 1910.

Original Designation: *Haplophragmoides bartensteini* Kalantari, 1969 (National Iranian Oil Company, Publication, 3. p. 19, pl. 7, figs. 16-18).

Synonyms: none verified.

Diagnosis: Test free, small, planspirally close coiled, subcircular in outline, moderately compressed. Periphery rounded with five to six slightly inflated triangular chambers. Chambers sizes increase gradually except for the last chamber that increases significantly

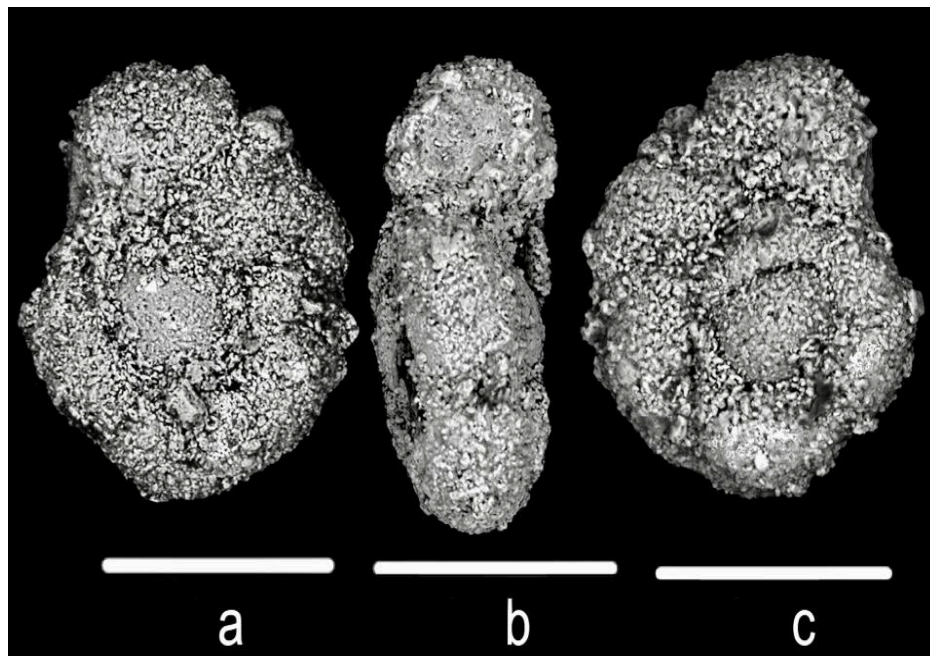
in size compared to the previous chambers. Wall consists of coarse agglutinated grains. Sutures are depressed and radial or gently curved toward the periphery. Aperture an opening at the base of last chamber and a low arch in shape.

Type Level: Middle Jurassic (Bajocian).

Remarks: According to Kalantari (1969), this species closely resembles the Kimmeridgian *Haplophragmoides haeusleri* Lloyd but differs in having a larger test and a broad umbilicus. In this study, 294 specimens were found in the beds of D1 unit of the Dhruma Formation (Bajocian).

Occurrences: In basal shales 3457 m below the top of a measured section at Khorkhod, 80 km northeast of Shahrud, NE Iran (Kalantari, 1969).

***Haplophragmoides barthouxi* Said & Barakat, 1958**



Genus: *Haplophragmoides* Cushman, 1910

Original Designation: *Haplophragmoides barthouxi* Said & Barakat, 1958, p. 240, pl. 2, fig. 4

Synonyms: none verified.

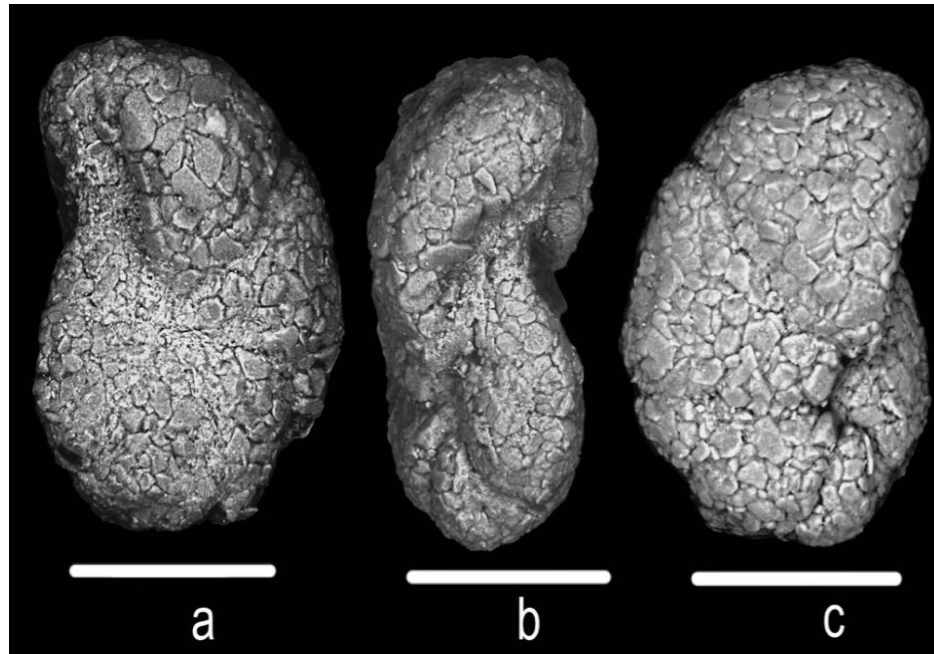
Diagnosis: Test free, medium size, planspirally coiled, partially evolute with depressed sides, noticeable central umbilicus. 8 to 10 inflated, gradually increasing in size chambers in the adult stage. Sutures depressed; wall is finely agglutinated. Aperture low, located at the base of the last chamber.

Type Level: Middle Jurassic (Bathonian).

Remarks: This species differs from the Cretaceous *Haplophragmoides glabra* Cushman and Waters in having a more evolute last coil and in having a smoothly finished test (Said & Barakat, 1958). Only 2 specimens were found in the beds of the D1 unit of the Dhruma Formation (Bajocian).

Occurrences: Gebel Maghara, Northern Sinai, Egypt (Said & Barakat, 1958).

Resembling to some extent: *Haplophragmoides canui* Cushman, 1930



Genus: *Haplophragmoides* Cushman, 1910.

Original Designation: *Haplophragmoides canui* Cushman, 1930, p.133, pl. 4, fig. 1a, b.

Synonyms: none verified.

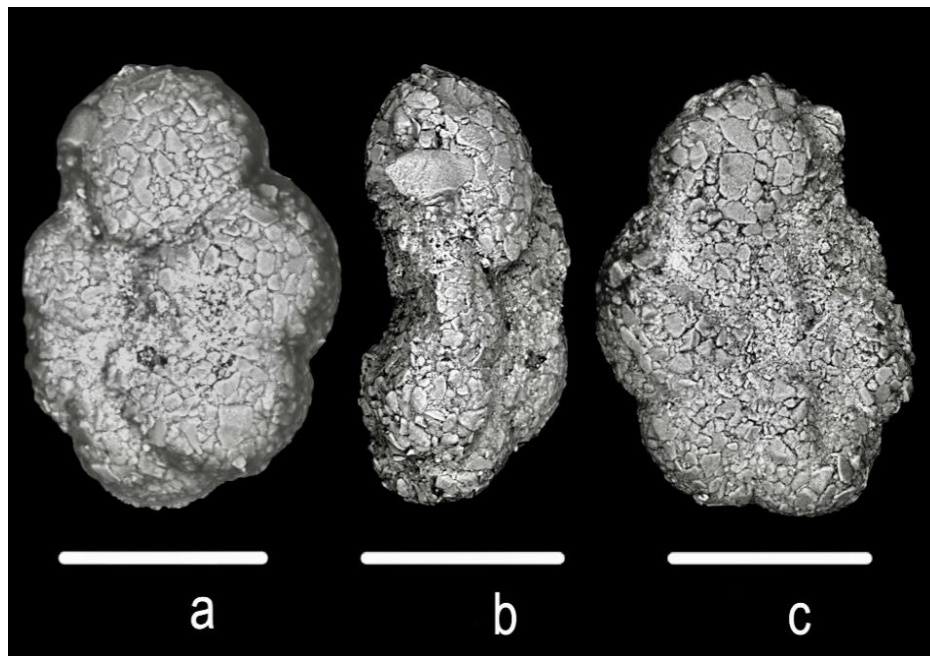
Diagnosis: Test small, planispiral, oval shaped, involute, 5 to 6 triangular chambers that increase gradually in size as added. Sutures depressed and radial. Wall is coarsely agglutinated. Aperture not visible.

Type Level: Upper Jurassic (Oxfordian).

Remarks: This species has an oval shape compared to the rounded *Haplophragmoides canui* Cushman, 1930. In this study, 47 specimens recorded from marly beds of the D1 unit of the Dhruma Formation.

Occurrences: Oxfordian of Calvados, France (Cushman, 1930), Upper Jurassic of Thakkhola, Nepal (Nagy et al., 1995).

Haplophragmoides cf. planus Antonova, 1958



Genus: *Haplophragmoides* Cushman, 1910.

Original Designation *Haplophragmoides planus* Antonova, 1958, p. 49, pl.1, fig. 7a, b.

Synonyms: none verified.

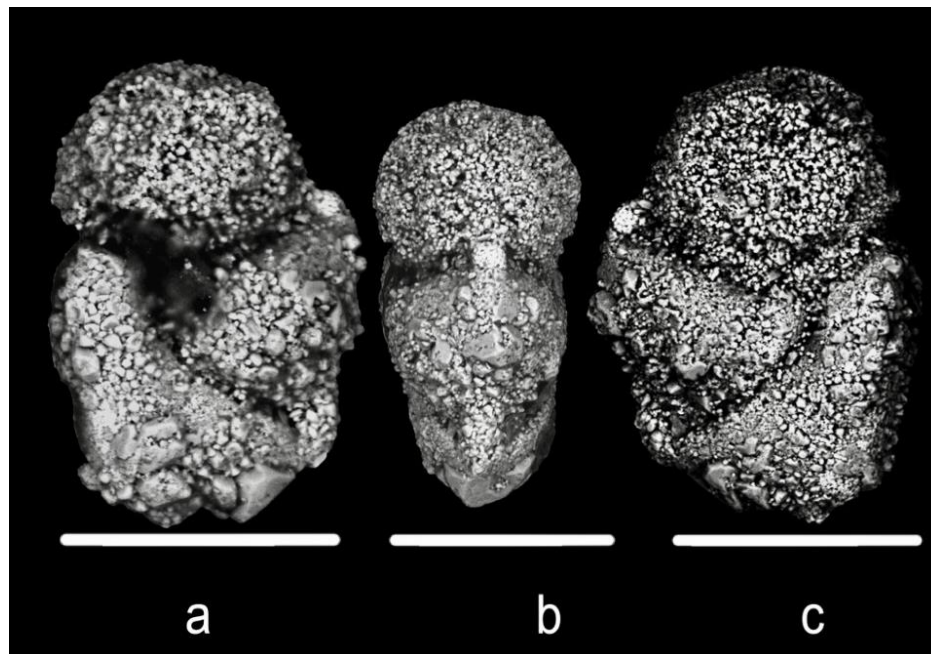
Diagnosis: Test small, oval to rounded, strongly flattened. Consist of 4-7 chambers on last whorl. Sutures curved, and depressed. Small umbilical depression on both sides of the test in the central part. Wall finely agglutinated and smooth. Aperture not visible.

Type Level: Middle Jurassic (Bajocian).

Remarks: This species has variable size and chamber numbers that range from 4 to 8 (Antonova, 1958). In this study, 264 specimens found on the marly beds of D1 unit of the Dhruma Formation.

Occurrences Bajocian of the Northern Caucasus (Antonova, 1958).

***Haplophragmoides* sp. 1**



Genus: *Haplophragmoides* Cushman, 1910

Original Designation: *Haplophragmoides* sp. 1

Synonyms: none verified.

Diagnosis: Test small, irregular oval in shape, planspirally coiled, 3 to 4 inflated chambers, increasing gradually in size. Chambers are triangular in shape except the last chamber that has a rounded shape. Sutures depressed and radial, wall is finely agglutinated. Aperture low and located at the base of last chamber.

Type Level: Middle Jurassic (Bajocian).

Remarks: In this study, 21 specimens found on the marly beds of D1 unit of the Dhruma Formation.

Occurrences: Riyadh district of Saudi Arabia.

Ammobaculites alaskensis Tappan, 1955



Genus: *Ammobaculites* Cushman, 1910

Original Designation *Ammobaculites alaskensis* Tappan, 1955, pl.12, fig. 1a, b.

Synonyms: *Lituola agglutinans* (d'Orbigny). - Blake 1976, (pl. 17, fig. 40)

Haplophragmium coprolithiforme Schwager. – Deecke 1884, (pl. 4 fig. 7, 20)

Haplophragmium agglutinans (d'Orbigny). – Häusler 1890, (pl. 4, fig. 5, 6, 18)

Ammobaculites agglutinans (d'Orbigny). – Franke 1936, (pl. 12, fig. 25)

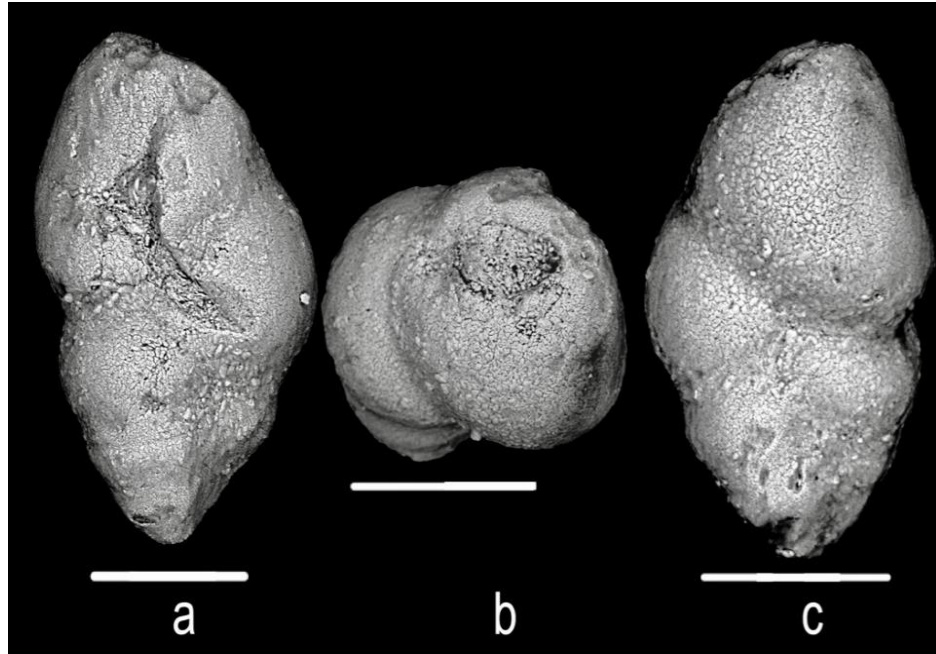
Diagnosis: Test free, early portion close coiled, biumbilicate, later uniserial, chamber inflated. 4 to 5 chambers in the coil, followed by 3 to 8 uniserial chambers. Sutures straight, wall coarsely agglutinated. Aperture terminal and rounded.

Type Level: Lower Jurassic.

Remarks: There is a variation in size and number of chambers of this species. The stratigraphic range of this species extends from the Lower Jurassic to Recent, but it is recorded under different synonyms. 44 specimens found on D1 unit of the Dhruma Formation in this study.

Occurrences: Northern Alaska (Tappan, 1955), Neuquén basin in Argentina, Jurassic (Ballent, 2004), Eastern Sana'a basin in Yemen, Middle Jurassic (Al-Wosabi et al., 2017).

***Plectinella aegyptiaca* Said & Barakat, 1958**



Genus: *Plectinella* Marie, 1956

Original Designation *Arenovirgulina aegyptiaca* Said and Barakat, 1958, pl. 3, fig. 38 a-b.

Synonyms: none verified.

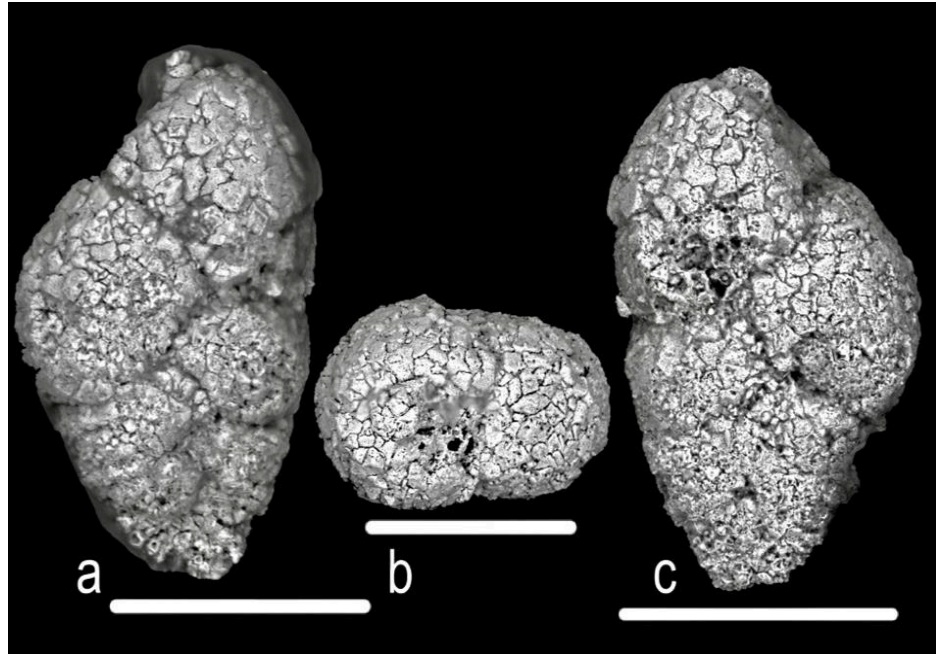
Diagnosis: Test small, chambers arranged in biserial to loosely biserial form along a slightly twisted axis. Chambers slightly inflated and increase in length and breadth as added. Sutures distinct and depressed slightly. Wall agglutinated with smooth surface. Aperture subterminal and slitlike on the final chamber.

Type Level: Middle Jurassic (Callovian).

Remarks: Said & Barakat (1958) reported this new species and assigned it to a new genus called *Arenovirgulina* Said & Barakat. This genus name is no longer in use and the species is assigned to *Plectinella* Marie, 1956 by Loeblich and Tappan (1988). Only 2 specimens found in the D2 unit of the Dhurma Formation in this study.

Occurrences: Gebel Ingbashi, Northern Sinai, Egypt (Callovian) (Said & Barakat, 1958), Eastern Sana'a basin in Yemen, Middle Jurassic (Al-Wosabi et al., 2017), Wadi Al Karn, Syria (Oxfordian) (Kuznetsova, 1991).

Pseudobolivina? sp. 1



Genus: *Pseudobolivina* Wiesner, 1931

Original Designation *Pseudobolivina* sp. 1.

Synonyms: none verified.

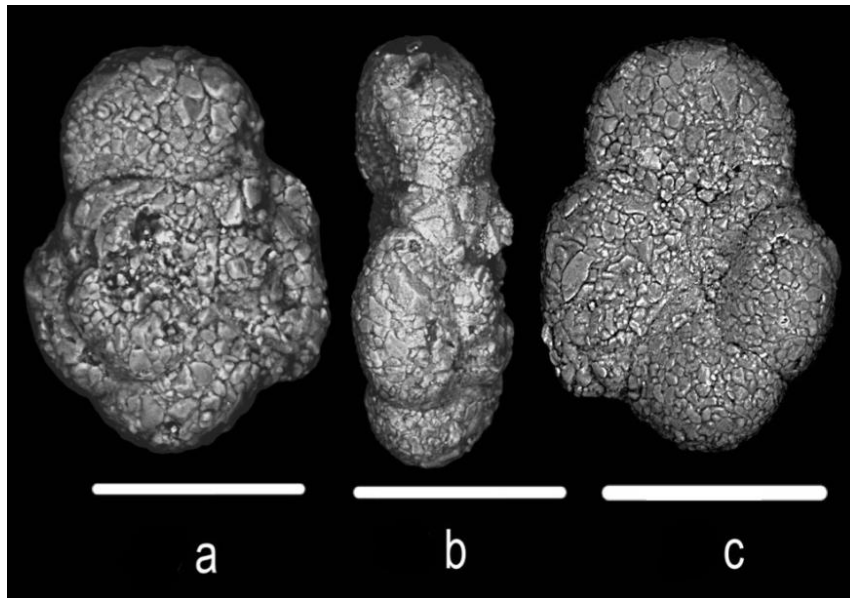
Diagnosis: Test small, chambers arranged in biserial to loosely biserial form along a slightly twisted axis, flaring. Chambers slightly inflated and increase in length and breadth as added. Sutures distinct and depressed slightly. Wall finely agglutinated. Aperture terminal, at the end of a short neck.

Type Level: Middle Jurassic (Bajocian).

Remarks: This species differ than *Pseudobolivina elongate* Kalantari, 1969 from Bajocian of Iran in having more flaring outline and a smaller number of chambers. 16 specimens found in the D1 unit of the Dhurma Formation in this study.

Occurrences: Riyadh district of Saudi Arabia.

***Trochammina elevata* Kosyreva in Dain, 1972**



Genus: *Trochammina* Parker & Jones, 1859

Original Designation *Trochammina elevata* Kosyreva in Dain, 1972, p.88, pl. 23, fig. 8-11, 13.

Synonyms: none verified.

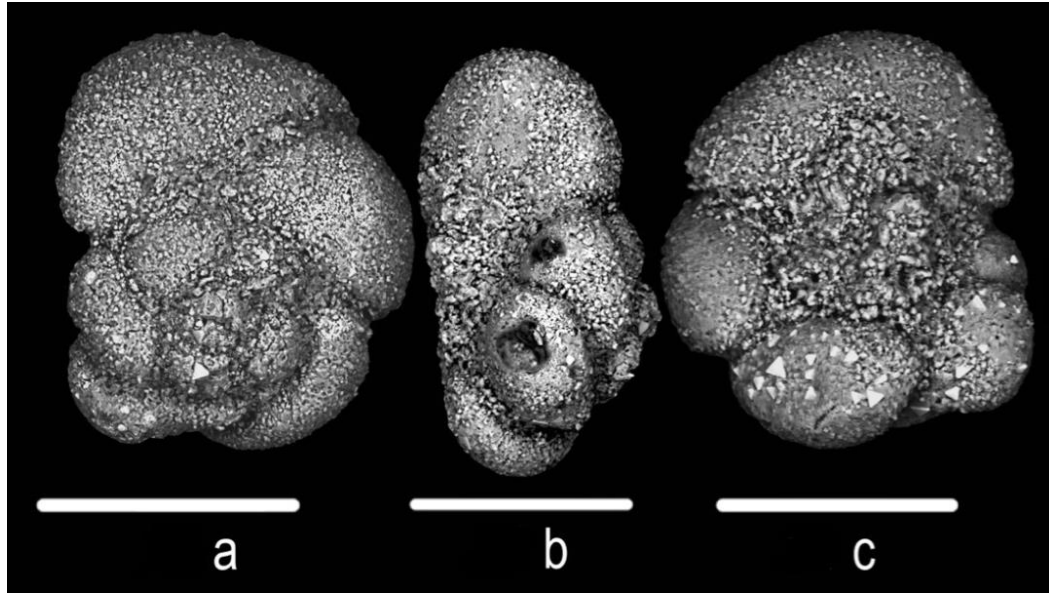
Diagnosis: Test small, high trochospiral, conical in shape and, a lobate outline, planoconvex. Chambers quadrangular and gradually increased in size as added. Sutures curved toward the periphery and slightly depressed. 2 to 2.5 whorls are visible on the dorsal side while on the ventral side only the chambers of the final whorl are visible. Wall finely agglutinated. Aperture not visible.

Type Level: Upper Jurassic (Kimmeridgian).

Remarks: In this study, a total of 143 specimens are recorded from the marly beds of the D1 unit of the Dhruma Formation (Bajocian).

Occurrences: Kimmeridgian at a depth of 1393-1401 m in Tyumen' city, Ustyurt Province, Russia (Dain, 1972).

***Trochammina instabilis* Vassilenko, 1988**



Genus: *Trochammina* Parker & Jones, 1859

Original Designation *Trochammina instabilis* Vassilenko, 1988, p. 67, pl. 26, figs. 4-5.

Synonyms: none verified.

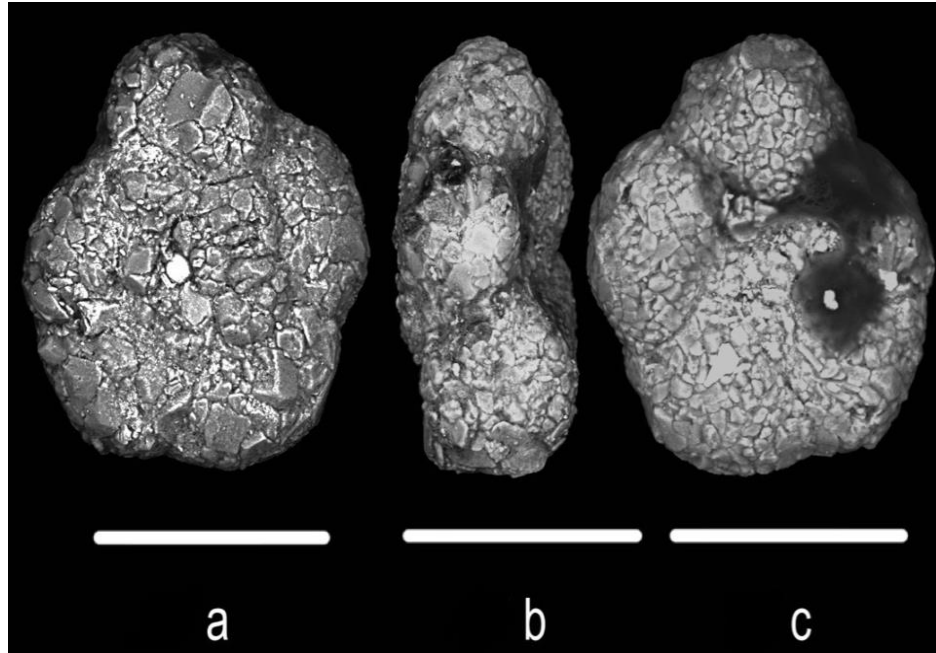
Diagnosis: Test small, low trochospiral with a lobate outline, convex on ventral side. Chambers are rounded and increase in size as added, $4\frac{1}{2}$ in the final whorl. Chambers in the first whorl are more rounded while on the last whorl they are more rounded-triangular. Sutures oblique on the spiral side, radial and depressed on the umbilical side. Umbilicus broad and shallow. Wall finely agglutinated. Aperture indistinct.

Type Level: Lower Cretaceous (Middle Albian).

Remarks: This species differs from *Trochammina dampelae* Dain, 1961 in having more oblique sutures and in the number of chambers. In this study, a total of 41 specimens are recorded from the marly beds of the D1 unit of the Dhruma Formation (Bajocian).

Occurrences: South of Mangyshlak peninsula, Kazakhstan (Vassilenko, 1988).

***Trochammina cf. numerosa* Akimets, 1966**



Genus: *Trochammina* Parker & Jones, 1859

Original Designation *Trochammina numerosa* Akimets, 1966, p. 348, pl. 3, figs. 2-5.

Synonyms: none verified.

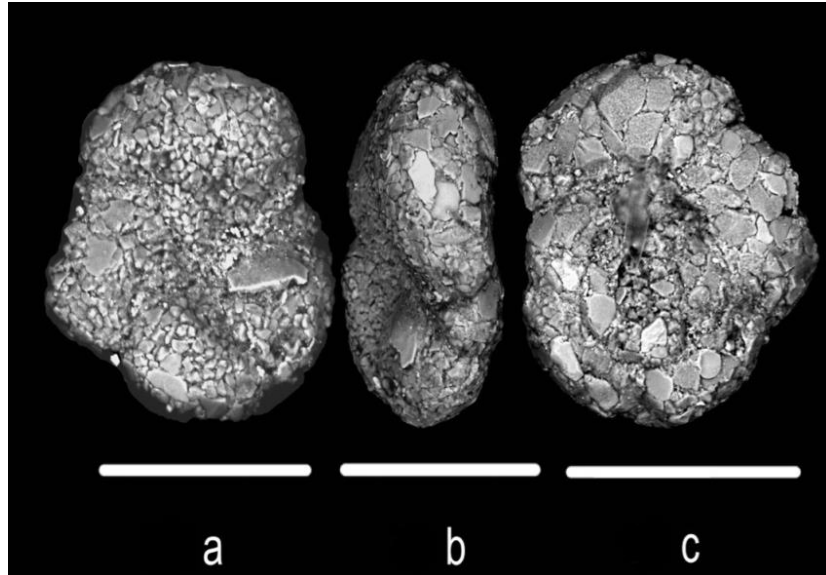
Diagnosis: Test small, trochospiral, rounded in outline. Dorsal side weakly convex. Chambers trapezoidal and weakly convex to flattened on both sides of the test. Sutures weakly depressed. Peripheral margin compressed to rounded. Wall coarsely agglutinated. Aperture slit shaped located at the base of the septal surface of the last chamber.

Type Level: Lower Cretaceous (Hauterivian–Barremian).

Remarks: *Trochammina numerosa* has a variable shape of test (from round to oval) and varies on the degree of evoluteness on the dorsal sides (from semi evolute to almost evolute) (Akimets, 1966). In this study 16 specimens were found in the marly beds of the D1 unit of the Dhruma Formation.

Occurrences: Gomel region, Belarus (Akimets, 1966).

***Trochammina squamataformis* Kaptarenko-Chernousova, 1959**



Genus: *Trochammina* Parker & Jones, 1859

Original Designation: *Trochammina squamataformis* Kaptarenko-Chernousova, 1959, p. 51, pl. 8, fig. 1-2.

Synonyms: none verified.

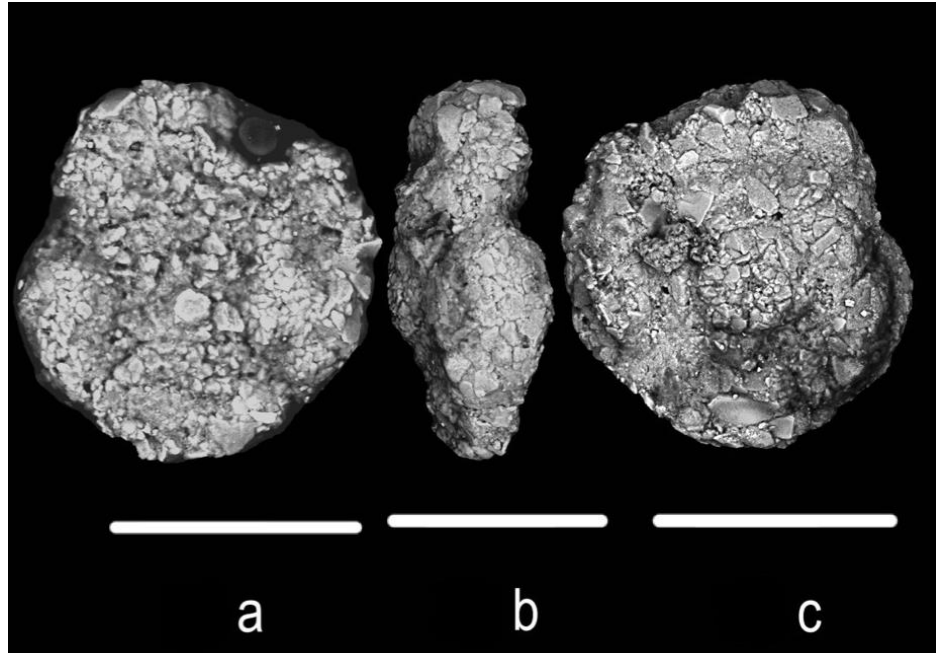
Diagnosis: Test small, asymmetrical, trochospiral, planoconvex. Chambers quadrangular and gradually increasing in size as added. Sutures curved toward the periphery and slightly depressed. Two to 2.5 whorls are visible on the dorsal side while on the ventral side only the chambers of the final whorl are visible. Periphery sharp and lobate. Wall finely agglutinated with occasional larger platy grains. Aperture not visible.

Type Level: Lower Jurassic (Upper Toarcian).

Remarks: The stratigraphic range of this species is from Lower to Upper Jurassic (Toarcian to Oxfordian). In this study 41 specimens are recorded from the shale beds of the D1 unit of the Dhruma Formation (Bajocian).

Occurrences: Pliensbachian and Toarchain of the Caucasus and Ukraine (Azbel & Grigalis, 1991), Pliensbachian and Toarchain of SW part of the Hammerfest Basin, Barents Sea (Hess et al., 2014).

Trochammina sp. 1



Original Designation *Trochammina* sp. 1

Synonyms: none verified.

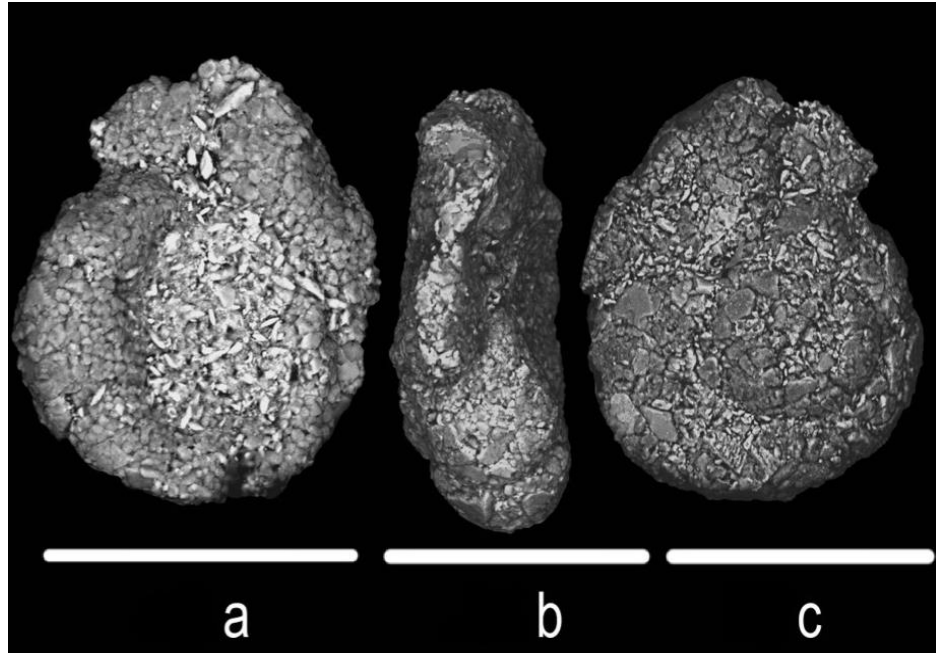
Diagnosis: Test small, trochospiral, circular in outline. Sutures weakly depressed. Wall finely agglutinated. Aperture not visible. Chambers flattened. On the ventral side, chambers trapezoidal with weakly depressed sutures. On the dorsal side, first whorl is rounded, sutures flat and indiscernible. Peripheral margin sharp. Wall finely agglutinated. Aperture not visible.

Type Level: Middle Jurassic (Bajocian).

Remarks: This species differs from *Trochammina* cf. *numerosa* in having a sharp peripheral margin, rounded first whorl, and finely agglutinated wall. In this study 72 specimens were found in the marly beds of the D1 unit of the Dhurma Formation.

Occurrences: Riyadh district of Saudi Arabia.

Trochammina sp. 2



Original Designation *Trochammina* sp. 2

Synonyms: none verified.

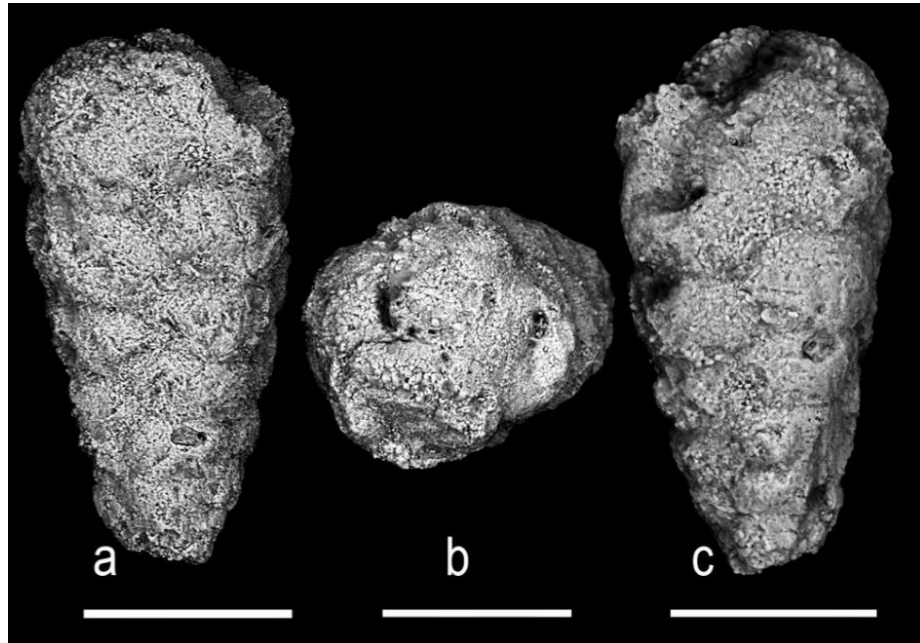
Diagnosis: Test small, low trochospirally coiled, circular in outline, sutures weakly depressed, becoming oblique on the spiral side. Wall finely agglutinated with occasional larger platy grains. Aperture indistinct.

Type Level: Middle Jurassic (Bajocian).

Remarks: In this study, 155 specimens are recorded from shale beds of the D1 unit of the Dhruma Formation (Bajocian).

Occurrences: Riyadh district of Saudi Arabia.

Riyadhella arabica Redmond, 1965



Genus: *Riyadhella* Redmond, 1965

Original Designation *Riyadhella arabica* Redmond, 1965, p. 136, pl. 1, fig. 35.

Synonyms: none verified.

Diagnosis: Test elongate, trochospiral in the early stage with 4 to 5 chambers per whorl. In later stages the number of chambers can reduce to 3 per whorl. Chambers increasing in height as added. Wall finely agglutinated, with calcareous cement. In the initial stage the wall is solid, and chambers are nearly flat. In the final stage the wall becoming canaliculate

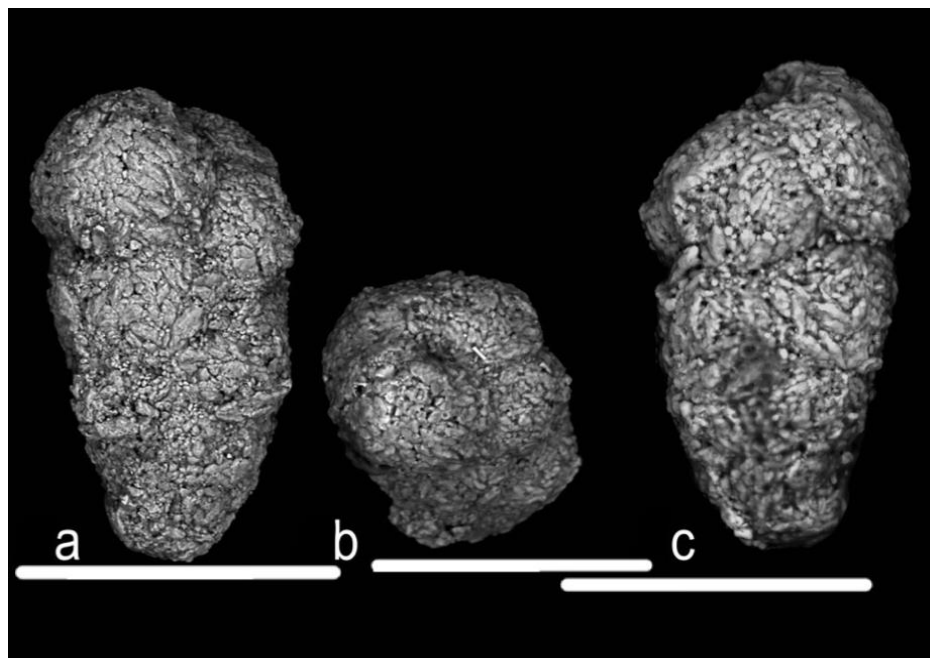
and chambers are slightly inflated. Sutures depressed and distinct. Aperture a high interiomarginal arch.

Type Level: Middle Jurassic (Bathonian).

Remarks: Redmond (1965) reported this species as rare from the middle of the Dhurma Formation (Bathonian). In this study, 135 specimens are reported from the lower part, D1 Unit, of the Dhurma Formation (Bajocian).

Occurrences: Riyadh water well (Bathonian) Saudi Arabia (Redmond, 1965), Middle Jurassic of western Qatar (Hewaidy & Al-Saad, 1992); Bathonian of Rajasthan, western India (Jain and Garg, 2014).

***Riyadhella sibirica* (Mjatliuk, 1939)**



Genus: *Riyadhella* Redmond, 1965

Original Designation *Verneuilina sibirica* Mjatliuk, 1939, p. 232, pl. 1, fig. 9a, b.

Synonyms: *Riyadhella sibirica* (Mjatliuk). – Yakovleva, 1973, p. 232, pl.6, figs. 8a, b,c; 9; 10.

Riyadhella sibirica (Mjatliuk). – Basov et al., 1989, textfig.2, fig.13.

Riyadhella sibirica (Mjatliuk). – Azbel & Grigalis, 1991, pl. 24, fig.5.

Verneulinoides sp.2 – Morris & Coleman, 1989, p. 234, pl. 6.3.12, figs. 10,11,12.

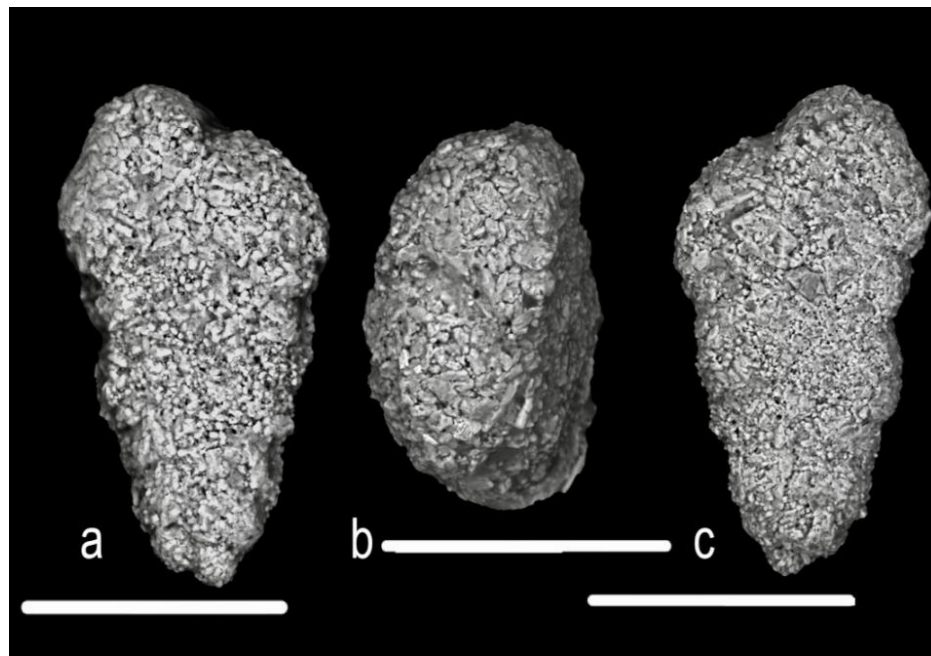
Diagnosis: Test high trochospiral, initially conical, later subparallel sides. The early stage has 4 – 5 chambers per whorl and reduced at the final stage to 3 chambers per whorl. Chambers rounded with depressed sutures. Wall is finely agglutinated with elongated agglutes. Aperture a low interiomarginal arch, umbilical in position.

Type Level: Middle Jurassic (Bajocian–Bathonian)

Remarks: According to (Yakovleva-O'Neill et al., 2008) this species is identical with *Verneuilioides* sp. 2. of Morris & Coleman (1989) but is assigned tentatively to the genus *Riyadhella* because its cement was originally organic rather than calcareous. In this study, 61 specimens reported from the D1 Unit of the Dhruma Formation (Bajocian).

Occurrences: Pechora basin, the Barents Sea, Siberia (Nagy et al., 1990), offshore mid-Norway (Kaminski et al., 1997, unpublished), Viking Graben, the North Sea (Morris & Dyer, 1990).

***Gaudryinopsis* sp. 1**



Genus: *Gaudryinopsis* Podobina, 1975

Original Designation *Gaudryinopsis* sp. 1

Synonyms: none verified.

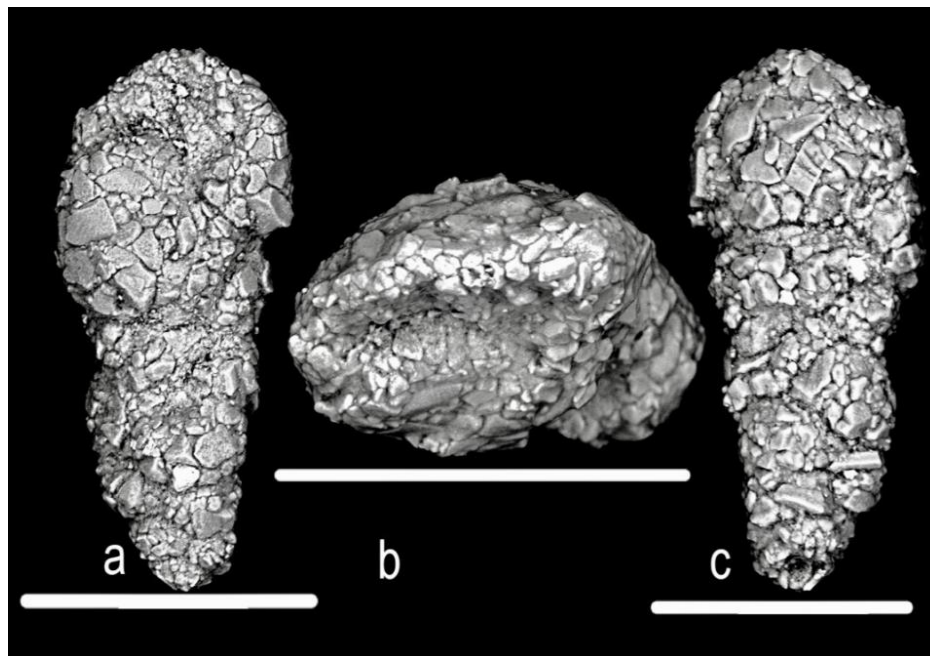
Diagnosis: Test elongate, flaring, with short early triserial stage followed by biserial stage with nearly parallel sides. Chambers subglobular, sutures slightly appressed. Wall finely agglutinated. Aperture a low arch at the base of the apertural face.

Type Level: Middle Jurassic (Bajocian).

Remarks: In this study, 21 specimens were found in shale beds of the D1 unit of the Dhruma Formation.

Occurrences: Riyadh district of Saudi Arabia.

***Gaudryinopsis* sp. 2**



Genus: *Gaudryinopsis* Podobina, 1975

Original Designation *Gaudryinopsis* sp. 2

Synonyms: none verified.

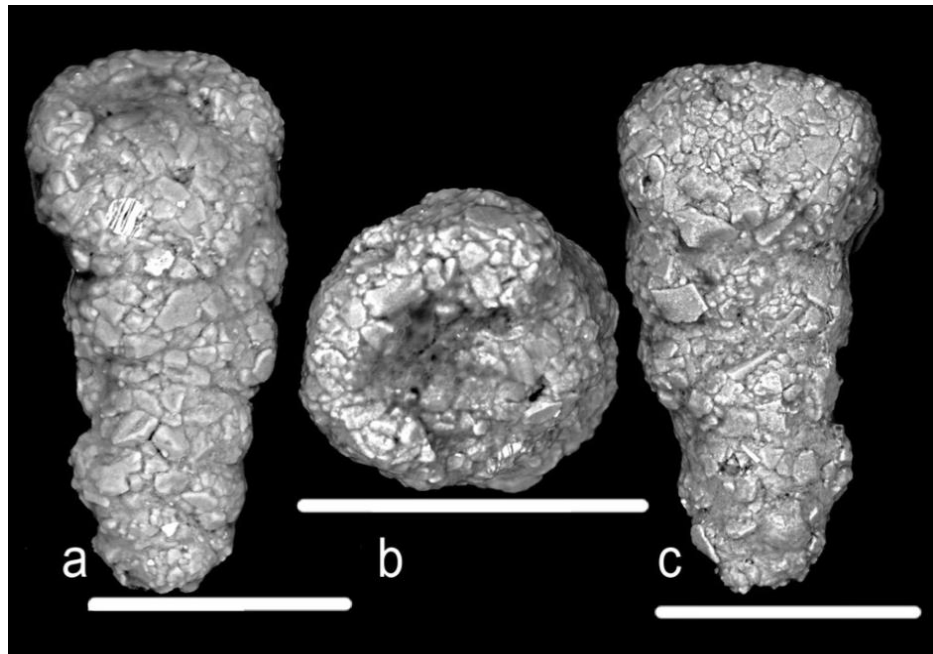
Diagnosis: Test elongate, with short early trochospiral stage and three chambers per whorl followed by loosely biserial stage and narrow end. Chambers subglobular, sutures slightly appressed. Wall coarsely agglutinated. Aperture a low arch at the base of the apertural face.

Type Level: Middle Jurassic (Bajocian)

Remarks: In this study, 47 specimens were found in shale beds of the D1 unit of the Dhruma Formation.

Occurrences: Riyadh district of Saudi Arabia.

***Gaudryinopsis* sp. 3**



Genus: *Gaudryinopsis* Podobina, 1975

Original Designation *Gaudryinopsis* sp. 3

Synonyms: none verified.

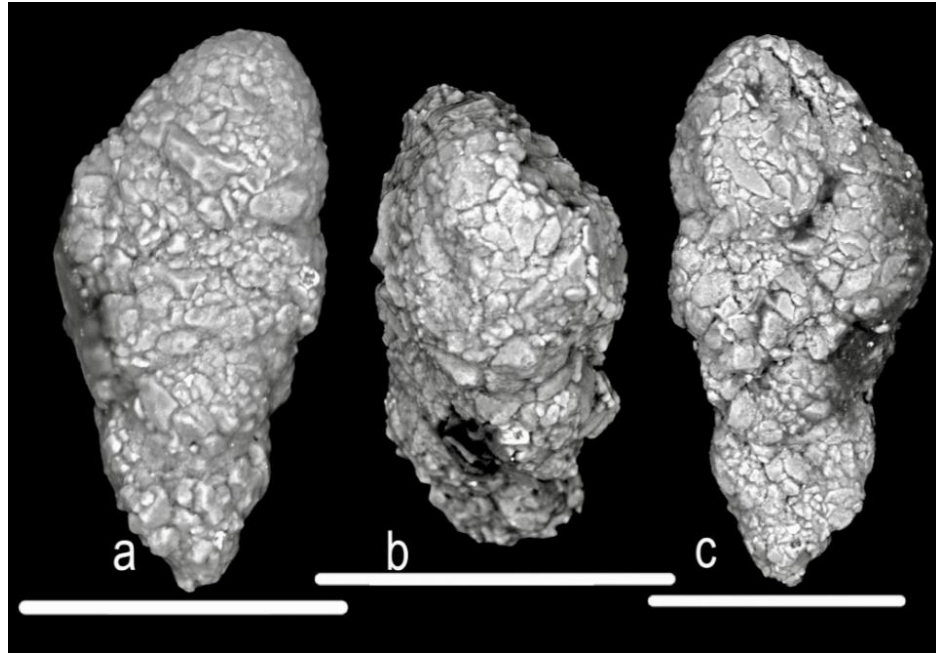
Diagnosis: Test elongate, with short early trochospiral stage and three chambers per whorl followed by a loosely biserial stage with parallel sides. Chambers subglobular, sutures slightly depressed. Wall coarsely agglutinated. Aperture a low arch at the base of the apertural face.

Type Level: Middle Jurassic (Bajocian).

Remarks: In this study, 61 specimens were recovered from shale beds of the D1 unit of the Dhurma Formation.

Occurrences: Riyadh district of Saudi Arabia.

***Gaudryinopsis* sp. 4**



Genus: *Gaudryinopsis* Podobina, 1975

Original Designation *Gaudryinopsis* sp. 4

Synonyms: none verified.

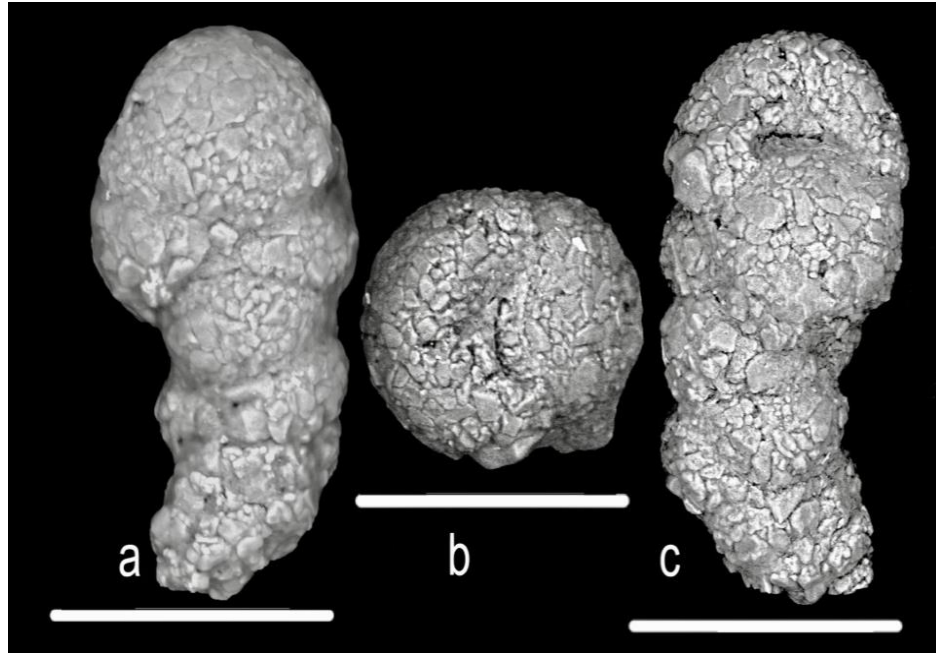
Diagnosis: Test elongate, widened, with short early triserial stage with small chambers, followed by a loosely biserial stage with larger chambers that increase in size as added, and parallel sides in the terminal stage. Chambers subglobular, sutures slightly depressed. Wall coarsely agglutinated. Aperture a low arch at the base of the apertural face.

Type Level: Middle Jurassic (Bajocian).

Remarks: A total of 61 specimens were found in shale beds of the D1 unit of the Dhruma Formation.

Occurrences: Riyadh district of Saudi Arabia.

***Gaudryinopsis* sp. 5**



Genus: *Gaudryinopsis* Podobina, 1975

Original Designation *Gaudryinopsis* sp. 5

Synonyms: none verified.

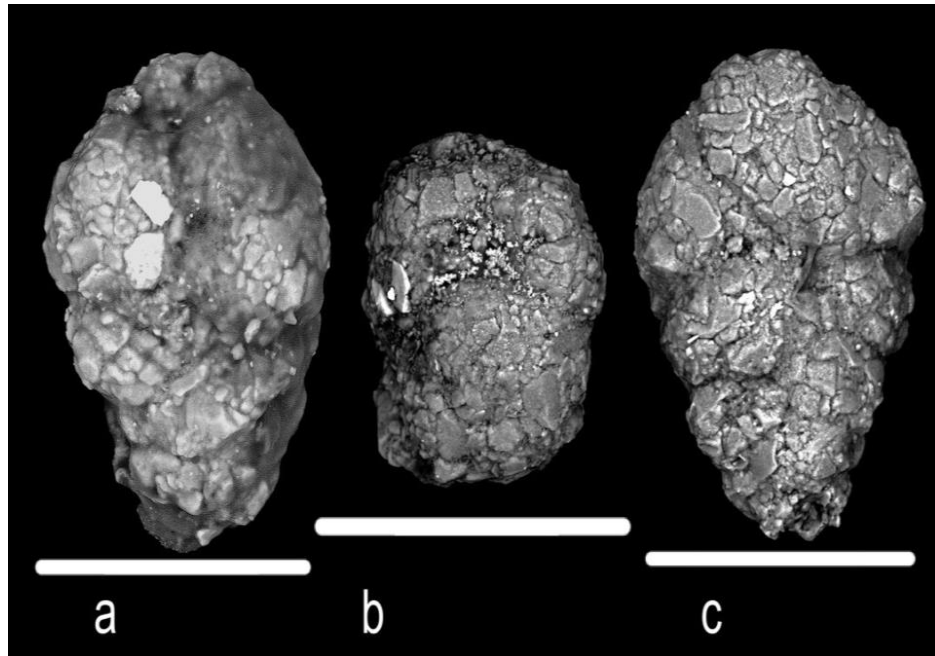
Diagnosis: Test elongate, slightly curved, expanding towards the apertural end. Start with small trochospiral chambers at the early stage followed by loosely biserial stage with subglobular and inflated chambers on the final stage. Sutures slightly depressed. Wall coarsely agglutinated. Aperture a low slit at the base of the apertural face.

Type Level: Middle Jurassic (Bajocian)

Remarks: In this study, 10 specimens were found in the marly beds of the D1 unit of the Dhruma Formation.

Occurrences: Riyadh district of Saudi Arabia.

***Verneuilinoides cf. asperulus* Crespin, 1963**



Genus: *Verneuilinoides* Loeblich & Tappan, 1949

Original Designation *Verneuilinoides asperulus* Crespin, 1963, p. 57, pl. 15, figs. 8-12.

Synonyms: none verified.

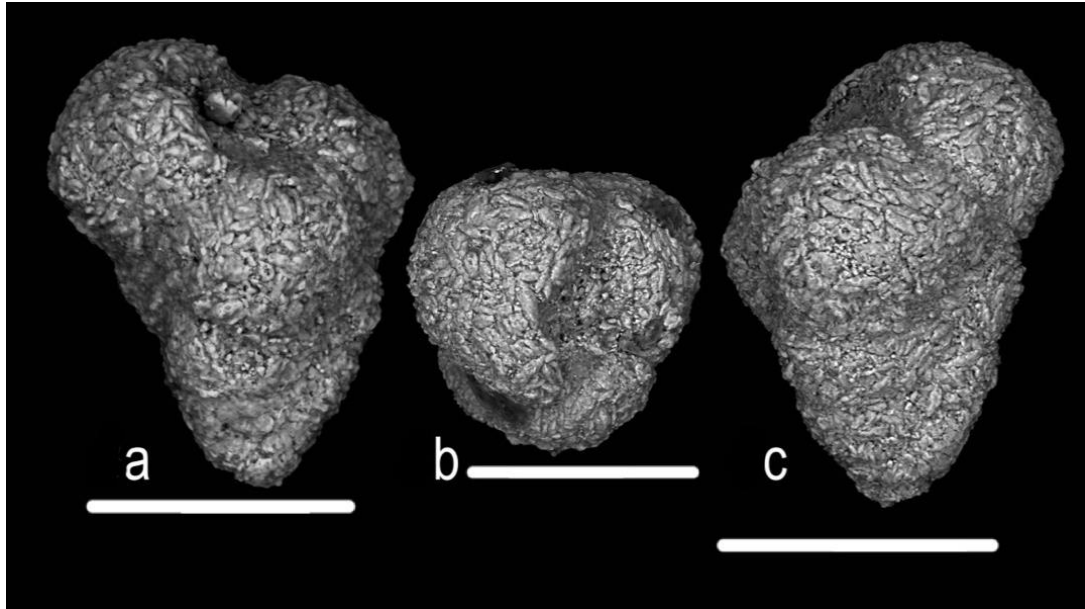
Diagnosis: Test small, tapering, triserial throughout with rounded sides, 4-5 whorls. Chambers slightly inflated and increase in size as added with greatest width at the apertural end. Sutures indistinct and slightly depressed. Wall coarsely agglutinated. Aperture a low opening at base of final chamber.

Type Level: Lower Cretaceous.

Remarks: This species resembles *Verneuilinoides asperulus* Crespin, 1963 but differs in its smaller size and smaller number of whorls. In this study, 40 specimens were found in the marly beds of the D1 unit of the Dhurma Formation (Bajocian).

Occurrences: Mount Whelan, Australia (Crespin, 1963).

Verneuulinoides conoidalis Azbel, 1977



Genus: *Verneuulinoides* Loeblich & Tappan, 1949

Original Designation *Verneuulinoides conoidalis* Azbel, 1977, p. 168, pl. 3, fig. 13a-c.

Synonyms: none verified.

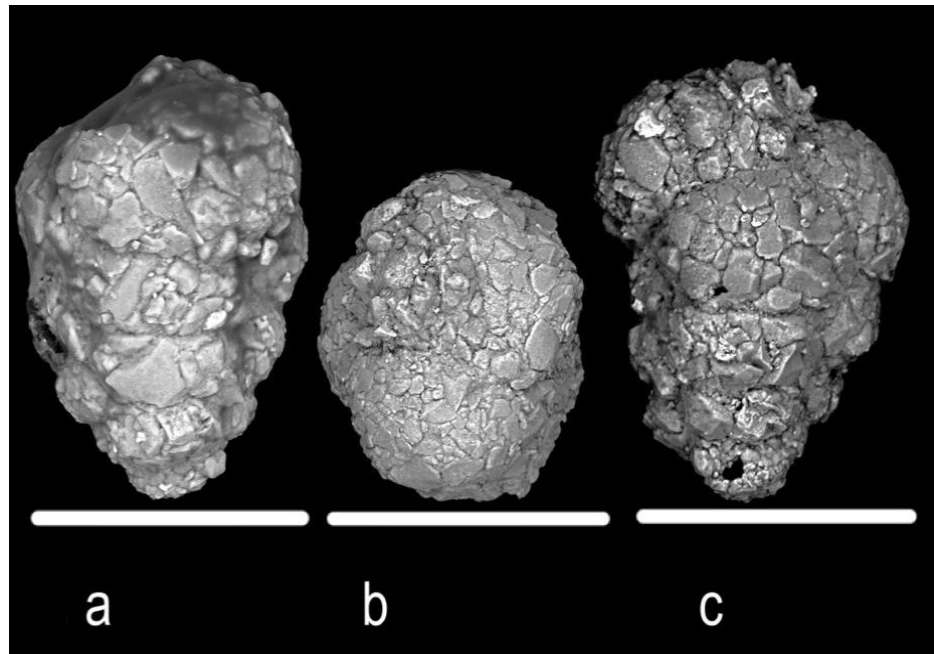
Diagnosis: Test small, slightly elongated and twisted, flaring toward apertural end, edge broadly rounded. Consists of 4 to 5 whorls. Chambers increase in size as added and the chambers of last whorl significantly larger and have globular shape. Sutures depressed. Wall finely agglutinated. Aperture an interiomarginal arch.

Type Level: Upper Jurassic (Upper Oxfordian).

Remarks: This species differs from *Verneulinoides graciosus* Kozyreva in Dain, 1972 in having a strongly widening test and less inflated chambers, rapidly increasing in size as added. In this study, 234 specimens were found in the marly beds of the D1 unit of the Dhruma Formation (Bajocian).

Occurrences: Mangyshlak Peninsula, Kazakhstan (Azbel, 1977).

Verneuulinoides kirillae Dain, 1971



Genus: *Verneuulinoides* Loeblich & Tappan, 1949

Original Designation *Verneuulinoides kirillae* Dain, 1971, p. 113, pl. 20, fig. 1a-d.

Synonyms: none verified.

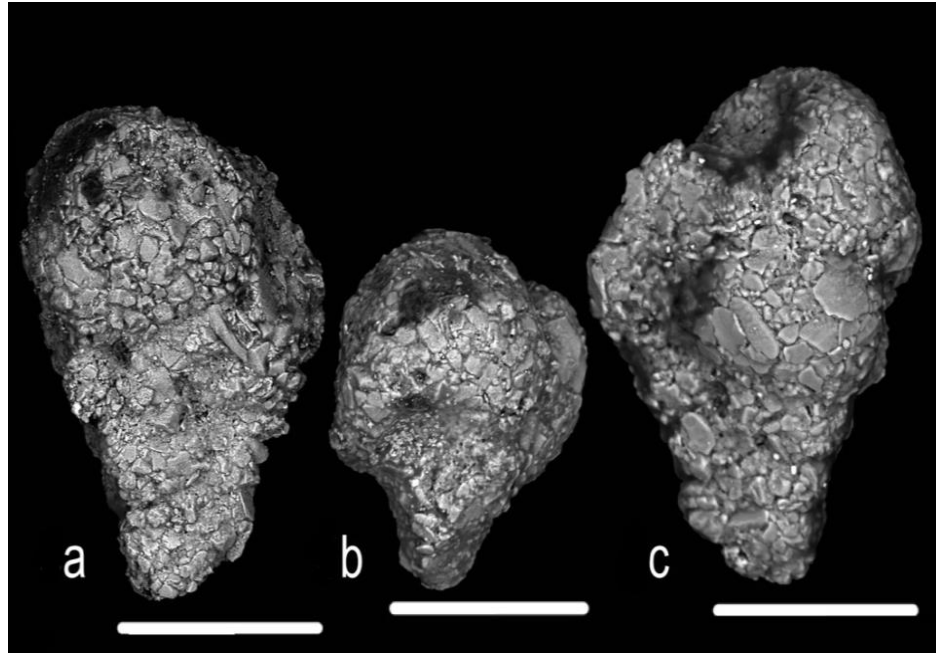
Diagnosis: Test small, triserial throughout, comprised of 4-6 whorls. Chambers increase in size as added and chambers of the last whorl are significantly inflated. Sutures weakly depressed. Wall coarsely agglutinated. Aperture interiomarginal, a short arcuate slit at the base of the last chamber.

Type Level: Upper Jurassic.

Remarks: A total of 390 specimens were found in the marly beds of the D1 unit of the Dhruma Formation (Bajocian).

Occurrences: Volga region, Russia (Dain, 1971), Southern Poland and southwestern Ukraine (Król & Krajewski, 2012).

***Verneuulinoides aff. minutus* Said and Barakat, 1958**



Genus: *Verneuulinoides* Loeblich & Tappan, 1949

Original Designation *Verneuulinoides minuta* Said and Barakat, 1958, p. 242, pl. 4, fig. 25a, b.

Synonyms: none verified.

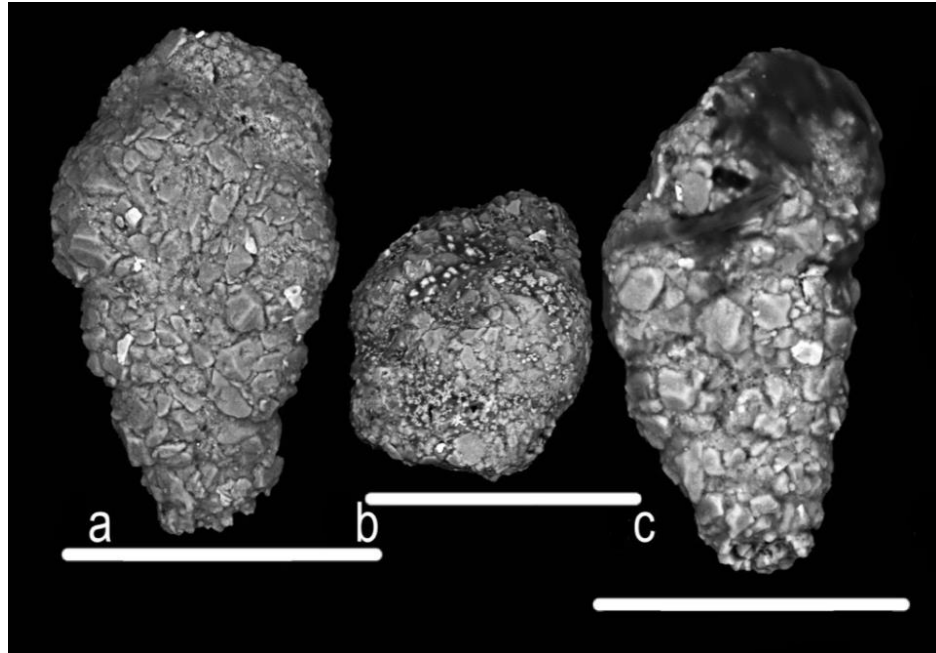
Diagnosis: Test small, triserial, consisting of 4 whorls. Chambers increase rapidly in size as added and the chambers of last whorl significantly larger, have globular shape, and comprise about half the length of the test. Sutures slightly depressed. Wall coarsely agglutinated. Aperture a small arch at the base of the last formed chamber.

Type Level: Upper Jurassic (Kimmeridgian)

Remarks: In accordance with Declaration 40 of the International Commission on Zoological Nomenclature, generic names having the termination “oides” are to be treated as masculine in gender. This species was also given the name *Verneuilioides minuta* (Ellis & Messina Catalog). In this study, 19 specimens were found in the upper part of the D1 unit of the Dhurma Formation (Bajocian).

Occurrences: Kimmeridgian of Egypt, in Wadi Imshash Rashed, northern Sinai (Said & Barakat, 1958), Eastern Sana’a basin in Yemen, Middle Jurassic (Al-Wosabi et al., 2017).

***Verneuulinoides* sp. 2 of Jenkins & Murray, 1989**



Genus: Verneuulinoides Loeblich & Tappan, 1949

Original Designation *Verneuulinoides* sp. 2 (Jenkins & Murray, 1989), pl. 6.3.12, fig. 10-12.

Note: This form is synonymized under *Riyadhella siberica*. It is a new species. It will be called “*Verneuulinoides* sp. 1” here.

Synonyms: none verified.

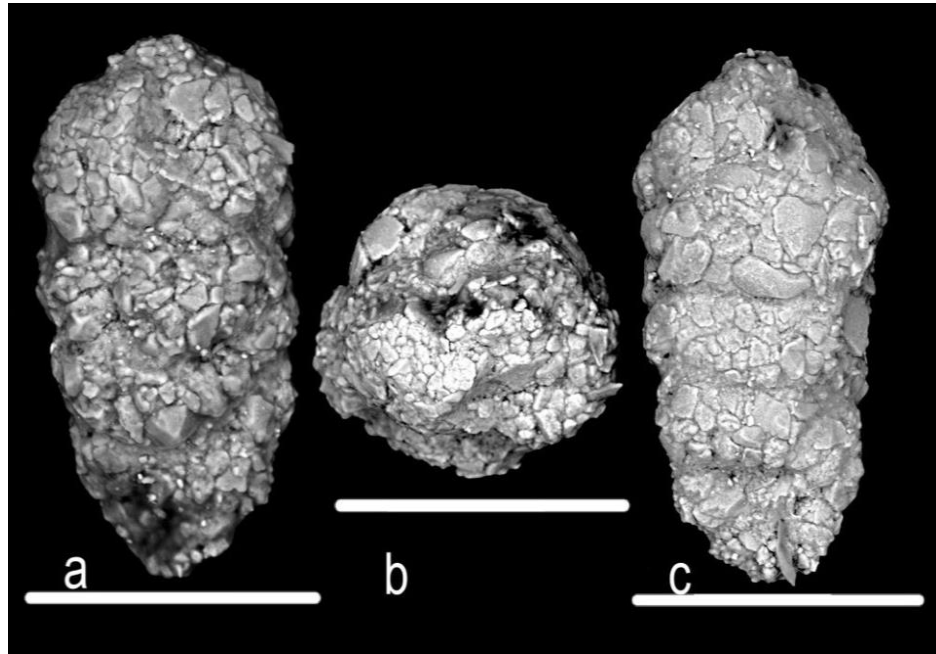
Diagnosis: Test medium size, triserial and flaring throughout. Chambers subglobular. Sutures depressed. Wall coarsely agglutinated. Aperture not visible.

Type Level: Middle Jurassic (Middle Bathonian–Early Callovian)

Remarks: In this study, 39 specimens were found in D1 unit of the Dhurma Formation (Bajocian).

Occurrences: Riyadh district of Saudi Arabia.

***Pseudoreophax* aff. *cisovnicensis* Geroch, 1961**



Genus: *Pseudoreophax* Geroch, 1961

Original Designation: aff: *Pseudoreophax cisovnicensis* Geroch, 1961, p. 160, pl.17, fig. 1-20.

Synonyms: none verified.

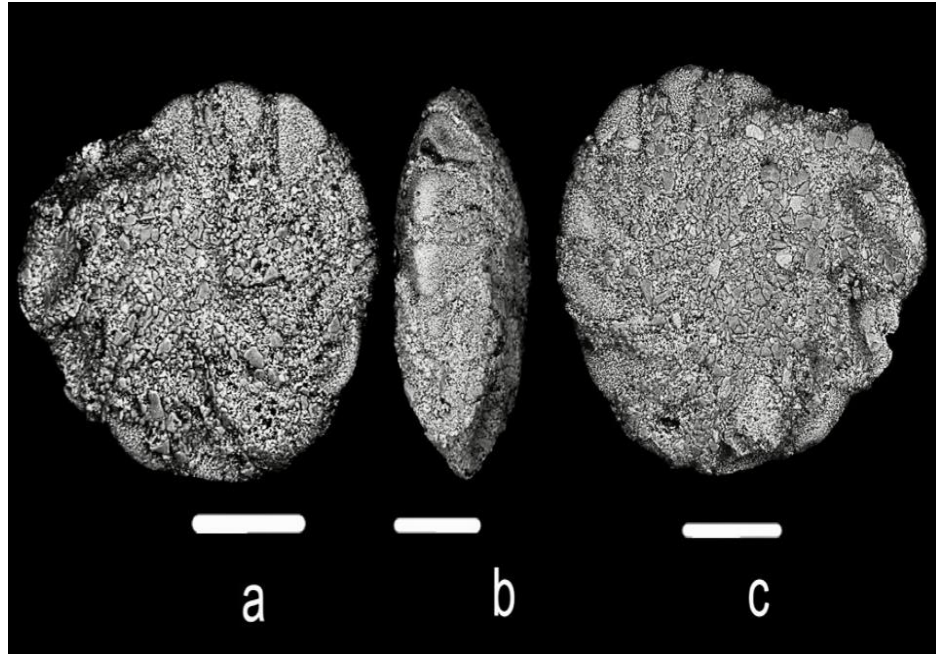
Diagnosis: Test elongated, narrow, starts with single trochospiral whorl followed by an irregular uniserial portion consisting of 3-4 chambers. Sutures depressed. Wall coarsely agglutinated. Aperture terminal or subterminal to terminal, rounded on a short neck.

Type Level: Lower Cretaceous Upper Cieszyn Sales (Valanginian–Hauterivian) of the Polish Carpathians.

Remarks: This species differs from *Pseudoreophax cisovnicensis* in having a coarsely agglutinated test wall, and in its older stratigraphic occurrence Very rare, only 3 specimens were found in D1 unit of the Dhruma Formation (Bajocian).

Occurrences: Valanginian to Barremian of the Outer Carpathians in Poland (Geroch and Nowak, 1984). Tithonian to Valanginian at Site 765 on the Argo Abyssal Plain (Kaminski et al. 1992).

***Nautiloculina oolithica* Mohler, 1938**



Genus: *Nautiloculina* Mohler, 1930

Original Designation: *Nautiloculina oolithica* Mohler, 1938, p. 19.

Synonyms: none verified

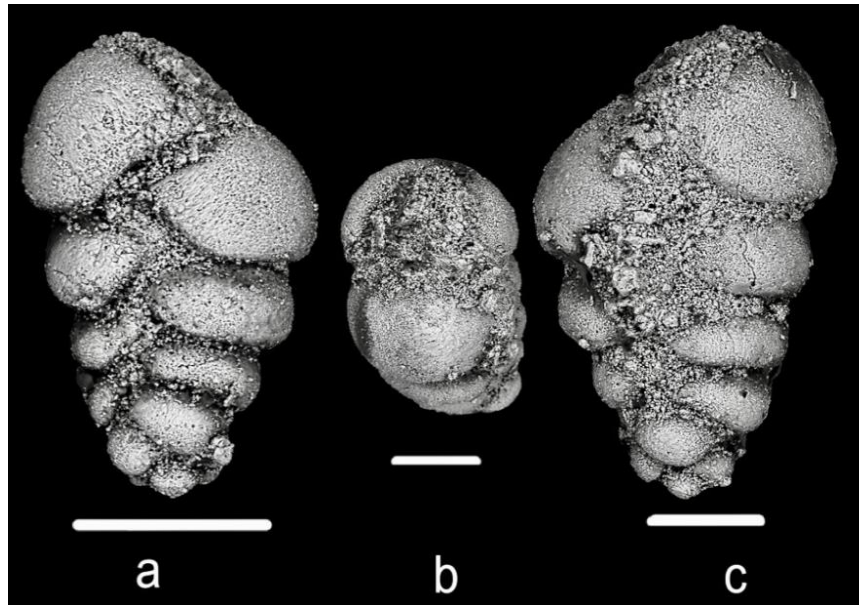
Diagnosis: Test free, lenticular in form, planspirally enrolled and involute, globular proloculus followed by numerous small chambers per whorl that increase in size gradually. Sutures radial to very slightly arched. Wall microgranular calcareous, agglutinated. Aperture equatorial, a low interiomarginal arch.

Type Level: Middle Jurassic.

Remarks: *Nautiloculina* is widely distributed in the Jurassic of Saudi Arabia, but it characterizes the more open marine (deeper shelf) and deeper lagoonal environments (Hughes, 2006, 2008). It is also common in transgressive sequences, such as in the J30 maximum flooding horizon in the D5 unit (Kaminski et al., 2020). This species is more common in the D2 unit layers than in the D1.

Occurrences: Upper Liassic to Bathonian of Switzerland and France (Mohler, 1938; Brönnimann, 1968), upper Liassic? to Dogger of the Taurus mountains in Turkey (Brönnimann, 1968); Kimmeridgian of Cuba (Brönnimann, 1968) and Mexico (Omaña and González Arreola, 2008); Toarcian to Lower Cretaceous of southern Spain (Fourcade and Neumann, 1966; Reolid et al., 2015; Campos-Soto et al. 2016); Bajocian to Kimmeridgian of Saudi Arabia (Hughes, 2018) and Kuwait (Crespo de Cabrera et al., 2020); Lower Cretaceous (Berriasian–Valanginian) of Iran (Hosseini et al. 2016; Oxfordian to Berriasian of the Ukraine (Krajewski and Olszewska, 2007); and the Tithonian to Berriasian of Japan (Kobayashi and Vuks, 2006). The species has also been reported from Romania, Croatia, Russia, Syria, and Egypt.

***Siphovalvulina colomi* BouDagher-Fadel, Rose, Bosence & Lord, 2001**



Genus: *Siphovalvulina* Septfontaine, 1988

Original Designation: *Siphovalvulina colomi* BouDagher-Fadel, Rose, Bosence & Lord, 2001, p. 504, pl.1, figs. 1-4.

Synonyms: *Eggerellina* sp. Colom, 1980, fig. 4.28-33.

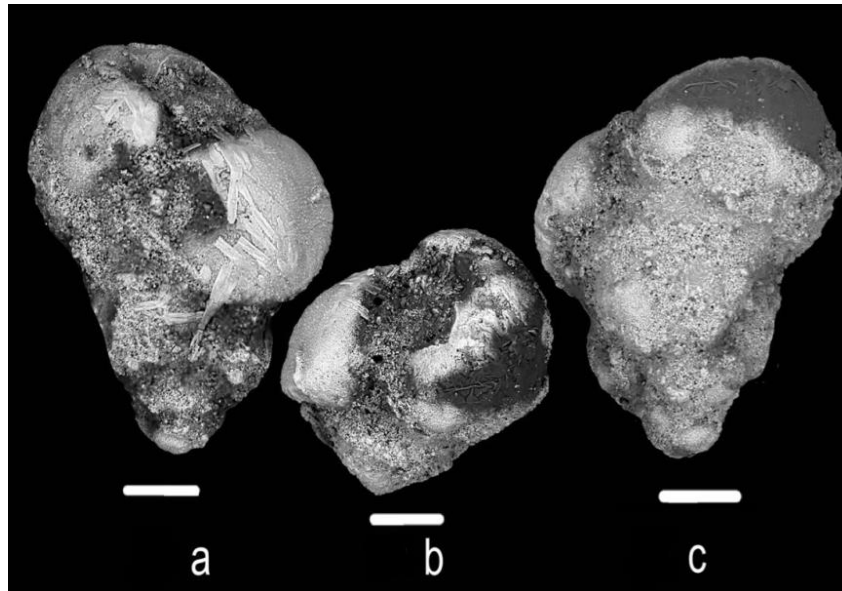
Diagnosis: Test elongate, initially trochospiral, later triserial, reducing to biserial, with of up to five whorls of chambers. Chambers oviform in shape. rapidly enlarging and increasing in height as added. Sutures depressed. Aperture basal, with a twisted siphonal canal connecting successive apertures (Septfontaine, 1988).

Type Level: Lower Jurassic (Sinemurian).

Remarks: This species is more elongated and lesser flaring in shape compared with *Siphovalvulina gibraltarensis*. In this study 103 specimens were found from the D1 and D2 units of the Dhurma Formation.

Occurrences: Lower Jurassic (Lower Lias) of Cabrera, Balearic Islands of Spain (Colom 1980); Sinemurian of the Gibraltar Limestone Formation of Gibraltar (BouDagher-Fadel, 2001). In Saudi Arabia, Hughes (2018) reported it from the Toarcian Marrat Formation. It has been reported it as *Siphovalvulina* sp. from the Bathonian Dhurma Formation D4 and D5 units by Malik et al. (2020).

***Siphovalvulina gibraltarensis* BouDagher-Fadel, Rose, Bosence and Lord, 2001**



Genus: *Siphovalvulina* Septfontaine, 1988

Original Designation: *Siphovalvulina gibraltarensis* BouDagher-Fadel Rose Bosence & Lord 2001, p. 65, pl.1, fig. 6-11.

Synonyms: *Eggerellina* sp. Colom, 1980, fig. 4.64,66,75,76.

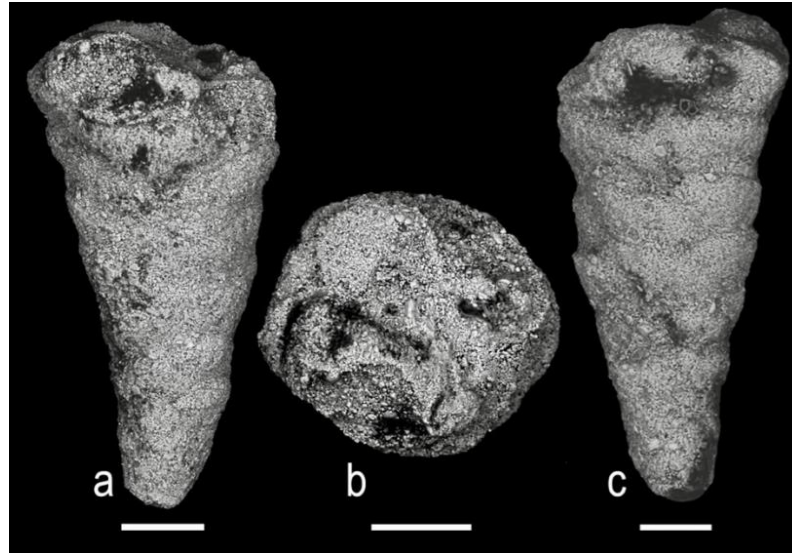
Diagnosis: Test widely flaring and lobulate in outline, trochospirally coiled with up to four rapidly enlarging whorls of chambers. Three chambers in each whorl. Sutures depressed. Wall agglutinated, imperforate, and microgranular. Aperture basal, with a twisted siphonal canal connecting successive apertures (Septfontaine, 1988)

Type Level: Lower Jurassic (Sinemurian).

Remarks: The test wall was reported by Septfontaine (1988) as agglutinated, calcareous microgranular. The test wall is poorly preserved in our material, and the specimens mainly consist of infillings. A total of 56 specimens were found in this study from the D1 and D2 units of the Dhruma Formation. It has been reported from the D4 and D5 units as well (Bathonian) by (Malik et al. 2020).

Occurrences: Lower Jurassic (Lower Lias) of Cabrera, Balearic Islands of Spain (Colom 1980); Sinemurian of the Gibraltar Limestone Formation of Gibraltar (BouDagher-Fadel, 2001).

***Redmondoides medius* Redmond, 1965**



Genus: *Redmondoides* Banner, Simmons & Whittaker, 1991

Original Designation: *Pseudomarssonella media* Redmond, 1965, p. 135, pl. 1, fig. 11-13.

Synonyms: *Pseudomarssonella biangulata* Redmond, 1965, p. 134, pl. 1, fig. 1.

Pseudomarssonella bipartita Redmond, Delance & Ruget, 1989, pl. 3, fig. 16.

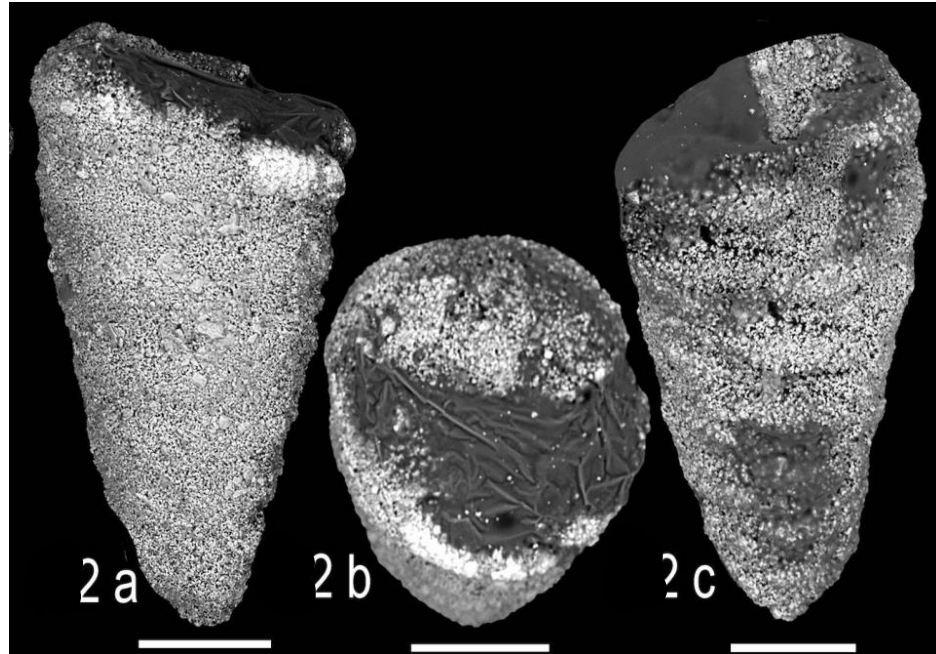
Diagnosis: Test high trochospiral cone with diverging sides. Initially quadserial or quinqueseiral and quinqueseiral in the adult stage. Chambers increase slowly in size as added. Chamber surfaces flat in earlier stages, inflated in later stages. Sutures depressed. Wall composed of microgranular calcite with little or no adventitious agglutinated material. Aperture interiomarginal, umbilical, with an apertural flap or lip.

Type Level: Middle Jurassic (Bathonian).

Remarks: *Redmondoides medius* is less slender and less slowly tapering than *Redmondoides primitivus* and slenderer and more slowly tapering than *Redmondoides inflatus*. Otherwise, these three species are very similar (Banner et al., 1991). In this study 157 specimens were found from the D1 and D2 units of the Dhruma Formation.

Occurrences: Reported as common in the upper part of the Dhruma Formation of Saudi Arabia (Redmond, 1965). Kuznetsova (1996) reported it from the Bathonian in the Coastal Mountains of Syria.

***Redmondoides primitivus* Redmond, 1965**



Genus: *Redmondoides* Banner, Simmons & Whittaker, 1991

Original Designation: *Pseudomarssonella primitiva* Redmond, 1965, p. 134, pl. 1, figs.16-18.

Synonyms: none verified.

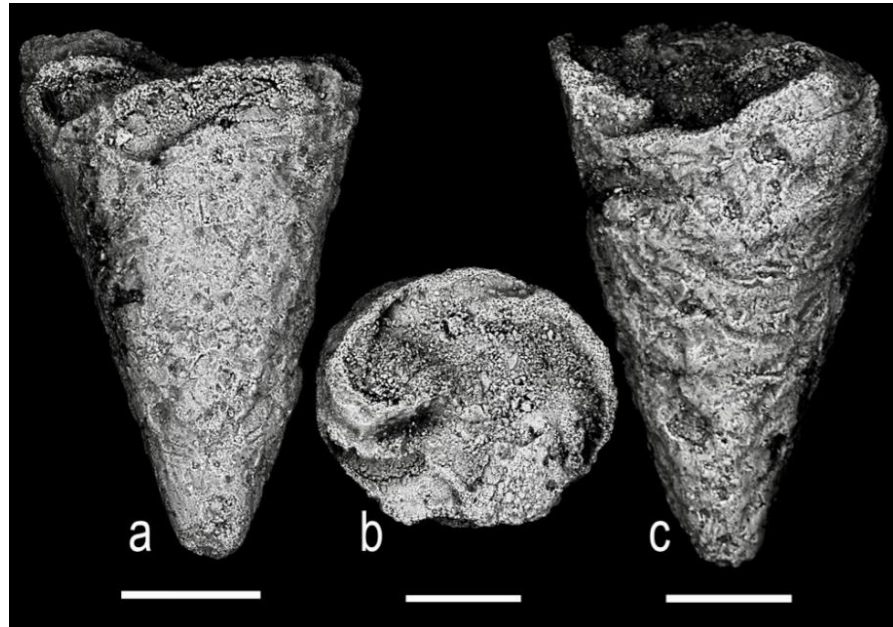
Diagnosis: Test high trochospiral cone with sides diverging at a uniform rate. Chambers increase slowly in size as added. Four chambers in final whorl. Sutures slightly depressed. Wall composed of microgranular calcite with little or no adventitious agglutinated material. Aperture interiomarginal, umbilical, with an apertural flap or lip.

Type Level: Middle Jurassic (Bathonian).

Remarks: (Banner et al., 1991) demonstrate the difference between *Redmondoides medius* and *Redmondoides primitivus* as follows: *Redmondoides medius* is less slender and less slowly tapering than *Redmondoides primitivus* and slenderer and more slowly tapering than *Redmondoides inflatus*. Otherwise, these three species are very similar. 145 specimens found on this study from the D1 and the D2 units of the Dhruma Formation (Bajocian).

Occurrences: Originally reported as common in the upper part of the Lower Dhruma Formation and from the lower part of the middle Dhruma Formation in Saudi Arabia (Redmond, 1965). Malik et al. (2020) reported it from the D5-D6 units of the Dhruma Formation. Kuznetsova (1996) reported it from the Bathonian in the Coastal Mountains of Syria.

***Pseudomarssonella maxima* Redmond, 1965**



Genus: *Pseudomarssonella* Redmond, 1965

Original Designation: *Pseudomarssonella maxima* Redmond, 1965, p. 133, pl.1, figs. 6-7.

Synonyms: none verified.

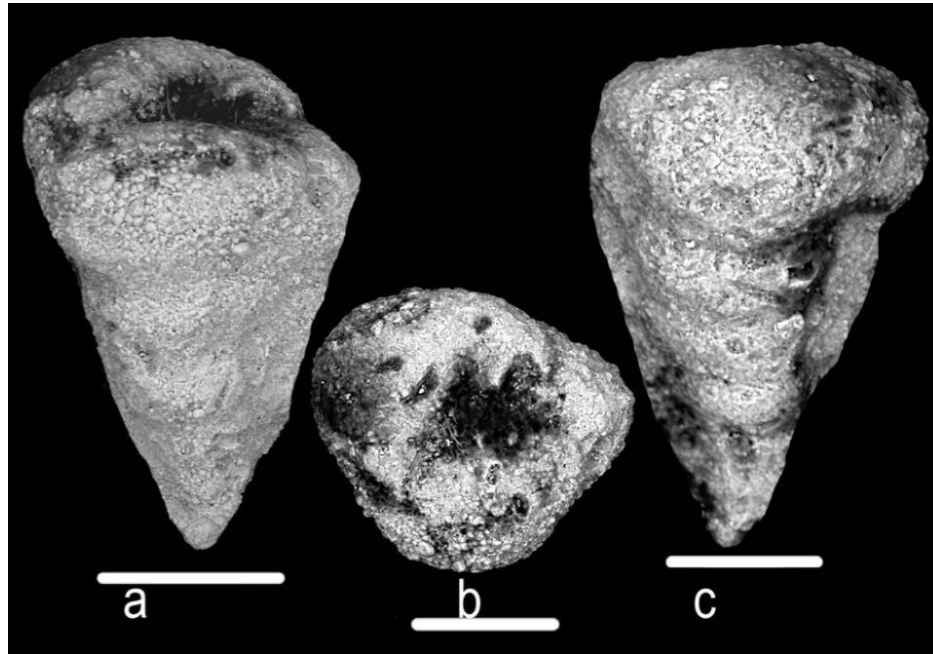
Diagnosis: Test elongate conical, broad with sides diverging at a uniform rate. Coiling trochospiral. early stage with four to five chambers per whorl and later may have three to five chambers per whorl. Sutures narrow and depressed. Wall calcareous microgranular with little or no agglutinated material. Aperture interiomarginal, cribrate, covered by an apertural flap that fuses to the apertural flap of an opposing chamber.

Type Level: Middle Jurassic (Bathonian).

Remarks: This is the type species of the genus *Pseudomarssonella*. In this study, 153 specimens were found from the D1 and D2 units of the Dhurma Formation.

Occurrences: Basal member of the upper Dhurma Formation in Saudi Arabia (Redmond, 1965). Hughes (2018) reported it from the D2 unit of the Dhurma Formation Also reported from the Bathonian of Syria (Kuznetsova, 1996) and southern Turkey (Tasli & Altiner, 2010).

***Pseudomarssonella reflexa* Redmond, 1965**



Genus: *Pseudomarssonella* Redmond, 1965

Original Designation: *Pseudomarssonella reflexa* Redmond, 1965, p. 136, pl. 1, fig. 19a, b.

Synonyms: none verified.

Diagnosis: Test elongate conical, broad with sides diverging at uniform rate. Initial part a narrow cone made up of small flat chambers increase slowly in size as added. Chambers of final whorl slightly inflated. Aperture interiomarginal.

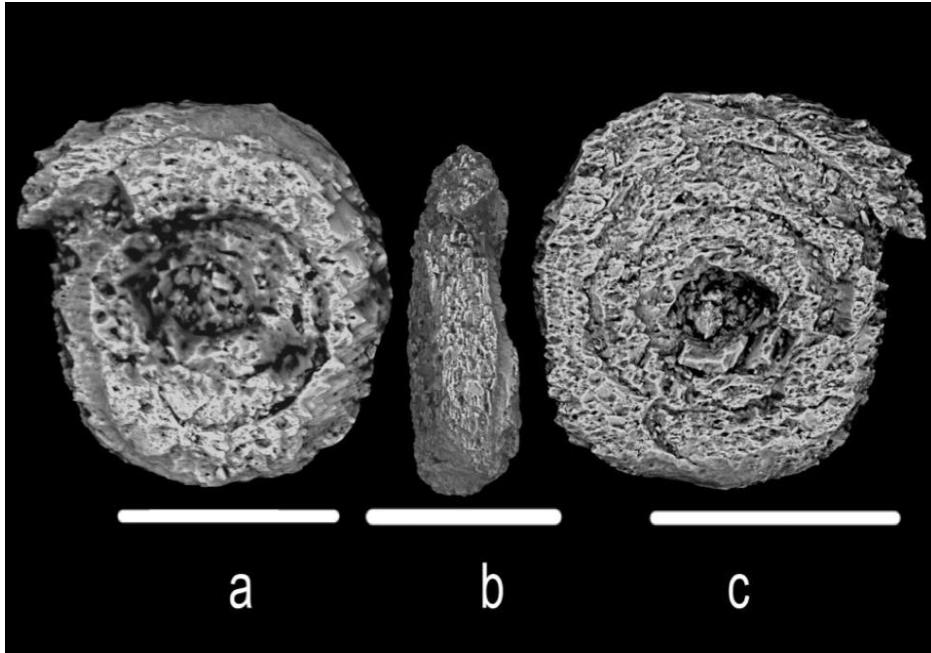
Type Level: Middle Jurassic (Bathonian).

Remarks: In this study 83 specimens were found from the D1 and the D2 units of the Dhruma Formation (Bajocian).

Occurrences: Redmond (1965) reported the species as common in the middle part of the middle Dhruma Formation in Saudi Arabia.

Calcareous Species

***Spirillina involuta* Antonova, 1958**



Genus: *Spirillina* Ehrenberg, 1843

Original Designation: *Spirillina involuta* Antonova, 1958, p. 65, pl. 4, fig. 1a, b.

Synonyms: none verified.

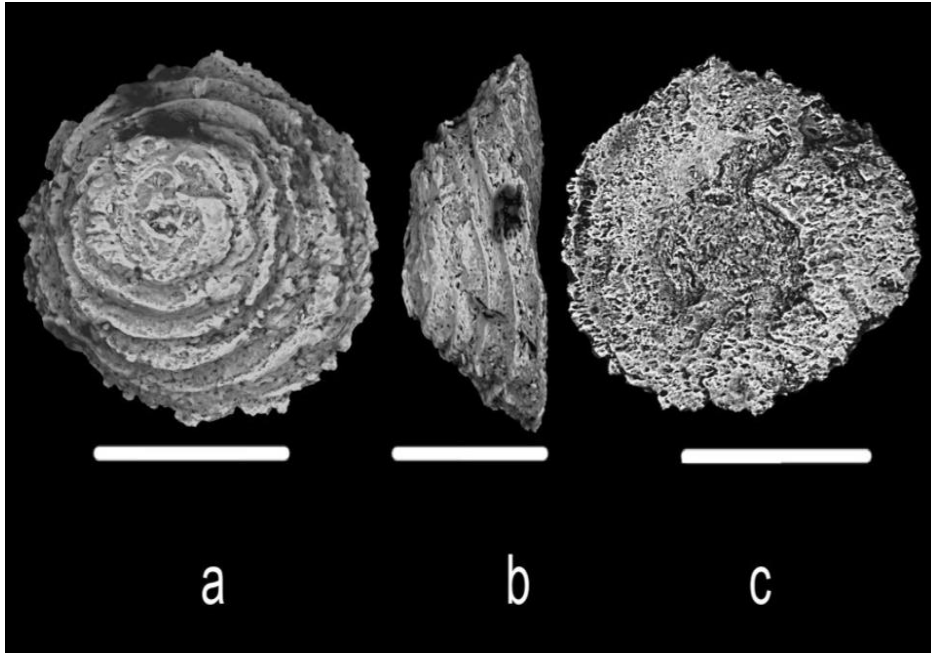
Diagnosis: Test free, planispiral, rounded. Consists of a spherical proloculus and a second tubular chamber forming 5-6 whorls. Wall calcareous, semitransparent and perforate. Sutures spiral and slightly depressed. Aperture is the open end of the tube.

Type Level: Middle Jurassic (Bajocian).

Remarks: This species differs to *Spirillina kuebleri* Mjatliuk in having involute coiling and rapid increase in diameter of the tubular chamber (Antonova, 1958). In this study 112 specimens recovered from the D1 & D2 units of the Dhruma Formation.

Occurrences: Bajocian of Pseba region (Northern Caucasus).

***Spirillina trochoides* Berthelin, 1879**



Genus: Conicospirillina Cushman, 1927

Original Designation: *Spirillina trochoides* Berthelin, 1879, p. 37, pl. 1, figs. 20-22.

Synonyms: none verified.

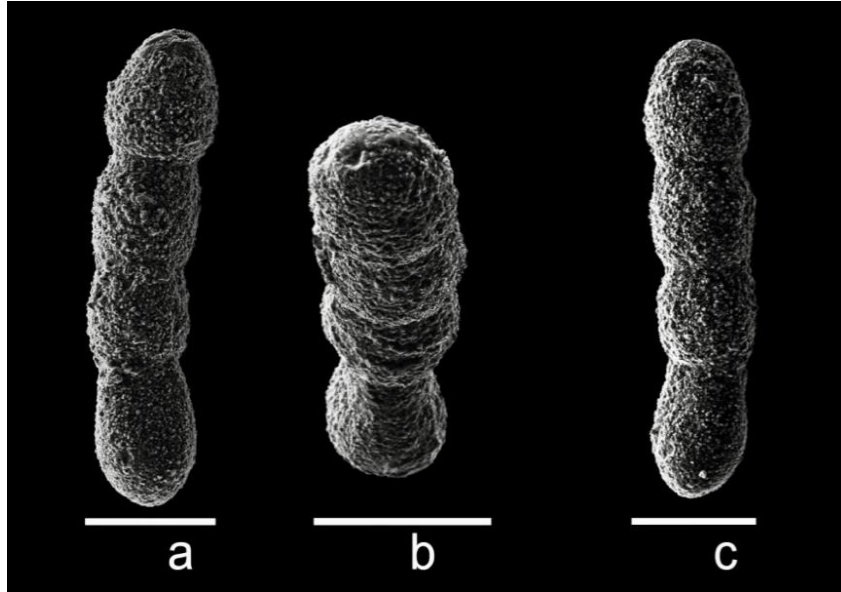
Diagnosis: Test conical, proloculus followed by undivided tubular and trochospirally enrolled second chamber, spiral side evolute and strongly convex, involute umbilical side flat to concave and may leave open a small umbilicus; aperture at the open end of the spiraling tube (Loeblich and Tappan, 1987).

Type Level: Lower Jurassic (Pliensbachian).

Remarks: In this study 55 specimens were recovered from the D1 & the D2 unit of the Dhruma formation.

Occurrences: Pliensbachian of France (Berthelin, 1879).

***Paralingulina cernua* Berthelin, 1879**



Genus: *Paralingulina* Gerke, 1969

Original Designation: *Frondicularia cernua* Berthelin, 1879, p. 32, pl. 1, figs. 7,8.

Synonyms: *Lingulina cernua* (Berthelin). – Franke, 1936, p. 61, pl. 6, fig. 5a-d.

Paralingulina cernua (Berthelin). – Copestake and Johnson, 2014, p. 182, pl. 9, figs. 9,18,26.

Diagnosis: Test free, smooth elongate, uniserial, slightly curved with rounded ends, length about four times as width, width almost uniform from end to end. Four slightly inflated

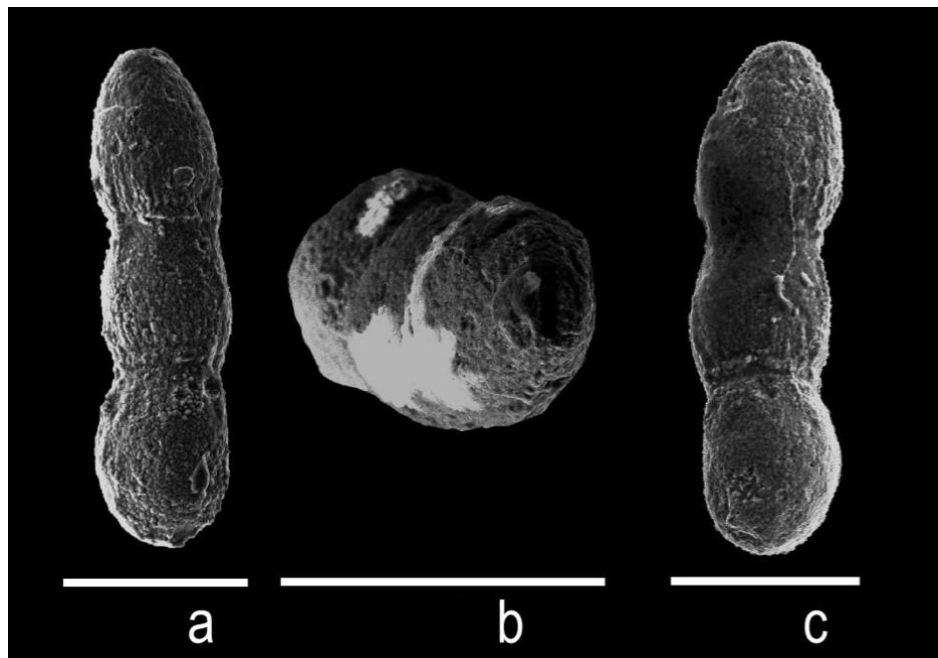
chambers. Wall calcareous, sutures depressed and straight. Aperture terminal rounded or oval.

Type Level: Lower Jurassic (Sinemurian).

Remarks: Copestake & Johnson (2014) described *Paralingulina cernua* and a subspecies *Paralingulina cernua* spp. A with a variety of sizes, shapes of the chambers and outline. In this study 113 specimens recovered from the D1 unit of the Dhruma formation.

Occurrences: Rhaetian to Bajocian of Britain, France, Germany, Morocco (Copestake & Johnson, 2014).

***Prodentalina digitalis* Berthelin, 1879**



Genus: *Prodentalina* Norling, 1968

Original Designation: *Dentalina digitalis* Franke, 1913, p. 269, pl. 5, fig. 1.

Synonyms: *Prodentalina digitalis* (Franke). – Copestake & Johnson, 2014, p. 258, pl. 14, fig. 29.

Diagnosis: Test free, smooth, uniserial, rectilinear, spherical proloculus. Three to four slightly inflated Chambers. Wall calcareous, sutures horizontal, straight, and slightly depressed. Aperture slightly eccentric and rounded.

Type Level: Lower Sinemurian.

Remarks: Very rare, only 3 specimens recovered from the D1 unit of the Dhruma formation in this study.

Occurrences: Lower to Upper Cretaceous of Britain and Germany (Copestake & Johnson, 2014).

***Dentalina bicornis* Terquem, 1870**



Genus: *Dentalina* Risso, 1826

Original Designation: non: *Dentalina bicornis* Terquem, 1870, p. 370, pl. 29, fig. 13,17.

Synonyms: *Dentalina bicornis* Terquem, 1870 of Görög 1995, p.42, pl.3, fig. 10.

Diagnosis: Test free, elongated, straight or sickle shaped, surface smooth. Test consists of 4 to 6 chambers, nearly uniform in width. Final chamber elongated and sharpened. Sutures flush except the suture of the last chamber. Aperture terminal and radiate.

Type Level: Middle Jurassic (Bathonian)

Remarks: This species differs from the type specimens of Terquem (1870) in having indistinct and straight sutures while on the type specimens of Terquem sutures are highly oblique and chambers have a rhombohedral shape, and the general outline of the test is more curved. In this study, 36 specimens were recovered from the D1 unit of the Dhruma Formation.

Occurrences: S. France: Middle Jurassic, NW Germany: Middle to lower part of the Upper Jurassic; Portugal: Middle Bathonian; Ukraine: Lower Aalenian; Hungary: Mecsek Mts: Hidas Valley: Upper Bathonian (Görög 1995).

***Dentalina botuliformis* Terquem, 1870**



Genus: *Dentalina* Risso, 1826

Original Designation: *Dentalina botuliformis* Terquem, 1870, p. 370, pl. 29, fig. 12.

Synonyms: none verified.

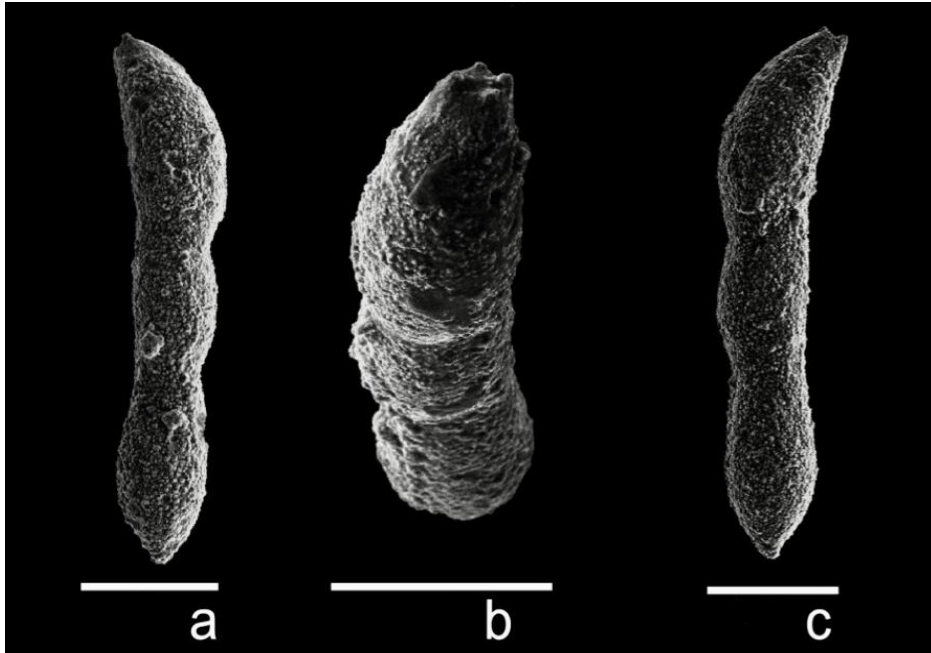
Diagnosis: Test free, elongate, uniserial, slightly curved with rounded ends, Chambers slightly inflated and increase in size as added. Wall calcareous, sutures depressed and straight. Aperture terminal rounded or oval.

Type Level: Parkinsoni Ammonite zone (Upper Bajocian, Jurassic)

Remarks: In this study, 113 specimens were recovered from the D1 unit of the Dhruma Formation.

Occurrences: Moselle region, France (Terquem, 1870).

***Dentalina digitata* Paalzow, 1932**



Genus: *Dentalina* Risso, 1826

Original Designation: *Dentalina digitata* Paalzow, 1932, p.115, pl. 8, figs. 2-3.

Synonyms: none verified.

Diagnosis: Test free, uniserial, slightly curved, tapered at both ends. Three to four slightly inflated Chambers. Wall calcareous, sutures horizontal, straight, and slightly depressed on the dorsal side. Aperture terminal, small and situated on the ventral side.

Type Level: Jurassic (Oxfordian).

Remarks: In this study 64 specimens recovered from the D1 unit of the Dhruma formation.

Occurrences: Transversarius beds (The white Jurassic) of Germany (Paalzow, 1932).

***Dentalina guembeli* Schwager, 1865 of Gordon 1966**



Genus: *Dentalina* Risso, 1826

Original Designation: non: *Dentalina guembeli* Schwager, 1865, p. 101, pl. 2, fig. 20.

Synonyms: pars: *Dentalina guembeli* Schwager, 1865 of Gordon 1966, p. 333, pl. 2, fig 3a, 4a.

Prodentalina guembeli (Schwager). – Wasim et al. 2020, p. 330, fig. 6.5.

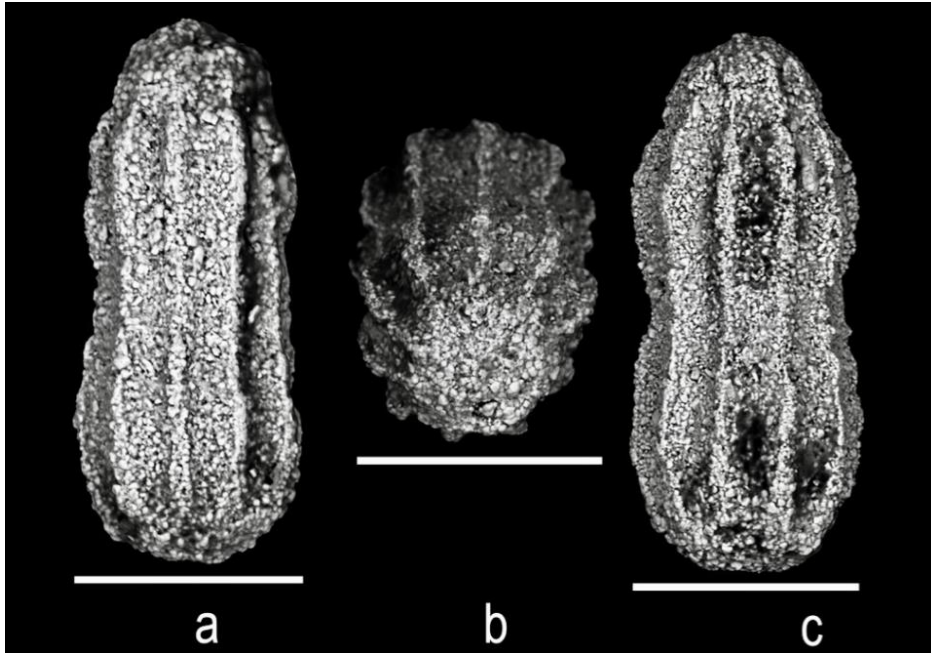
Diagnosis: Test free, straight, surface smooth, uniserial. Chambers slightly inflated and increase in size gradually with final chamber significantly larger. Sutures depressed and horizontal. Wall calcareous. Aperture terminal and radiate.

Type Level: Upper Jurassic (Oxfordian).

Remarks: This species differs from the type specimens of Schwager (1865) in having less curved outline. 24 specimens recovered from the D1 unit of the Dhurma formation in this study.

Occurrences: Jurassic of Germany (Schwager, 1865) and Scotland (Gordon, 1967). Also reported from the Aalenian to Oxfordian of India (Al Hussain, 2014, Wassim et al., 2020). In Saudi Arabia, the species has been reported from the D5 Unit of the Dhurma Formation (Kaminski et al., 2020).

***Nodosaria cf. geniculata* (Terquem & Berthelin, 1875)**



Genus: *Nodosaria* Lamarck, 1812

Original Designation: *Dentalina geniculata* Terquem & Berthelin, 1875, p. 32, pl. 2, fig. 22.

Synonyms: *Nodosaria dispar* Franke, 1957, p. 356, fig. 80.

Nodosaria geniculata Riegraf, 1984, p.682, pl.4, fig. 121.

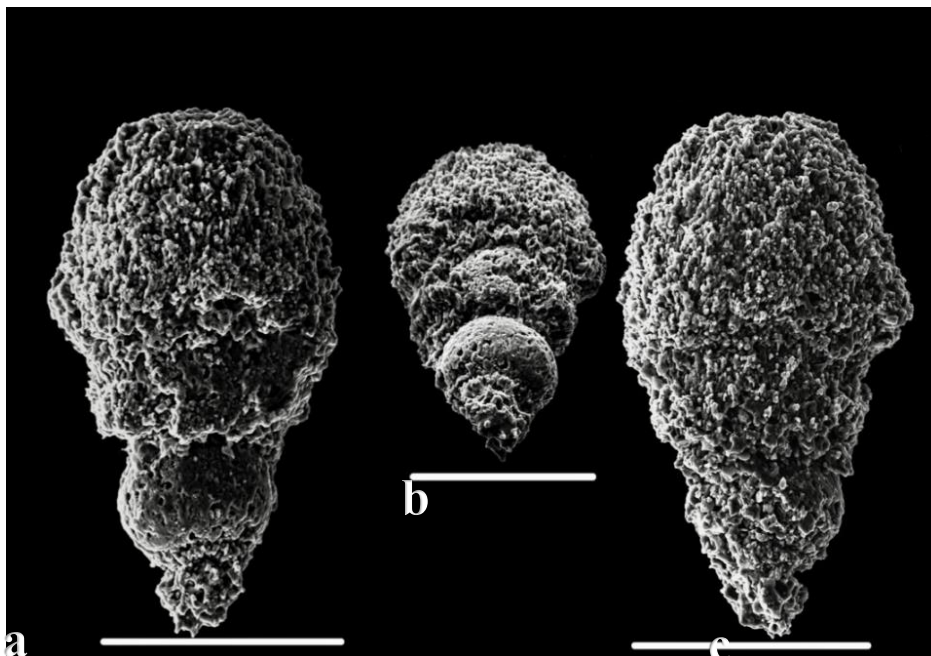
Diagnosis: Test free, rectilinear, chambers uniserially arranged. Chambers are slightly inflated. Sutures indistinct. Wall calcareous with prominent approximately 9 to 10 coste that extend along the full length of the test. Aperture terminal.

Type Level: Margaritatus Ammonite zone (Early Jurassic, Pliensbachian)

Remarks: This species differs from the type of Terquem & Berthelin in having more coste and less distinct sutures. Very rare only 1 specimen recovered from D2 unit of the Dhruma Formation (Bajocian). This species has been reported from the middle Dhruma formation (D5 unit, Bathonian) by (Kaminski et al., 2020) from the Riyadh district of Saudi Arabia.

Occurrences: France, Morocco, Saudi Arabia.

***Lingulina cf. ampliata* Loeblich & Tappan, 1950**



Genus: *Lingulina* d'Orbigny, 1826

Original Designation: *Lingulina ampliata* Loeblich & Tappan, 1950, p. 50, pl. 13, figs. 25-26.

Synonyms: none verified.

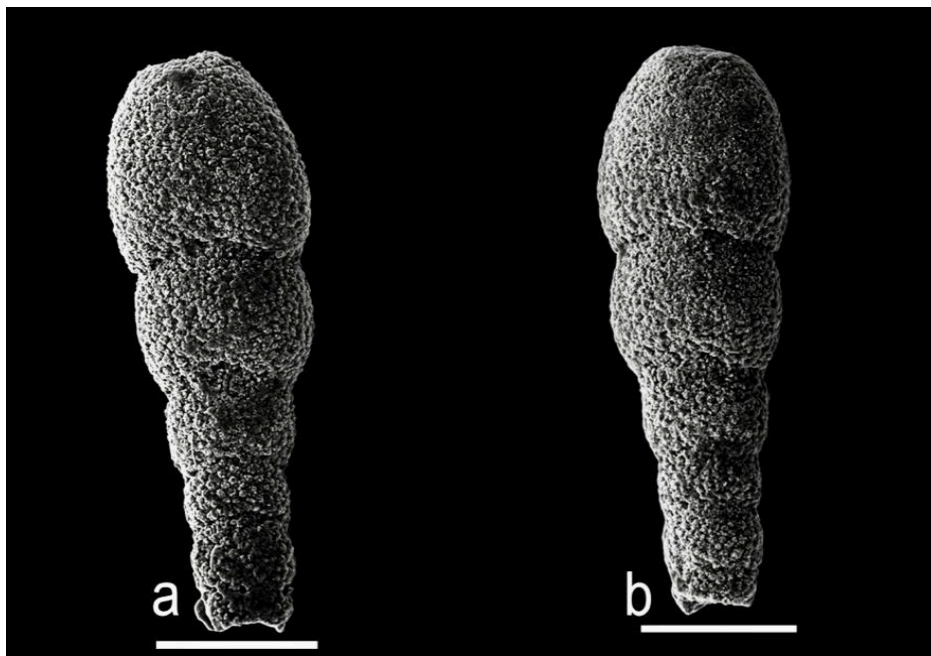
Diagnosis: Test free, small, subtriangular outline, compressed, equitant chambers increasing more rapidly in breadth than height. Sutures distinct, depressed and arched centrally. Wall calcareous, finely perforate. Aperture terminal, elongate.

Type Level: Upper Jurassic (Oxfordian).

Remarks: This species differs from the type specimens of Loeblich & Tappan (1950) in having fewer number of chambers and larger final chamber. 39 specimens recovered from the D1 & D2 unit of the Dhruma formation in this study.

Occurrences: Oxfordian of USA (Loeblich & Tappan, 1950), Barremian of Austria (Fuchs, 1971).

***Lingulina pregradniensis* Mamontova, 1957**



Genus: *Lingulina* d'Orbigny, 1826

Original Designation: *Lingulina pregradniensis* Mamontova, 1957, p. 185, pl. 1, fig. 10.

Synonyms: none verified

Diagnosis: Test long, narrow, flat, pointed at the base, gradually broadening toward the apertural chamber. The last chamber twice as broad and high as the preceding chamber and more inflated and sharply differentiated from all other chambers. Wall calcareous. Test with 6 chambers. Sutures weakly depressed. Periphery rounded. Aperture terminal and elliptical.

Type Level: Lower Jurassic (Toarcian).

Remarks: This species was originally described as new species by Mamontova, 1957 because of the disproportional increase in size of the final chamber compared to *Lingulina cernua* Berthelin, 1879. 39 specimens recovered from the D1 & D2 unit of the Dhruma formation in this study.

Occurrences: Russia.

***Frondicularia longiscata* Terquem, 1870**



Genus: *Frondicularia* Defrance, 1826

Original Designation: *Frondicularia longiscata* Terquem, 1870, p. 216, pl. 22, fig. 23, 24.

Synonyms: *Paralingulina longiscata* (Terquem). – Copestake & Johnson, 2014, p. 185, pl. 8, figs. 24, 29, 35.

Ichthyolaria longiscata (Terquem). – Talib et al. 2016, p. 263, pl. 2, fig. 1.

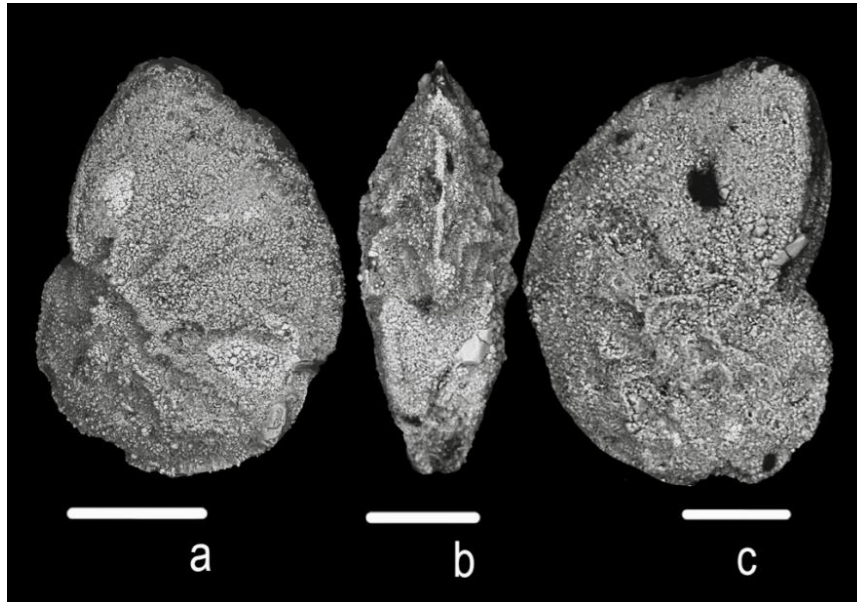
Diagnosis: Test free, elongated, compressed, rectilinear, striate, 5 chambers, sutures highly arched, wall calcareous. Aperture terminal on a small neck.

Type Level: Middle Jurassic.

Remarks: Only 2 specimens were recovered from the D1 unit of the Dhruma formation in this study.

Occurrences: Hettangian to Bathonian of Britain, France, Germany, and Morocco (Copestake and Johnson, 2014). Also reported from the Middle Jurassic (Bathonian) of India (Talib et al. 2016). In Saudi Arabia, Kaminski et al. (2020) reported this species from the D5 unit of the Dhruma Formation (Bathonian).

***Lenticulina cf. papillaecostata* Bielecka & Styk, 1981**



Genus: *Lenticulina* Lamarck, 1804

Original Designation: *Lenticulina papillaecostata* Bielecka & Styk, 1981, p. 29, pl.2, figs.19, 20.

Synonyms: *Cristellaria mamilligera* Karrer. – Brückmann, 1904, pl. 3, fig. 17.

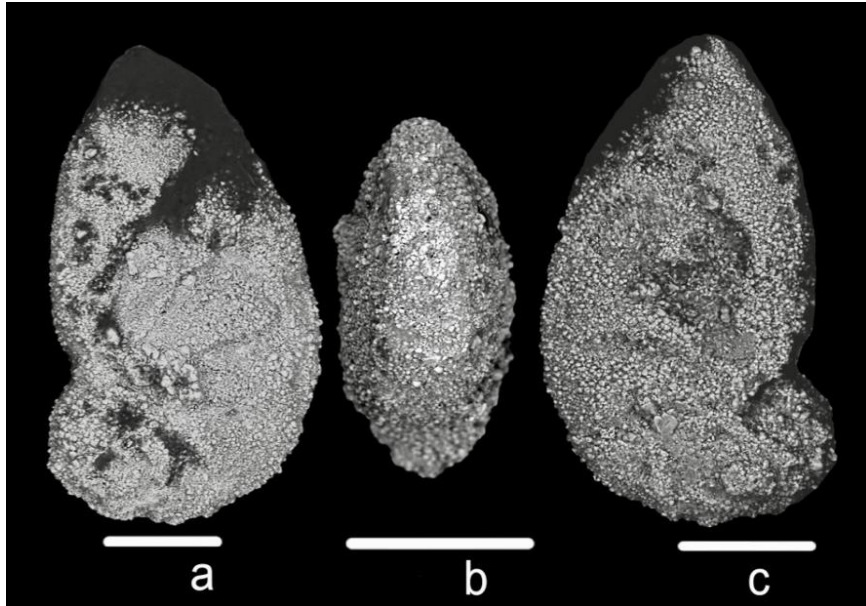
Diagnosis: Test oval in outline, flattened bilaterally. Peripheral margin sharp resembling a keel. Seven to ten chambers. Sutures raised, radiating from the middle of the test with some papillate ornamentation on the early part of the last whorl. Wall calcareous. Aperture circular or radial.

Type Level: Middle Jurassic (Callovian).

Remarks: This species differs from the type specimens of Bielecka & Styk (1981) in having raised sutures and papillate ornamentation only on the early stage of the last whorl. 89 specimens recovered from the D1 & D2 unit of the Dhruma formation in this study. However, the preservation is very poor and occasionally only a cast of the specimen which make it difficult to characterize all the features of the species.

Occurrences: NW of Poland (Callovian), East European platform in Russia (Callovian) (Bielecka & Styk, 1981).

***Lenticulina* sp. 1**



Genus: *Lenticulina* Lamarck, 1804

Original Designation: *Lenticulina* sp1, this volume.

Synonyms: cf. *Cristellaria* (*Lenticulina*) *varians* Bornemann, 1864 of Franke, 1936 p.1112, pl.11, fig. 9-11.

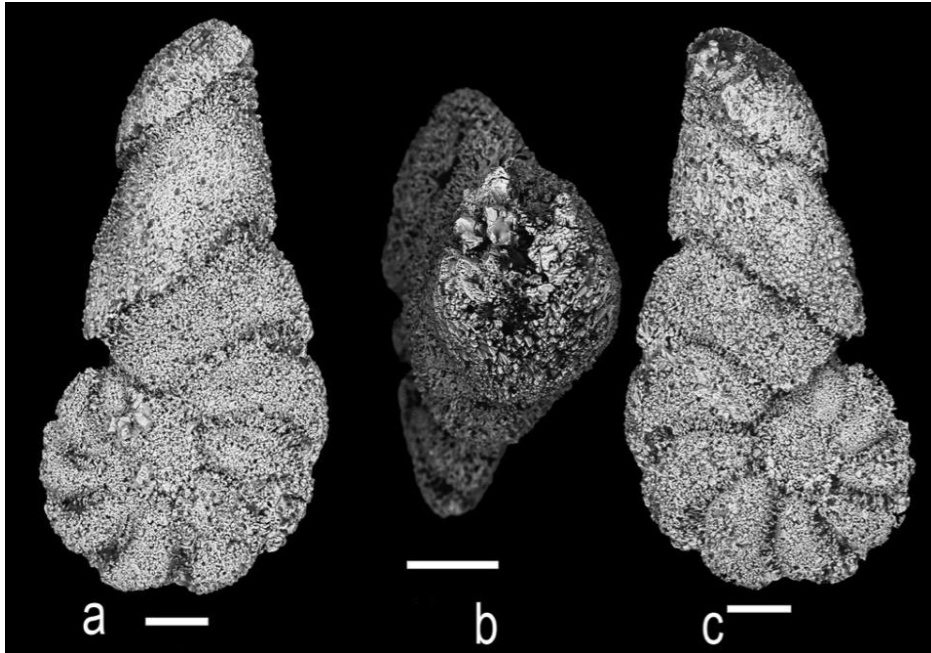
Diagnosis: Test elongated in outline, laterally compressed, periphery sharp. Coiling involute and umbilicus covered by chambers of last whorl. Seven to nine chambers in the final whorl. Chambers increase in height rapidly. Sutures slightly curved and flush. Wall calcareous. Aperture circular or radial.

Type Level: Middle Jurassic (Bajocian)

Remarks: This species most closely resemble *Cristellaria (Lenticulina) varians* Bornemann, 1864 of Franke, 1936. However, the preservation is very poor and occasionally only a cast of the specimen is found so we leave this species in open nomenclature. 98 specimens recovered from the D1 & D2 unit of the Dhurma formation in this study.

Occurrences: Riyadh district of Saudi Arabia.

***Vaginulinopsis eritheles* Loeblich & Tappan, 1950**



Genus: *Vaginulinopsis* Silvestri, 1904

Original Designation: *Vaginulinopsis eritheles* Loeblich & Tappan, 1950, p. 9, pl. 1, fig. 9-13.

Synonyms: *Marginulina* sp.? Wickenden, 1933, p. 163, pl. 1, fig. 12 a, b.

Diagnosis: Test free, large, elongate, early portion close coiled and cristellarian, later portion uncoiling, uniserial with periphery broadly rounded. Sutures slightly curved. Wall calcareous, surface smooth. Aperture radiate at the peripheral angle.

Type Level: Upper Jurassic (Callovian)

Remarks: This species resembles one of the varieties of *Cristellaria centralis* Terquem from Upper Bajocian of France in size and general appearance but is less compressed and has more horizontal and less depressed sutures. Only 1 specimen recovered from the D1 unit of the Dhruma formation in this study.

Occurrences: Callovian of Wyoming and North Dakota (USA).

***Vaginulina parva* Franke, 1936 of Copestake & Johnson 2014**



Genus: *Vaginulina* d'Orbigny, 1826

Original Designation: non: *Vaginulina parva* Franke, 1936, p. 83, pl. 8, fig. 23 a, b.

Synonyms: *Vaginulina parva* Franke, 1936, of Copestake & Johnson 2014, p. 289, pl. 13, fig. 26.

Pars: *Vaginulina strigillata* Issler, 1908 p.71, pl.4, fig.201.

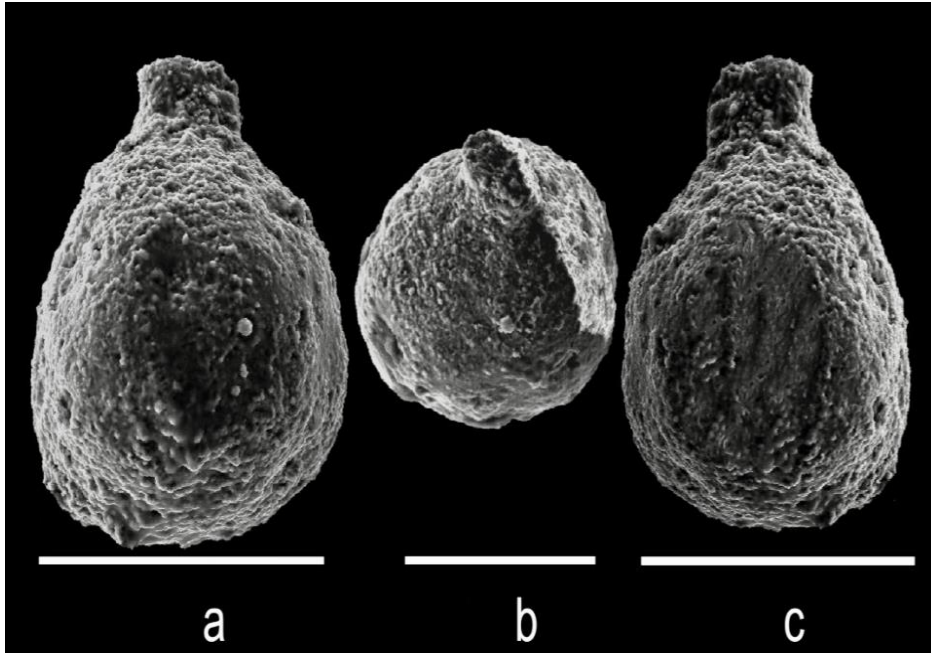
Diagnosis: Test smooth, proloculus ovoid, 5 to 8 broad, low chambers. Test initially curved, subsequently rectilinear. Sutures straight, parallel and oblique. Dorsal margin angular while ventral margin rounded. Aperture marginal, produced and radiate.

Type Level: Lower Jurassic (Hettangian–Toarcian).

Remarks: *Vaginulina parva* differs from *Vaginulina constricta* Terquem & Berthelin, 1875 in having flush sutures and a less compressed, much more regular test (Copestake & Johnson, 2014). Only 2 specimens were recovered from the D1 unit of the Dhruma formation in this study.

Occurrences: Hettangian to Toarcian of Germany (Franke, 1936), Upper Cretaceous of the Czech Republic (Issler, 1908) and Lower Jurassic of North Wales (Copestake & Johnson 2014).

***Lagena haeusleri* Copestake & Johnson, 2014**



Genus: *Lagena* Walker & Jacob, 1798

Original Designation: *Lagena haeusleri* Copestake & Johnson, 2014, p. 295, pl. 10, figs. 27, 30, 31)

Synonyms: *Lagena marginata* Haeusler, 1887, p. 186, pl. 4, figs. 51, 52, 53).

Diagnosis: Test free, small, unilocular, sub polygonal outline, flattened at base, tapering distally, laterally compressed. Wall calcareous, surface smooth. Aperture rounded and slightly produced.

Type Level: Lower Jurassic to Cretaceous.

Remarks: Test range from being rounded to having slightly carinate margins. The rest surface varies from being smooth to occasionally hispid (Copestake & Johnson, 2014). In this study 41 specimens were recovered from the D1 unit of the Dhruma formation.

Occurrences: Jurassic (Hettangian) to Cretaceous of Britain and Germany (Copestake & Johnson, 2014).

***Ramulina* sp. 1 resembling *muricata* Loeblich & Tappan, 1949**



Genus: *Ramulina* T.R. Jones, 1875

Original Designation: *Ramulina abscissa* Loeblich and Tappan, 1946, p. 261, pl. 81, figs. 7.

Synonyms: none verified.

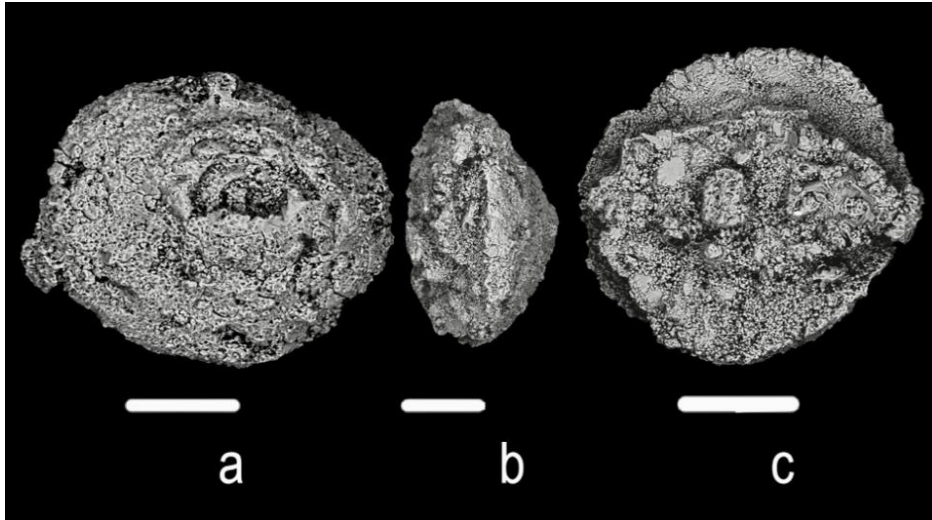
Diagnosis: Test free, consisting of an elongate tube of nearly equal diameter throughout and branching. Wall calcareous. Surface smooth. Aperture at the open ends of the tube.

Type Level: Lower Cretaceous.

Remarks: This species differ to *Ramulina muricata* in lacking fine spines that cover the test and to *Ramulina abscissa* in the degree and irregularity of the branching of the test. In this study 167 specimens were recovered from the D1 unit of the Dhruma Formation.

Occurrences: Albian of USA.

***Epistomina* sp. 1**



Genus: *Epistomina* Terquem, 1883

Original Designation: *Epistomina* sp. 1

Synonyms: none verified.

Diagnosis: Test trochospiral, lenticular to planoconvex, sharp periphery, sutures curved, wall calcareous. Very poorly preserved so chambers and other features are indistinguishable.

Type Level: Middle Jurassic (Bajocian).

Remarks: 183 specimens found on this study from D1 and D2 units of the Dhruma Formation (Bajocian) in well lithified limestone beds with very poor preservation.

Occurrences: Riyadh district of Saudi Arabia.

CHAPTER 4

DISCUSSION AND CONCLUSION

4.1 Discussion

This study is the first detailed foraminiferal taxonomic study for the Bajocian outcrops in Saudi Arabia using disaggregated samples. Contrary to popular perceptions about the lack of diversity and poor fauna presence in the Bajocian strata of Saudi Arabia, the results here show high diversity and abundance of foraminiferal taxa and other microfauna. A total of 32 genera and 63 species are identified from D1 and D2 units corresponding to the Bajocian age. These numbers are much higher compared to reported numbers from other studies covering the lower Dhruma or upper units of the formation in central Saudi Arabia. Ismanto et al. (2019) reported 19 species belonging to 17 genera from outcrops in thin section samples from the upper part of D2, D3 and D4 units (Bajocian to early Bathonian) of the Dhruma formation where *Redmondoides lugeoni* and *Nautiloculina oolithica* are the most abundant species. Utilizing disaggregated samples, Malik et al.

(2020) reported 35 foraminiferal species belonging to 19 genera from the D5 and D6 units (Bathonian age) of the formation from outcrop samples. The agglutinated genera dominated the assemblages and the species *Redmondoides inflatus* and *Redmondoides medius* are the most abundant among them. In his thin-section based micropaleontological biozonation for the Jurassic of Saudi Arabia, Hughes (2018) described the foraminiferal taxa at the top of biozone Dm-1 which corresponds to Unit D1 as: “dwarf smaller agglutinated foraminiferal species including *Glomospira*, *Reophax*, *Siphovalvulina*, *Textulariopsis*, *Paleopfenderina salernitana*, *Timidonella sarda*, *Timidonella primitiva*, and a *Polarisella*-resembling nodosarid with extended apertural necks, and the last down whole occurrences of *Nautiloculina oolithica*, *Dhrumella evoluta*, *Kurnubia* spp., *Hauerina deserta*, *Bosniella bassoulleti*, *Coscinoconus alpinus*, and *Redmondoides lugeoni*”.

From the 50 samples covering the upper part of D1 and D2 Units examined in this study, the four most abundant species retrieved are cf. *Reophax dentaliniformis* Brady, *Nautiloculina oolithica* Mohler, *Haplophragmoides bartensteini* Kalantari, and *Verneuilinoides conoidalis* Azbel. Except for *Nautiloculina oolithica* Mohler, the other three species are reported for the first time from the Dhruma Formation of Saudi Arabia. Therefore, their abundance could be used as a local marker for the Bajocian age, at least in the outcrops, until further proof of their occurrence is obtained from subsurface samples. Among the 63 species reported here, many are reported from other localities around the world and have variable stratigraphic ranges. In chronological order, 8 species have been

reported from the lower Jurassic: *Trochammina squamataformis*, *Siphovalvulina colomi*, *Siphovalvulina gibraltarensis*, *Spirillina trochoides*, *Prodentalina digitalis*, *Lingulina pregradniensis*, *Vaginulina parva* and *Lagena haeusleri*. Seven species are reported from the Bajocian stage of different countries: *Glomospira gordialis* (Jones & Parker) var. *chodzica* Antonova, cf. *Reophax dentaliniformis*, *Haplophragmoides bartensteini*, *Haplophragmoides* cf. *planus*, *Spirillina involuta*, *Paralingulina cernua* spp. A Berthelin, *Dentalina botuliformis*. Eleven species are reported from Bathonian age (including Saudi Arabia): *Miliammina grana*, *Haplophragmoides barthouxi*, *Riyadhella arabica*, *Riyadhella sibirica*, *Redmondoides medius*, *Redmondoides primitivus*, *Pseudomarssonella maxima*, *Pseudomarssonella reflexa*, *Dentalina bicornis*, *Nodosaria* cf. *geniculata* and *Fronicularia longiscata*. Three species were reported from Callovian age, but none of them have been reported from Saudi Arabia before: *Plectinella aegyptiaca*, *Lenticulina* cf. *papillaecostata* and *Vaginulinopsis eritheles*. Five species were reported from Oxfordian age (including the Oxfordian of Saudi Arabia): *Haplophragmoides* resembling *canui*, *Verneuilinoides conoidalis*, *Dentalina digitata*, *Dentalina guembeli*, *Lingulina* cf. *ampliata*. Two species were reported from Kimmeridgian, none of them have been reported from Saudi Arabia before: *Trochammina elevata*, *Verneuilinoides* aff. *minutus*. Five species were reported from the Lower Cretaceous: *Trochammina instabilis* Vassilenko, *Trochammina* cf. *numerosa* Akimets, *Verneuilinoides* cf. *asperulus*, *Pseudoreophax* aff. *cisovnicensis* and *Ramulina* resembling *muricatina*. Moreover, 10 species reported here are new to science: *Haplophragmoides* sp. 1, *Pseudobolivina*? sp. 1, *Trochammina* sp. 1, *Trochammina* sp. 2, *Gaudryinopsis* sp. 1, *Gaudryinopsis* sp. 2, *Gaudryinopsis* sp. 3, *Gaudryinopsis* sp. 4, *Gaudryinopsis* sp. 5 and *Lenticulina* sp. 1. There is a high chance

these are endemic species considering the Central Arabia Basin are known to have various marine macro and micro endemic species i.e., ammonites (Arkell, 1952), echinoids (Kier, 1972) brachiopods (Cooper, 1989), gastropods (Fischer, 2001) and foraminifera (Redmond, 1964, 1965). Furthermore, Al Saad (2008) reported a total of 35 endemic foraminiferal species from the Middle Jurassic of the Central Arabian Basin.

From the rarefaction curve of this study, 67.5% of species in studied area are identified with 95% statistical confidence. In other word, more sampling might lead to identifying 32.5 % Smore species. Several species reported by Hughes (2018) from Dm-1 biozone are not present here. Another notable missing species here is the *Ammobaculoides dhrumaensis* which dominated the assemblage reported by (Kaminski et al. 2018 b) from the D1 Unit of the formation from a nearby locality in Central Saudi Arabia. This signifies the great diversity of the species in the lower Dhruma. The difference of reported species by different studies for the same zone of interest could be the consequence of using different analysis technique (thin-section vs disaggregated) or the minor differences in processing the sample when the acetic acid leaching technique is applied. Thus, integrating both techniques should result in better results taking on consideration the nature of the sample and induration of the rock.

In addition to the diversity and abundance of foraminiferal taxa and the diversity of the morphotypes of the taxa, the samples have good recovery and preservation of other marine

micro biocomponents such as ostracods, holothurian sclerites, fragments of echinoid spines, juvenile gastropods, and monaxon and triaxon sponge spicules. All these elements clearly suggest a marine environment with relatively normal environmental conditions.

Since this study is solely based on disaggregated samples, the results might be incomplete and not fully represent the actual existence of the taxa. For example, the decreased number of recoveries from limestone samples in D1B and D2W sections could be the effects of high induration of the rock. Highly indurated rock samples are more difficult to break down and the matrix does not dissolve enough to liberate the microfossils within them. This might also explain the absence of larger foraminifera from the D2 unit samples here. The integration of thin-section and disaggregated analyses should resolve such a concern.

4.2 Conclusions & Recommendations

The three studied Bajocian outcrops, representing the D1 and D2 units of the Dhruma formation, proved that the lower Dhruma units host a high diversity and richness of microfaunas. The acetic acid method to extract foraminifera was successfully applied to the lower Dhruma limestones. Most retrieved specimens are in a good preservation condition, which makes it possible to carry out full taxonomic and statistical analyses.

A total of 63 species belonging to 32 genera were identified. The assemblages are dominated by the family Polymorphinidae, Haplophragmoididae and Verneulinidae. The most abundant species are cf. *Reophax dentaliniformis* Brady, *Nautiloculina oolithica* Mohler, *Haplophragmoides bartensteini* Kalantari, and *Verneulinoides conoidalis* Azbel. Ten new endemic species were found.

The result of morphogroup analysis and the presence of other biocomponents i.e., sponge spicules (monaxon and triaxon, echinoid spines, ostracods, holothurian sclerites, juvenile gastropods and calcareous nannofossils, suggest that deposition occurred in a normal marine setting. The high diversity and abundance of foraminiferal taxa and other microfauna suggest the paleoenvironment elements (nutrient availability, oxygen level and water salinity) were suitable for microfauna to thrive.

Further work is needed to investigate the lateral and vertical extension of the reported taxa on the Dhruma Formation outcrops and in age-equivalent subsurface samples.

References

- Akimets, V. S., 1966. Stratigraphy and foraminifera of the Lower Cretaceous deposits of Belarus. Paleontology and stratigraphy of the Baltic States and Belarus, Vilnius: Mintis, 1 (6), 293–375.
- Al-Dhubaib, A. J., 2010. Taxonomy and Paleoenvironments of Middle and Late Jurassic Foraminifera and its associations of Saudi Arabia (Unpublished PhD thesis). University College London, 401 pp.
- Al-Husseini, M. I., 1997. Jurassic Sequence Stratigraphy of the Western and Southern Arabian Gulf. *GeoArabia*, 2 (4), 361–382.
- Al-Husseini, M. I., 2000. Origin of the Arabian Plate structures: Amar collision and Najd rift. *GeoArabia*, 5 (4), 527–542.
- Al-Mojel, A., 2017. Sedimentology and Sequence Stratigraphy of the Jurassic, Jebel Tuwaiq, Central Saudi Arabia (PhD Thesis). University Bordeaux, France.
- Al-Qahtani, A. M., Abdel, G. A., Pierre, J., Laer, V. and Tariq, U., 2004. Arabian Platform structural growth and its impact on facies distributions and hydrocarbon occurrence. Abstract, *GeoArabia*, 9 (1), 32.
- Al-Saad, H., 2008. Stratigraphic distribution of the Middle Jurassic foraminifera in the Middle East. *Revue de Paléobiologie*, 27, 1–13.
- Antonova, Z. A., 1958. Foraminifera of the Middle Jurassic of the Laby River basin. *Trudy Krasnodarskoy filii VNII*, 17, 41–80.
- Arkell, W. J., 1952. Jurassic ammonites from Jebel Tuwaiq, central Arabia. *Royal Society London Philosophical Transactions, Series B*, 36, 241–313.

- Arkell, W. J., 1957. Mollusca 4-Cephalopoda, Ammonoidea: In: Moore, R. C. (Ed.), Treatise on Invertebrate Paleontology: New York and Lawrence, Kans., Geol. Soc. America and Univ. Kansas Press, 490 pp.
- Azbel, A. Y., 1977. The agglutinated foraminifers of the Jurassic deposit. Academy of Sciences USSR Questions of Micropaleontology, 5, 71–157.
- Bielecka, W. and Styk, O., 1981. Biostratigraphy of the Bathonian and Callovian deposits of northwestern Poland based on occurrence of foraminifers and ostracods. Prace Instytutu Geologicznego, 100, 5–56.
- Berggren, W. A. and Kaminski, M. A., 1990. Abyssal agglutinates: back to basics. In: Hemleben, C., Kaminski, M.A., Kuhnt, W. and Scott, D.B., (eds), *Paleoecology, Biostratigraphy, Paleooceanography and Taxonomy of Agglutinated Foraminifera*, NATO ASI Series C, 327, Kluwer Acad. Publ. 53–76.
- Berthelin, G., 1879. Foraminifères du Lias moyen de la Vendée. Revue et Magasin de Zoologie Pure et Appliquée, Paris, 3 (7): 24–41.
- Bourdon, M. 1956. Études micropaléontologiques; utilisation de l'acide acétique dans la désagrégation des roches dures. Revue de L'institut Français du Pétrole, 12, 14–15.
- Bramkamp, R. A. and Steineke, M., 1952. Stratigraphical introduction: In: W.J. Arkell, (Ed.), Jurassic ammonites from Jebel Tuwaiq, central Arabia. Royal Society London Philosophical Transactions, Series B, 236, 241–313.
- Bernier, P., 1987. *Petrascula arabica* nov. sp. nouvelle espèce d'algue dasycladacée du Bathonien d'Arabie Saoudite. Geobios, 20, 293–303.
- BouDagher-Fadel, M. K., and Bosence, D. W., 2007. Early Jurassic benthic foraminiferal diversification and biozones in shallow marine carbonates of the Tethys. Senckenbergiana Lethaea, 87 (1), 1–39.

- Boudagher-Fadel, M. K., Rose, E. P. F., Bosence, D. W. J., and Lord, A. R., 2001. Lower Jurassic Foraminifera and Calcified Microflora from Gibraltar, Western Mediterranean. *Palaeontology*, 44 (4), 601–621
- Bramkamp, R. A. and Steineke, M., 1952. Stratigraphical introduction: In: W.J.Arkell, (Ed.), *Jurassic ammonites from Jebel Tuwaiq, central Arabia*. Royal Society London Philosophical Transactions, Series B, 236, 241–313.
- Catalogue of Foraminifera (1942+). New York: Micropaleontology Press, Ellis and Messina catalogues of Micropaleontology (unpaginated).
- Chan, S. A., 2016. *Biostratigraphy and Benthic Foraminiferal Morphogroups of the Miocene Mixed Carbonate and Siliciclastic Dam Formation in the Al-Lidam Area, Eastern Province of Saudi Arabia* (Unpublished Master Thesis), King Fahd University of Petroleum and Minerals.
- Clark, G. N. and BouDagher-Fadel, M. K., 2001. The larger benthic foraminifera and stratigraphy of the Upper Jurassic/Lower Cretaceous of Central Lebanon. *Revue de Micropaléontologie*, 44 (3), 215–232.
- Cetean, C. G., Balci, R., Kaminski, M. A. and Filipescu, S., 2011. Integrated biostratigraphy and paleoenvironments of an upper Santonian – upper Campanian succession from the southern part of the Eastern Carpathians, Romania. *Cretaceous Research*, 32, 575–590.
- Copestake, P. and Johnson, B., 2014. Lower Jurassic Foraminifera from the Llanbedr (Mochras Farm) Borehole, North Wales, UK. *Palaeontological Society Monograph*, 641, 403 pp + 21 pls.
- Corliss, B.H. and Chen, C., 1988. Morphotype patterns of Norwegian Sea deep-sea benthic foraminifera and ecological implications. *Geology*, 16, 716–719.
- Corliss, B.H., 1985. Microhabitats of benthic foraminifera within deep-sea sediments. *Nature*, 314, 435–438.

- Crespin, I., 1963. Lower Cretaceous arenaceous Foraminifera of Australia. *Bull. Bur. Min. Res. Geol. Geophys. Australia*, 66: 1–110.
- Cushman, J. A., 1930. Note sur quelques foraminifères Jurassiques d'Auberville (Calvados). *Bulletin de la Société Linnéenne de Normandie*, 8 (2), 132–135.
- Dain, L. G., (Ed.), 1972. Foraminifera from Upper Jurassic deposits of Western Siberia. *Trudy VNIGRI*, 317, 1–272.
- Dain, L. G. and Kuznetsova, K., 1971. Zonal subdivision of the stratotype section of the Volga stage by foraminifera. *Academy of Sciences USSR, Questions of Micropaleontology*, 14: 103–124.
- Depeche, F., Le Nindre, Y.-M., Manivit, J. and Vaslet, D., 1987. Les ostracodes du Jurassique d'Arabie Saoudite centrale: systematique, repartition stratigraphique et paleogeographique. In, R. Enay (Ed.), *Le Jurassique d'Arabie Saoudite Centrale*. *Geobios*, Lyons, *Memoir Special*, 9, 221–275.
- Enay, R., Le Nindre, Y.-M., Mangold, C., Manivit, J. and Vaslet, D., 1986. The Jurassic of central Saudi Arabia: New data on lithostratigraphic units, paleoenvironments, ammonite faunas, ages and correlations. *Deputy Ministry of Mineral Resources, Jiddah, Technical Record BRGM-TRO6-3*, 65 pp.
- Enay, R., Le Nindre, Y.-M., Mangold, C., Manivit, J. and Vaslet, D., 1987 *Le Jurassique d'Arabie Saoudite Centrale: nouvelles donnees sur la lithostratigraphie, les paleoenvironnements, les faunes d'ammonites, les ages et les correlations*: In R. Enay (Ed.), *Geobios*, Lyons, *Memoir Special*, 9, 13–65.
- Enay, R., Mangold, C. and Almeras, Y., 2009. Le "delta" du Wadi ad Dawasir, Arabie saoudite centrale: une base du niveau marin relatif du Bathonien inferieur. *GeoArabia*, 14 (1), 17–52.
- Farahani, T. S., Reolid, M., Yazdi, M. and Majidifard, M. R., 2018. Benthic foraminiferal assemblages of the Middle and Upper Jurassic sediments from the northeastern

- Alborz and western Koppeh Dagh, Iran: Systematic paleontology and paleoecology. *Annales de Paléontologie*, 104, 249–265
- Fischer, J. C., Le Nindre, Y. M., Manivit, J. and Vaslet, D., 2001. Jurassic gastropod faunas of Central Saudi Arabia. *GeoArabia*, 6 (1), 63–100
- Franke, A., 1936. Die Foraminiferen des deutschen Lias. *Abhandlungen der Preussischen Geologischen Landesanstalt*, 169: 1–138.
- Geroch, S., 1961. *Pseudoreophax* a new genus of Foraminifera from the Neocomian in the Flysch Carpathians. *Annales Societatis Geologorum Poloniae*, 31 (1), 159–165.
- Gordon, W. A., 1965. Foraminifera from the Corallian Beds, Upper Jurassic, of Dorset, England. *Journal of Paleontology*, 39, 828–863.
- Görög, A., 1995. Bathonian foraminifera from the Mecsek Mountains (South Hungary). *Annales Universitatis Scientiarum Budapestinensis de Rolando Eötvös Nominatae, Sectio Geologica*, 30, 7–82.
- Hammer, Ø, and Harper, D., 2005. *Paleontological data analysis*. Second Edition. Cambridge: Blackwell, 1–368.
- Haq, B. U. and Al-Qahtani, A.M., 2005. Phanerozoic cycles of sea-level change on the Arabian Platform. *GeoArabia*, 10 (2), 127–160
- Hughes, G. W., 2004. Middle to Upper Jurassic Saudi Arabian carbonate petroleum reservoirs: biostratigraphy, micropalaeontology and palaeoenvironments. *GeoArabia*, 9 (3), 79–114.
- Hughes, G. W., 2006. Biofacies and palaeoenvironments of the Jurassic Shaqra Group of Saudi Arabia. *Volumina Jurassica*, abstract, 4, 89–90
- Hughes, G. W., 2008. Jurassic Carbonates and Reservoir Equivalents of Saudi Arabia, Internal Saudi Aramco Technical Memorandum, 31, 147 pp

- Hughes, G. W., 2009. Biofacies and palaeoenvironments of the Jurassic Shaqra Group of Saudi Arabia, *Volumina Jurassica*, 6, 33–45.
- Hughes, G. W., 2018. A new thin-section based micropaleontological biozonation for the Saudi Arabia Jurassic carbonates, *Micropaleontology*, 64 (5-6), 331–364.
- Imlay, R., 1970. Some Jurassic ammonites from central Saudi Arabia. United States Geological Survey, Professional Paper, 644-D, 19 pp.
- Ismanto, A. W., Chan, S. A., Babalola, L. O., Kaminski, M. A., Al-Ramadan, K. A. and Abdulatif, O.M., 2019. Microfacies, biofacies, and depositional environments of the Bajocian–Bathonian Middle Dhurma carbonates, central Saudi Arabia. *International Journal of Earth Sciences*, 108, 2577–2601.
- Jenkins, D. G. & Murray, J. W., 1989. *Stratigraphical Atlas of Fossil Foraminifera*, 2nd edition. British Micropalaeontological Society Series, 593 pp.
- Jones, R. W. and Charnock, M. A., 1985. “Morphogroups” of agglutinating foraminifera. Their life position and feeding habits and potential applicability in (paleo)ecological studies. *Revue de Paléobiologie*, 4, 311–320.
- Kalantari, A. 1969. Foraminifera from the Middle Jurassic-Cretaceous Successions of Koppet Dagh Region (NE, Iran). Teheran National Iranian Oil Company, Geol. Labor., Publ, 3, 19.
- Kaminski, M. A., 2014. The year 2010 classification of the agglutinated foraminifera. *Micropaleontology*, 61 (1): 89–108.
- Kaminski, M. A., and Gradstein, F. M., 2005. *Atlas of Paleogene Cosmopolitan Deep-Water Agglutinated Foraminifera*: Grzybowski Foundation Special Publication, 10, 574+vii pp.
- Kaminski, M. A., Chan, S. A., Balc, R., Gull, H. M., Amao, A. O. and Babalola, L. O., 2018a. Middle Jurassic Planktonic Foraminifera in Saudi Arabia – a new

- biostratigraphical marker for the J30 maximum flooding surface in the Middle East. *Stratigraphy*, 15: 37–46
- Kaminski, M. A., Malik, M. H. and Setoyama, E., 2018b. The occurrence of a shallow-water *Ammobaculoides* assemblage in the Middle Jurassic (Bajocian) Dhurma Formation of Central Saudi Arabia. *Journal of Micropaleontology*, 37, 149–152.
- Kaminski, M. A., Amao, A. O., Babalola, L. O., Balci, R., Chan, S. A., Gull, H. M., Bu Khamsin, A. and Malik, M. H. 2020., Benthic foraminiferal assemblages from the Maximum Flooding surface J30, Middle Jurassic Dhurma Formation, Central Saudi Arabia. *Stratigraphy*, 17 (4), 279–292.
- Kaptarenko-Chernousova, O. K., 1959. Foraminifera of Jurassic strata of the Dnieper-Donets Basin, Trudy Instituta Geologicheskikh Nauk, Akademiya Nauk Ukraynskoy SSR, Kiev, Seriya Stratigrafii i Paleontologii, 15, 1–121.
- Konert, G., Afifi, A. M., Hajri, S. A, and Droste, H. J., 2001. Paleozoic stratigraphy and hydrocarbon habitat of the Arabian Plate. *GeoArabia*, 6 (3), 407–442.
- Loeblich, A.R. and Tappan, H., 1949. Foraminifera from the Walnut Formation (Lower Cretaceous) of Northern Texas and Southern Oklahoma. *Journal of Paleontology*, 23 (3), 245-266.
- Loeblich, A. R. and Tappan, H., 1950. North American Jurassic Foraminifera: I. The Type Redwater Shale (Oxfordian) of South Dakota. *Journal of Paleontology*, 24 (1), 39-60.
- Loeblich, A. R. and Tappan, H., 1987. Foraminiferal Genera and their Classification. New York: Van Nostrand Reinhold Company, 970 pp + 847 pls.
- Malik, M. H., 2016. Micropaleontology and Sequence Stratigraphy of Middle Jurassic D4-D5 Members of Dhurma Formation, Central Saudi Arabia (Unpublished master's thesis). King Fahd University of Petroleum and Minerals.

- Malik, M. H., Babalola, L.O., Al-Ramadan, K.A., and Kaminski, M.A., 2020. Integrated Micropaleontology, Sedimentology and Sequence Stratigraphy of the Middle Jurassic D5-D6 Members of the Dhurma Formation, Central Saudi Arabia. *Micropaleontology*, 66 (6), 519–547.
- Mjatliuk, E. V. and Vassilenko, V. P., 1988. Atlas of characteristic foraminifera of the Lower Cretaceous deposits of the Pre-Caspian Lowlands, Mangyshak Peninsula, and Ustyurt. *Vsesoyuznyy Neftyanoy Nauchno-Issladovatel'skiy Geologorazvedochnyy Institut (VNIGNI), Leningrad, Nedra*, 262 pp.
- Mjatliuk, E. V., 1939. Foraminifera from Upper Jurassic and Lower Cretaceous sediments of the Middle Volga region and Obshchyi Syrt. *Trudy Neftyanogo Geologo-Razvedochnogo Instituta. ser. A*, 1–75.
- Mamontova, E. V., 1957. Foraminifera from Toarcian deposits on the northern slope of the Greater Caucasus (Kuban-Laba). *Scientific notes of Leningrad State University, Ser. Geological Science*, 225 (9), 160–213.
- Manivit, H., Pellaton, J. C., Vaslet, D., Le Nindre, Y.-M., Brosse, J.-M., Breton, J.P. and Fourniguet, J., 1986. Geological map of the Darma' quadrangle, sheet 24 H, Kingdom of Saudi Arabia. Saudi Arabia Deputy Ministry of Mineral Resources, Geoscience Map GM-101, Scale 1:250,000, 33 pp.
- Manivit, H., 1987. Distribution des nannofossiles calcaires du Jurassique moyen et superieur en Arabie Saoudite centrale: In: Enay, R. (Ed.), *Geobios, Lyons, Memoire Special*, 9, 277–301.
- Mohler, W. A., 1938. Mikropaläontologische Untersuchungen in der nordschweizerischen Juraformation. *Abhandlungen der Schweizerischen Paläontologischen Gesellschaft*, 60, 1–53.
- Nagy, J., Grandstein, F. M., Kaminski, M. A., and Holbourn, A. E., 1995. Foraminiferal morphogroups, paleoenvironments and new taxa from Jurassic to Cretaceous strata of Thakkhola, Nepal. *Grzybowski Foundation Special Publication*, 3, 181–209.

- Nagy, J., 1992. Environmental significance of foraminiferal morphogroups in Jurassic North Sea deltas. *Palaeogeography, Palaeoclimatology, Palaeoecology*, 95, 111–134.
- Nötzold, T., 1965. Die Präparation von Gyrogoniten und kalkigen Charophyten-Oogonien aus festen Kalksteinen. *Monatsberichte der Deutschen Akademie der Wissenschaften zu Berlin*, 7, 216–221.
- Paalzow, R., 1932. Die Foraminiferen aus den Transversarius-Schichten und Impressatonen der nordöstlichen Schwäbischen Alb. *Jahreshefte des Vereins für vaterländische Naturkunde in Württemberg*, 88, 81–142.
- Powers, R. W., 1962. Arabian Upper Jurassic carbonate reservoir rocks. *American Association of Petroleum Geologists, Memoir*, 1, 122–192.
- Powers, R. W., Ramirez, L. F., Redmond, C. D. and Elberg, E. L., 1966. Geology of the Arabian Peninsula, Sedimentary geology of Saudi Arabia. Geological Survey Professional Paper 560-D, United States Government Printing Office, Washington, 147 pp.
- Powers, R. W., 1968. Saudi Arabia. *Lexique Stratigraphique International*, 3, Centre National de la Recherche Scientifique, Paris, 171 pp.
- Redmond, C. D., 1965. Three New Genera of Foraminifera from the Jurassic of Saudi Arabia, *Micropaleontology*, 11 (2), 133–140.
- Reolid, M. and Herrero, C., 2004. Evaluation of methods for retrieving foraminifera from indurated carbonates: application to the Jurassic spongiolithic limestone lithofacies of the Prebetic Zone (South Spain). *Micropaleontology*, 50 (3), 307–312.
- Reolid, M., Sebane, A., Rodríguez-Tovar, F. J., and Marok, A., 2012. Foraminiferal morphogroups as a tool to approach the Toarcian Anoxic Event in the Western Saharan Atlas (Algeria). *Palaeogeography, Palaeoclimatology, Palaeoecology*, 323, 87–99.

- Reolid, M., Nagy, J. and Rodriguez-Tovar, F. J., 2010. Ecostratigraphic trends of Jurassic agglutinated foraminiferal assemblages as a response to sea-level changes in shelf deposits of Svalbard (Norway). *Palaeogeography, Palaeoclimatology, Palaeoecology*, 293: 184–196.
- Reolid, M., Rodríguez-Tovar, F. J., Nagy, J. and Olóriz, F., 2008. Benthic foraminiferal morphogroups of mid to outer shelf environments of the Late Jurassic (Prebetic Zone, southern Spain): characterization of biofacies and environmental significance. *Palaeogeography, Palaeoclimatology, Palaeoecology*, 261 (3–4), 280–299.
- Said, R. and Barakat, M. G., 1958. Jurassic microfossils from Gebel Maghara, Sinai, Egypt. *Micropaleontology*, 4 (3), 231–272.
- Setoyama, E., 2012. Late Cretaceous Foraminifera from the northern proto-Atlantic – Arctic Seaway: Biostratigraphy, Palaeoenvironment, Palaeobiogeography. (Unpublished PhD Thesis), Instytut Nauk Geologicznych Polskiej Akademii Nauk, 275 pp.
- Sharland, P. P., Archer, R., Casey, D. M., Davies, R. G., Hall, S. H., Heward, A. P., Horbury, A.D. and Simmons, M.D., 2001. Arabian Plate Sequence Stratigraphy. *GeoArabia Special Publication*, 2, 371 pp.
- Steineke, M., Bramkamp, R. A. and Sander, N. J., 1958. Stratigraphic relations of Arabian Jurassic oil. American Association of Petroleum Geologists Symposium, Tulsa, OK, 1294–1329.
- Tappan, H., 1955. Foraminifera from the Arctic Slope of Alaska. Part 2, Jurassic Foraminifera. United States Geological Survey Professional Papers, 236-B: 1–124.
- Terquem, O., 1870. Deuxième série - Troisième mémoire sur les foraminifères du système oolithique comprenant les genres *Fronicularia*, *Flabellina*, *Nodosaria*, *Dentalina*, etc. de la zone à *Ammonites Parkinsoni* de Fontoy (Moselle). *Mémoires de l'Académie Impériale de Metz*, 51: 299–380.

- Terquem, O. and Berthelin, G., 1875. Étude microscopique des marnes du Lias moyen d'Essey-lès-Nancy, zone inférieure de l'assise à *Ammonites margaritatus*. Mémoires de la Société Géologique de France (2e série), 10 (3), 1–126.
- Tintant, H., 1987. Les nautilus du Jurassique d'Arabie Saoudite: In: R. Enay (Ed.), Geobios, Lyons, Memoir Speciale, 9, 67–159.
- Tyszk, J. and Kaminski, M. A., 1995. Factors controlling the distribution of agglutinated foraminifera in Aalenian–Bajocian dysoxic facies (Pieniny Klippen Belt, Poland). Grzybowski Foundation Special Publication, 3, 271–291.
- Tyszk, J., 1994. Response of Middle Jurassic benthic foraminiferal morphogroups to dysoxic/anoxic conditions in the Pieniny Klippen Basin, Polish Carpathians. Palaeogeography, Palaeoclimatology, Palaeoecology, 110, 55–81.
- Vaslet, D., 1987. Géologie du Paléozoïque; Permien supérieur, Tias, Jurassique; lithostratigraphie. Livre 1. In: Histoire géologique de la bordure occidentale de la plate-forme Arabe du Paléozoïque inférieur au Jurassique Supérieur: Thèse d'état, University of Paris VI, Paris, France, 413 pp.
- Vaslet, D., Delfour, J. Manivit, J. Le Nindre, Y.-M. Brosse, J.-M. and Fourniquet, J., 1983. Geologic map of the Wadi ar Rayn quadrangle sheet 23H, Kingdom of Saudi Arabia (with text). Saudi Arabian Deputy Ministry Mineral Resources, Geoscience Map GM-63, scale 1:250,000.
- Vaslet, D., Al-Muallem, M. S., Maddah, S. S., Brosse, J.-M., Fourniquet, J., Breton, J.-P., and Le Nindre, Y.-M., 1991. Explanatory notes to the geologic map of the Ar Riyad quadrangle, Sheet 24 I, Kingdom of Saudi Arabia, 25 p.
- Ziegler, M. A., 2001. Late Permian to Holocene paleofacies evolution of the Arabian Plate and its hydrocarbon occurrences. GeoArabia, 6 (3), 445–504.

Vitae

Name	:Ali Hussain Bu Khamsin
Nationality	:Saudi
Date of Birth	:12/4/1985
Email	:ali.bukhamsin@gmail.com
Address	:Saudi Aramco. P.O.Box 10834, Dhahran, 31311
Academic Background	:BSs in Geology from KFUPM

Ali is a micropaleontologist with Geological Operations Department in Saudi Aramco. He has been focusing on applied biostratigraphy in Oil and Gas Exploration and Development. In 2016, he attended a workshop on Agglutinated Foraminifera in Micropress Europe - AGH University in Kraków, Poland. In 2017 and 2019, he attended the International School on Foraminifera in Urbino - Italy where Micropaleontologists from around the world meet to study and share their expertise on Foraminifera. Since 2019, Ali has concentrated on Jurassic foraminifera of Saudi Arabia. In his MSc., he worked on the taxonomy of Bajocian benthic foraminifera and reported 63 species from lower Dhurma Formation and discovered 10 new species of benthic foraminifera from Central region of Saudi Arabia.

Publication:

- Conference publication:

Impact of WITSML Data Surveillance on Shallow Casing Points. *By Khudiri, Musab M, James, John A, Gadri, Waleed I, **Bu Khamsin, Ali H**, Sanie, Faisal S, Miyajan, Ramzi A, Abbas, Mazin Y, Kashif, Muhammad, and Tony Jovin*

(Presented in: SPE Middle East Intelligent Energy Conference and Exhibition, Manama, Bahrain, 2013)

- Journal publications:

Detrital dolomite: Characterization and characteristics. *By: Omar Atef Radwan, **Bu Khamsin, Ali H** and Khalid Al-Ramadan*

(Journal: Geological Quarterly, January 2018)

Benthic foraminiferal assemblages from maximum flooding surface J30, Middle Jurassic Dhurma Formation, Central Saudi Arabia. *By: Michael A. Kaminski, Abduljamiu O. Amao, Lamidi O. Babalola, Ramona Balc, Septriandi A. Chan, Hafiz M. Gull, **Bu Khamsin, Ali H** and Muhammad H. Malik.*

(Journal: Stratigraphy, November 2020)

Substrate temperature as a primary control on meiofaunal populations in the intertidal zone: A dead zone attributed to elevated summer temperatures in eastern Bahrain. *By: Michael A. Kaminski, Abduljamiu Amao, Lamidi Babalola, **Bu Khamsin, Ali H**, Flavia Fiorini, Andrea M. Garrison, Hafiz M. Gull, Robert L. Johnson, Bassam Tawabini, Fabrizio Frontalini, Thomas F. Garrison*

(Journal: Regional Studies in Marine Science, January 2021)