

# Microfacial Study, Fossil Assemblages and Depositional Environment of Wadi As Sir Limestone Formation, Jordan

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## Abstract

This paper studies the microfacies, fossil contents, and the depositional environment of Wadi As Sir Limestone Formation exposed in the Al-tayyar area Zarqa Governorate, Northeastern Jordan. A total number of 35 samples were collected from a 30 m thick quarry section and used to prepare 35 thin sections. Some samples were washed over a 63  $\mu\text{m}$  sieve, oven-dried at 50°C, sieved, and picked for benthic foraminifera analysis. Microscope analysis used to describe the microfacies and fossil contents. Four microfacies types and four lithological units are distinguished and described from the bottom to the top; the chalky unit (Unit-1) composed of bioclastic wackestone and biomicrite microfacies, and the dolomitic unit (Unit-2) immediately is existed above unit 1 composed dominantly of bioclastic mudstone and biomicrite microfacies. Marly limestone (Unit-3) is the following upwardly unit composed of bioclastic packstone and biosparite Microfacies, and the uppermost unit is limestone (Unit-4) consisted of bioclastic grainstone and biosparite microfacies. The fossil contents that were recognized in the studied thin sections and samples; bivalves, gastropods, pelecypods, cephalopods echinoderms, radiolarian, stromatoporoids, bone fragments, *Saccaminopsis* sp., *Cibicoides* sp., *Cibicides* sp., *Cyclamina* sp., calcareous algae (*Koninckopora* and *gymnocodiaceans*), worm tubes, serpulids, and plentiful ostracods. The current study indicates that the Wadi As Sir Limestone Formation has deposited in a restricted circulation shallow shelf with low energy conditions most probably lagoonal environment.

## Keywords

Microfacies, Fossils, Depositional Environment, Wadi as Sir Limestone Formation, Jordan

## 1. Introduction

In Mesozoic times Jordan was standing at the southern margin of the Tethys Ocean. Sedimentation was controlled by the configuration of the Tethys to the north and north-west and the movement of the Arabia-Nubian shield and its cover-rocks in the south [1]. During the late Albian to Turonian times, the study area was part of a broad shallow carbonate platform situated on the passive margin of the Arabian Plate [1]. The Jordanian shelf was part of the Levant Platform which extended from Syria in the northeast to Egypt in the southwest. The late Cenomanian paleo-coastline ranged from southeast Jordan to present-day northwest Saudi Arabia [2].

The Late Cretaceous, Ajlun Group is probably Cenomanian to Turonian in age [1] consists of five formations from base to top composed of; Na'ur, Fuheis, Hummar, Shueib, and Wadi As Sir Limestone Formations [3]. The group composed exclusively of carbonate rocks except in the extreme southern part of the country where detrital rocks make up a great part of the sequence.

Wadi As Sir Formation in NW of Amman was deposited in the lagoonal environments except towards the end of the period where open shelf conditions prevailed [4]. The formation in SE of Ras En Naqab to Zakimat Al-Hasah is deposited on a wide shallow carbonate platform [1] in Azraq basin the Wadi as Sir Formation was deposited in a shallow marine environment except for the lower part which is deposited in outer open marine shelf [5].

The carbonate rocks can be divided based on mineralogy into limestone and dolostone. Two of the most widely used classifications for carbonate rocks are those of [6] [7] [8]. Both classifications subdivide limestone primarily based on their matrix content and their major component grains. The term microfacies type developed to reflect the depositional and ecological conditions in a certain sedimentary environment [9]. Microfacies analysis is an important tool to determine the relative sea-level changes in carbonates and associated non-clastic [10] [11].

In common the previous studies performed in Jordan left the significance of joining the microfacies and fossil contents into the environmental interpretation. The main objective of this study is to determine the depositional paleoenvironment of the study area (**Figure 1**) based on microfacies analysis and fossil contents.

## 2. Geological Setting

The overlying Ajlun Group contains largely of shallow marine carbonates deposited on a rimmed-shelf [12]. The group interfingers with marine and fluvial siliciclastic to the south and east and passes into basinal facies to the northwest [13].

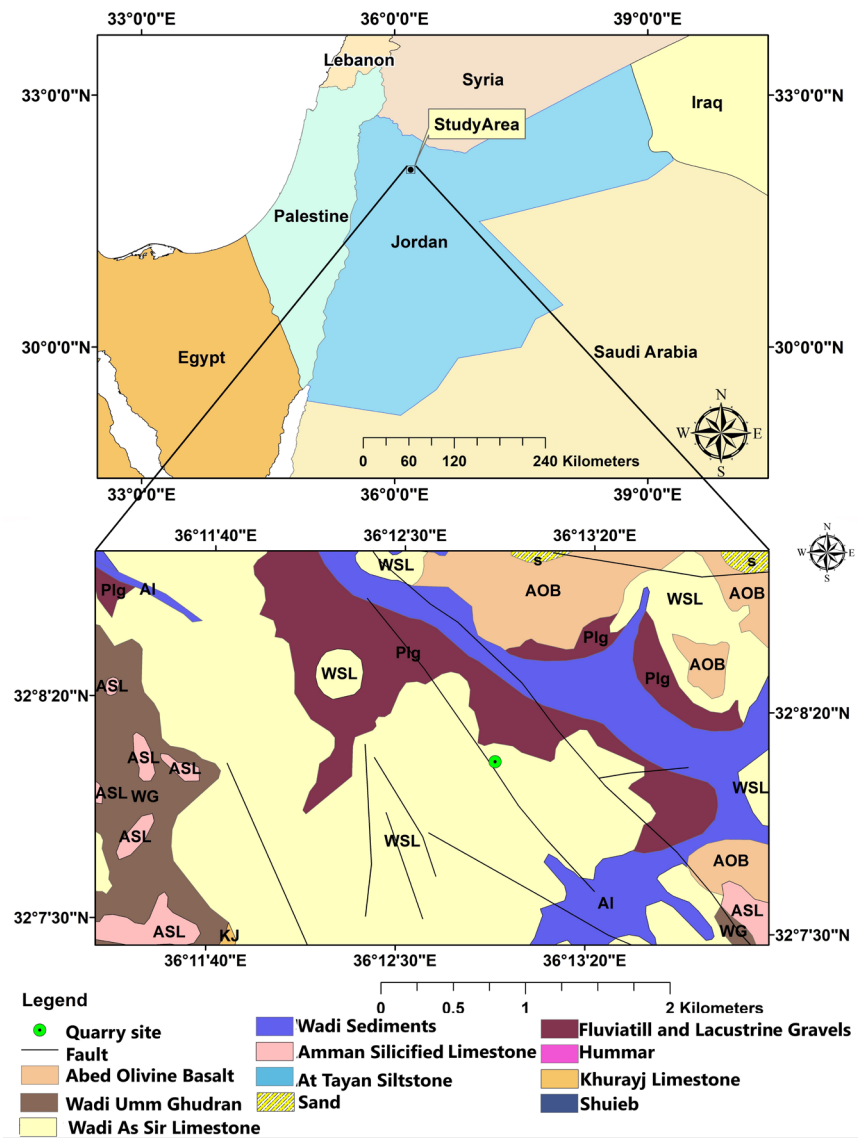
Based on [3] the thickness of Ajlun Group formations increases from about 100 m in the south to more than 600 m in the north of the country. The group is rich in well-preserved body fossils, such as bivalves, cephalopods, echinoderms,

and gastropods. The microfossils foraminifera, ostracodes, and serpulids are also common. Lithologically it consists of alternating limestones and dolostone, chalky, and some soft, interbedded yellowish-greenish marls to marly limestones.

These intercalations are used for subdividing the group into the following formations according to [3].

**Na'ur Formation:** It is an Early Cenomanian in age, its base consists of alternating marl and limestone, followed by gray hard marl interbedded with thin layers of marly limestone. The top of the Naur Formation is marked by light gray to dark gray thick-bedded limestone and pink at the base.

**Fuheis Formation:** It is Cenomanian in age, the dominant lithology is the yellowish-brown marly limestone followed by olive green to yellowish-brown marl and chalk at the top. It is well exposed in Amman along Na'ur-Jerash road, Suweileh-Jerash and suweileh-Fuheis highway and Ajlun area.



**Figure 1.** Location map of the study area.

**Hummar Formation:** It is an Upper Cenomanian in age and consists of light to dark gray-colored, hard dense dolomitic, highly fractured and fossiliferous limestone. The type locality is near Hummar 15 km NW Amman and at several other localities.

**Shueib Formation:** It is probably Cenomanian in age and consists mainly of Fossiliferous which contains chalky limestone and yellow to olive green marl and rarely dolomitic.

**Wadi As Sir Formation:** It is of Turonian age and consists of very light gray colored and bedded limestone, thin marl beds and chalky limestone, with medium, hard to very hard and occasionally dolomitized at the base with cherty nodules at the top.

### 3. Materials and Methods

Al-tayyar area is situated 2.3 km northeast of Hashemite University and 500 meters east of Zarqa-Mafraq main streets leading from the capital to Al-Mafraq Governorate. A Quarry with coordinates (32°8'0"N, 36°13'0"E) has 30 m thick carbonate rocks is the section from which the samples were taken (**Figure 1**).

Samples representing Wadi As Sir Formation have been collected at about 1.0 m intervals. Microfacies and paleontologic analysis of the samples were performed on thirty-five thin sections obtained from a total of thirty samples. Thin sections were examined with Alizarin-Red-S' before and after the staining. The microfacies analysis is based on semiquantitative component analysis and the guidelines classification of carbonate rocks [6] [8]. In contrast, when possessing little matrix, the two classifications called the rock rich in carbonate mud a micrite, and [6] considered it as a sparite. Rock rich in carbonate mud is referred to as mudstone or wackestone, and is called a grainstone or packstone if it contains a small matrix by classification [8]. A detailed analysis of microfacies and fossil contents were used for the paleoenvironmental interpretations in the present study and based on previous studies such as [10] [14] [15].

Samples for benthic foraminifera analysis were washed over a 63 µm sieve and were oven-dried at 50°C. After further drying the samples were sieved using a set of sieves then foraminiferas were picked under a binocular microscope from a known fraction. The taxonomy of benthic foraminifera in this article was based on the work by [16].

A scanning electron microscope was used to observe surface abnormalities in benthic foraminiferal tests that noted in thin section analysis. Thin sections labeled s-mf1-35 used for this work are stored at the Department of Applied Earth and Environmental Sciences, Al al-Bayt University, Jordan.

## 4. Wadi as Sir Limestone Formation

### 4.1. Geology

#### 4.1.1. Boundaries

The base of this formation is marked by the change from marly limestone to do-

lomitic limestone of the lower part of Wadi As Sir Limestone Formation and the top of this formation is noticeable by the change from gray, hard, medium to thick-bedded of limestone.

#### 4.1.2. Distribution, Morphology

Wadi As Sir Limestone Formation shows a variation in lithology from North to South and along the Rift, However, it is widely exposed in Jordan [1].

#### 4.1.3. Thickness

The thickness in north Jordan ranges from 80 - 200 m [1] [17], while the thickness in South Jordan ranges from 15 - 16 m [18].

#### 4.1.4. Lithology and Bedform

The Lithology of this formation consists of massive limestone, dolomitic limestone, chalky limestone, marly limestone and associated with thinly chert nodules.

### 4.2. Fauna and Age

Wadi As Sir Limestone Formation is highly fossiliferous and rich in echinoids and fragmented shells [19]. Macrofossils assemblages include bivalves, gastropods, pelecypods, cephalopoda and echinoderms. The foraminiferal species include; *Haplophragmoides gracilis*, *Ammomarginuluna aburoashensis*, and *ammobaculites turonicus* (Said & Kenawy), *Flabellamina aegyptia* (Omara), *Praebulimia prolixa* (Cushman & Parker), *Discorbis minutus*, *Nonion beadnelli*, and *Gavelinopsis pseudobaccata* (Said & Barakat), *Heterohelix globulosa* (Ehrenberg), *Hedbergella delrioensis* (Carsey), *Helvetoglobotruncana praealpina* (Trujillo) [20]. The Wadi as Sir Limestone Formation is Turonian in age based on foraminiferas and ostracods [21] [22].

## 5. Results and Discussion

### 5.1. Lithostratigraphy of the Studied Section

Wadi As Sir Limestone Formation covers the Al-tayyar area and the entire section of the study area comprised of 30 m thick. Wadi As Sir Limestone Formation significantly exposed in the area of study, and it consists of ten layers in the area of study from bottom to top (Table 1).

The lithological units beginning with the Chalky unit, defined by calcite-filled vugs and fractures with white to creamy color and 7.70 m thick which is about 25.6% of the section's entire thickness.

The section's second unit is the dolomite unit that consists of alternating dolomitic limestone with yellowish, white to a gray color and is 9.90 m thick which is about 33% of the section. The third unit of the section consists of a 7.60 m thick marl unit, which is about 25.3% of the section. The last top part of the section in the study area is the limestone unit with white partly dirty color and about 16% of the section's entire thickness is 4.80 m thick.

**Table 1.** Description of the lithological units in the study area.

Unit (bottom)	Bed No.	Description	Thickness (m)
Chalky unit	1	Chalky limestone, creamy color, partly stained with rosy color, vugs and fractures filled with calcite, laying with some nodules of chert black to brownish color, chemical originally, very hard.	4.10
	2	Chalky limestone, white color, partly with fractures filled calcite, jointed, partly with trace of bivalve's fossils as casts, soft to medium.	3.60
	3	Dolomitic limestone, gray to whitish color, with vugs filled with calcite (around 0.5 cm) formed as secondary phased, stained surface with rosy color.	3.35
Dolomitic unit	4	Dolomitic limestone, yellowish color, Medium to hard, with chert nodules, dark brown, very hard.	1.85
	5	Dolomitic limestone, white color, with black stained color and vugs, jointed, hard.	1.90
	6	Dolomitic limestone, light gray to beige color, conchoid fractures, hard, with laminated alteration of dark brown and reddish color (less than 1 cm)	2.80
Marl unit	7	Marly limestone, red color to brownish, hard to medium, fine grains.	1.95
	8	Marly limestone, yellowish color, soft to medium, fractures filled with calcite.	2.75
	9	Marly Limestone, pink color, fine grained, soft.	2.90
Limestone unit	10	Limestone, white partly dirty color, rich with calcite, and concretions (less 5 cm), hard.	4.80

## 5.2. Microfacies Analysis of Studied Section

Thirty-five thin sections are representing Wadi As Sir Formation selected for analysis of the microfacies in the studied area.

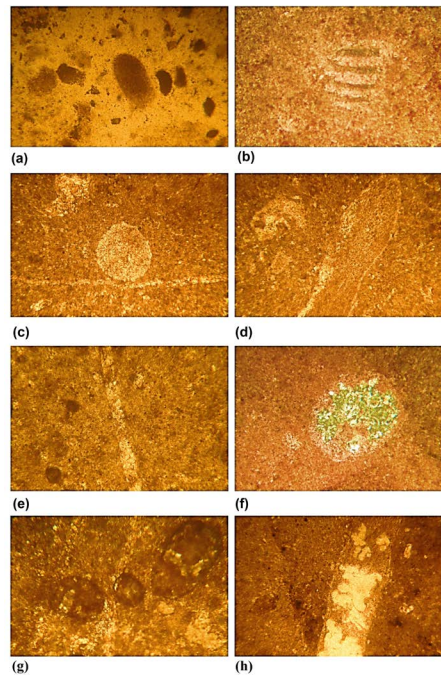
Thin sections were examined with Alizarin-Red-S' before and after the staining [6] [8] carbonate rock classification used to classify the rocks examined.

### MF1: Bioclastic Wackestone, Biomicrite Microfacies.

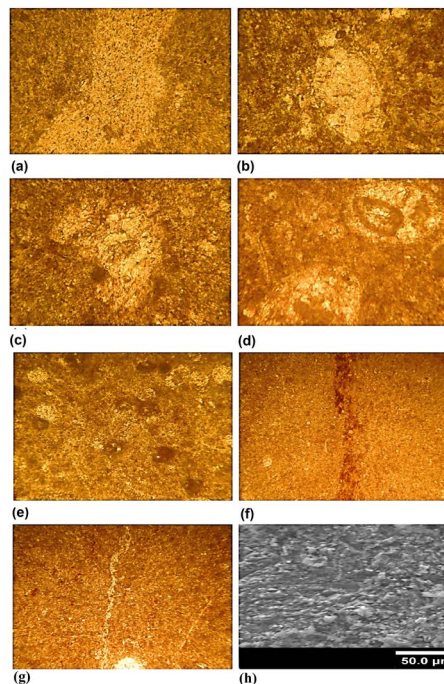
These microfacies represent the chalky unit consisting of chalky limestone alternation. The microfacies are composed of grains (30%) contained in a micritic ground layer. The heterogeneous matrix is mainly made by micrite with less microsparite.

Bioclasts are loose pellet mud grains; (Figure 2(a)), sediment-filled gastropod shells; (Figure 2(b)), echinoderms; (Figure 2(c)), pelecypods; (Figure 2(d) & Figure 2(e)). Silica-filled radiolarian shells; (Figure 2(f)). Cortoids grains; (Figure 2(g)), large bone fragment bioclasts; (Figure 2(h)), rudist fragment; (Figure 3(a)), foraminiferas are present; (*Saccaminopsis* sp); (Figure 3(b)), and deformed foraminifera's chambers; (Figure 3(c) & Figure 3(d)), other common allochems are peloids; (Figure 3(e)).

The foraminifera are often fully micritized and their shell partially damaged and can be barely distinguished from peloids that make up (15%) of the rock as vugs, they are mostly spherical and oval, sorted and range from (0.1 to 0.2 mm).



**Figure 2.** (a) Loose grains from the pellet muds, wackestone, 4X; (b) Gastropods shells, wackestone, 10X, XPL; (c) Echinoderms, wackestone 4X; (d) Pelecypod, wackestone, 4X; (e) Pelecypods, peloids, wackestone, 10X; (f) Radiolarian rich limestone composed of silica, wackestone, 4X, XPL.; (g) Foraminifera's, cortoids grains, wackestone, 10X; (h) Large bone bioclasts, wackestone 4X;



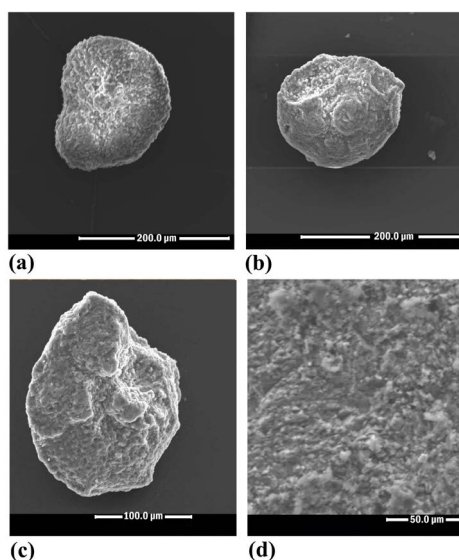
**Figure 3.** (a) Rudist fragment, wackestone, 10; (b) Foraminifera's (*Saccaminopsis* sp.), wackestone, 10X; (c) Deformed foraminifera shell, wackestone, 10X, XPL; (d) Foraminifera, wackestone, 10X.; (e) Peloids, wackestone, 10X; (f) Fractures filled with iron, wackestone, 4X; (g) Fractures filled with calcite, wackestone, 4X; (h) Wackestone microfacies types, SEM image, 50.0  $\mu\text{m}$ .

The fracture is filled with iron oxides and calcite; (**Figure 3(e)** & **Figure 3(f)** & **Figure 3(g)**) and the impact of diagenesis processes well illustrated by micritization, inversion, compaction, and dolomitization; SEM image of the types of Wackestone Microfacies (**Figure 3(h)**).

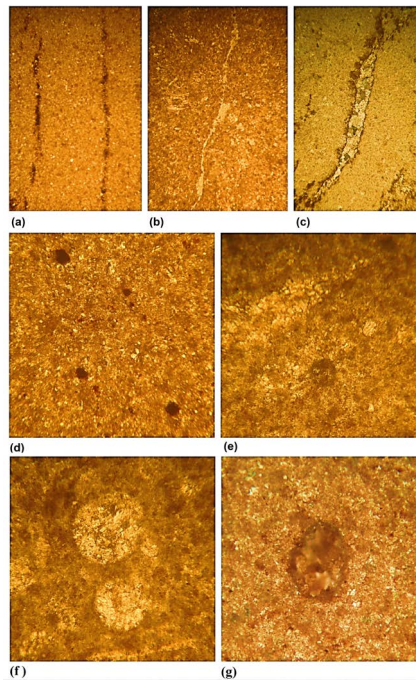
Some benthic foraminifera species scanned by scanning electron microscope to observe the deformed tests of their surface abnormalities which noted in thin section analysis; (**Figure 4(a)** & **Figure 4(b)** & **Figure 4(c)**), and Wackestone microfacies types; (**Figure 4(d)**).

#### MF2: Bioclastic mudstone, Biomicrite Microfacies.

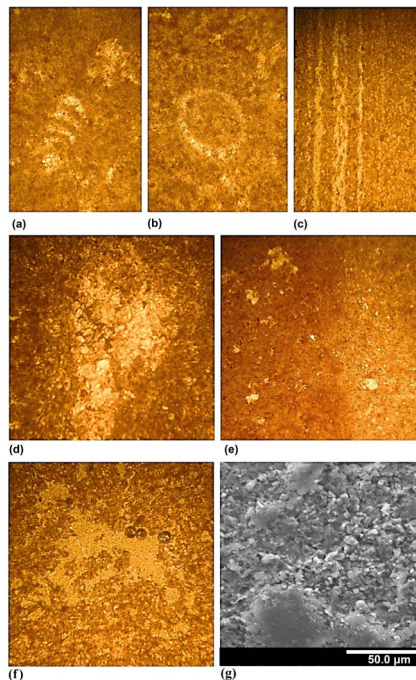
Such microfacies represent a dolomitic unit that consists of alternating calcareous dolomitic. The matrix was bioturbated and mostly composed of micrite (supported by mud); Mudstone containing grains of less than 10%. Iron oxide, calcite cements, and calcite cement post-dolomitization filled cracks and pores; (**Figure 5(a)** & **Figure 5(b)** & **Figure 5(c)**). The allochem assembly consists of some peloids, usually, the result of indurated carbonate mud erosion and abrasion, which are spherical in form and small size; (**Figure 5(d)** & **Figure 5(e)**). The bioclasts embedded in a micrite matrix consisting of cephalopods; (**Figure 5(f)**), benthic foraminifera; (**Figure 5(g)**). Mollusks shell; (**Figure 6(a)**), fragmented shell, and other Calcareous Algae (*Gymnocodiaceans*) allochem assembly; (**Figure 6(b)**). Lamination is a common feature in the lower beds of these microfacies, these hundreds of micron to about two millimeters thick laminates produced by the concentration of fossils parallel to the bedding planes; (**Figure 6(c)**). Completely dolomitized foraminifera; (**Figure 6(d)** & **Figure 6(e)**) and textures of the fine dolomite grains are found; (**Figure 6(f)**). The fossils are not well preserved due to compaction and the micritization process; SEM image of types of Mudstone Microfacies (**Figure 6(g)**).



**Figure 4.** Scanning electron microscope photographs showing the benthic foraminifera species and deformed tests; (a) *Cibicoides* sp., 800x; (b) *Cibicides* sp., 800x; (c) *Cyclammina* sp., 1000x; (d) Wackestone microfacies types, SEM image, 1400x, 50.0 µm.



**Figure 5.** (a) Iron oxides filled the fractures, mudstone, 4X; (b) Fractures filled with calcite, peloids, mudstone, 4X; (c) Fractures has been filled with a post dolomitization calcite cement. Mudstone, 4X, XPL; (d) Some of dark peloids, mudstone, 10X; (e) Peloids, mudstone, 10X.; (f) Cephalopods, bioclasts, mudstone, 10X; (g) Foraminiferas, mudstone, 10X, XPL

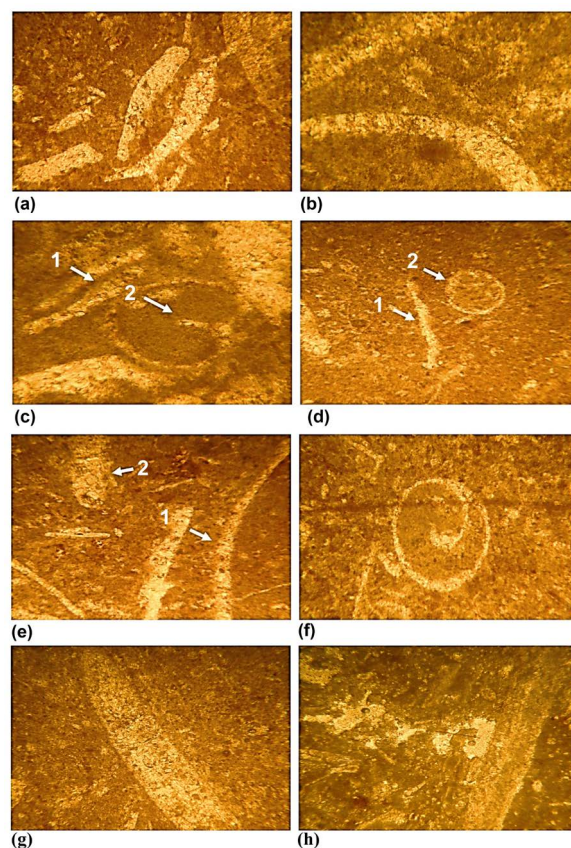


**Figure 6.** (a) Mollusks shell, mudstone, 10X; (b) Calcareous algae (*Gymnocoliaceans*), mudstone, 10X; (c) Laminae which are hundreds of micron to about two millimeters thick, mudstone, 4X, XPL; (d) Foraminiferas completely dolomitized, mudstone, 10X; (e) Completely dolomitization, mudstone, 4X.; (f) Dolomite fine grains textures, peloids, mudstone, 10X; (g) Mudstone microfacies types, SEM image, 50.0  $\mu\text{m}$ .

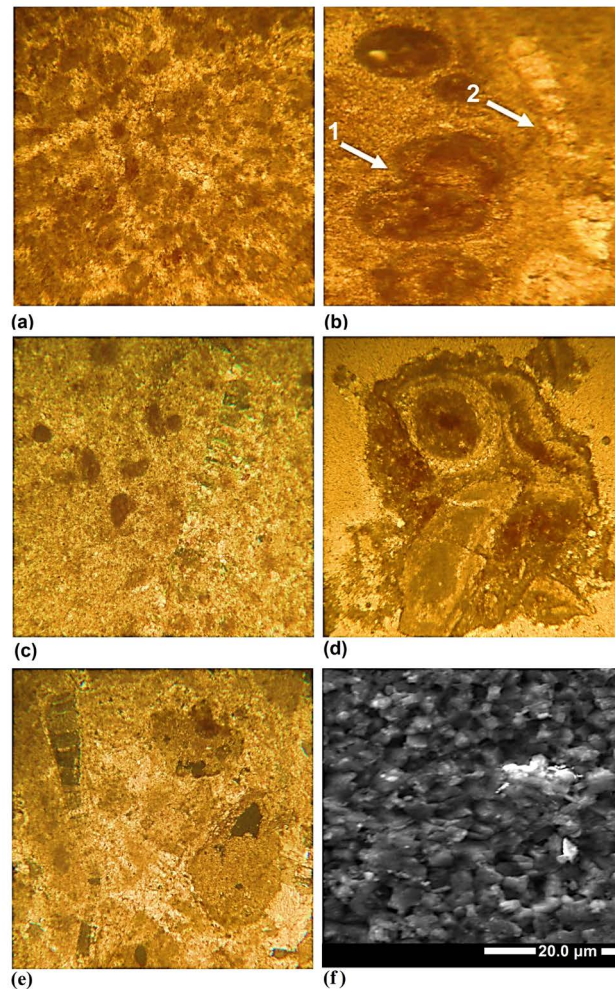
### MF3: Bioclastic packestone, Biosparite Microfacies.

Such microfacies represent a unit of marls. The calcareous matrix is composed of heterogeneously strongly bioturbated micrite, micro sparite, and less sparry calcite. Bioclast content (50%), consists of two curved bivalve shells containing calcite; (Figure 7(a)), thick bivalves are most common in these microfacies; (Figure 7(b) & Figure 7(c-1) & Figure 7(d-1) & Figure 7(e-1)), gastropods are composed of aragonite; Figure 7(c-2) & Figure 7(f)); crinoid elements-echinoderms embedded in sparry calcite; large micrite-embedded pelecypods; Figure 7(d-2) and (Figure 7(g)). Prismatic brachiopods layer; (Figure 7(h)), stromatoporoids; (Figure 8(a)), and some cortoid grains; (Figure 8(b-1)); shell fragments of molluscs; (Figure 8(b-2)). Calcareous algae (*Koninckopora*); (Figure 8(c)), intraclast aggregate grain variety; (Figure 8(d)), shell fragments of molluscs; (Figure 8(e)).

The result of the diagenesis cycle well reflected by micritization, dolomitization and some parts of them are dissolved and recrystallized to sparry calcite. SEM image of the Packestone Microfacies types (Figure 8(f)).



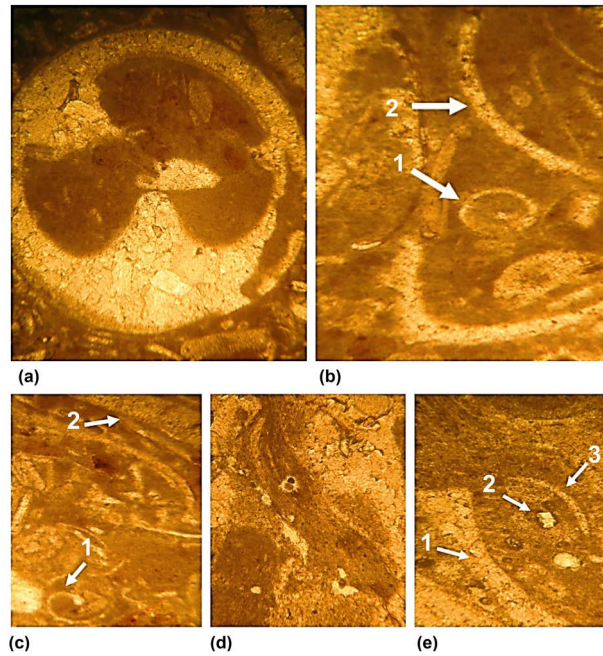
**Figure 7.** (a) Two curved Bivalve shells composed of calcite, packestone, 4X; (b) Thick Bivalves, packestone, 10X; (c) Bivalve's shells (1), gastropods (2), bioclastic, packestone, 10X; (d) Bivalves shells (1), echinoderms in the right side of the picture (2), and peloids, packestone, 4X. (e) Bivalves shells (1), Pelecypods (2), packestone.; (f) Gastropods composed of Aragonite, packestone, 4X.; (g) Large pelecypods embedding in micrite, packestone, 4; (h) Prismatic brachiopods, bioclasts, packestone, 4X, XP.



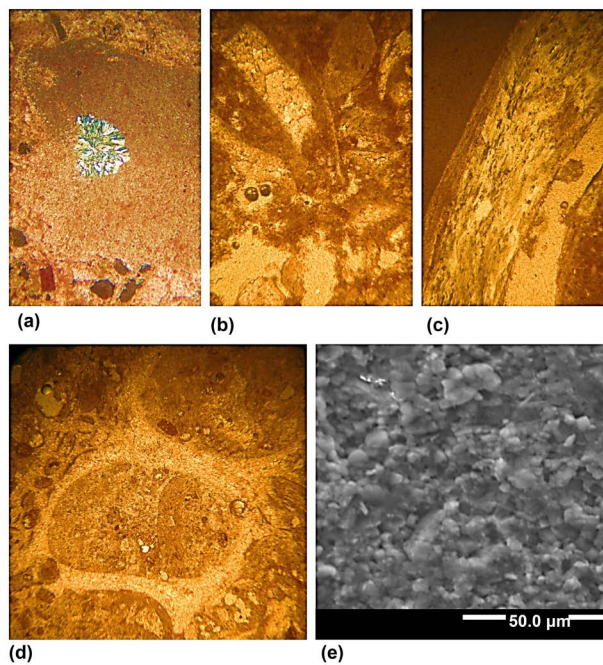
**Figure 8.** (a) Stromatoporoids, packestone, 10X; (b) Biomicrite with planktonic foraminifera's, cortoids grains (1), Mollusca shell fragment (2), Packestone, 4X.; (c) Calcareous algae (*Koninckopora*), peloids, packestone, 10X, XPL; (d) Aggregate grains variety of an intraclasts, packestone, 4X; (e) Mollusca shell fragment, bioclastic, packestone, 4X, XPL; (f) Packestone microfacies types, SEM image, 20.0  $\mu\text{m}$ .

#### MF4: Bioclastic Grainstone, Biosparite Microfacies.

These microfacies depict the limestone unit in some thin sections, the layer composed of about 90% grains embedded in a matrix of neomorphic sparite and microsparite as well as micrite. The bioclastic content consists of thick-shelled Gastropods which replaced the original aragonite shell with blocky calcite; (Figure 9(a) & Figure 9(b-1)), and (Figure 9(c-1)). Bivalves; (Figure 9(b-2)). Worm tubes serpulids; (Figure 9(d)), pelecypods; (Figure 9(c-2)), and plentiful ostracods; (Figure 9(e-2)). Some quartz grains have identified; (Figure 10(a)), the elements of some crinoids (Figure 9(e-1)), and; (Figure 10(b)). Bivalve shell (Oyster) two layers, with a dense, inner layer of calcite and a thinner, outer aragonite layer; (Figure 10(c)). In these microfacies, large amounts of gastropod distinguished; (Figure 10(d)). This microfacies consists of mostly broken angular to rounded skeletons.



**Figure 9.** (a) Big Gastropods mollusks, bioclastic, grainstone, 4X; (b) Gastropods (1), bivalves (2), grainstone, 4X; (c) Gastropods (1), pelecypods (2), bioclastic, grainstone, 4X; (d) Serpulids worm tubes, bioclasts, grainstone, 4X; (e) Biomicrite with foraminiferas, cortoids grains (2), ostracods valves (3), echinoderms (1), grainstone, 4X.



**Figure 10.** (a) Quartz grains, grainstone, 4X, XPL; (b) Crinoids elements-echinoderms, bioclasts, grainstone, 4X; (c) Bivalves shells (Oyster), grainstone, 4X; (d) Large shells of gastropods, grainstone, 4X; (e) Grainstone microfacies types, SEM image, 50.0 µm.

Microfacies analysis in comparison with other previous studies [4] recorded the following types of microfacies which are compatible with the present study

results; Globigerinid mudstones, bioclastic grainstone, miliolid packestone, peloidal packestone, and pure mudstone. And corresponded with [23] results; Benthic Foraminifera-peloidal-bioclastic wackestone, Benthic foraminifera peloidal-bioclastic mudstone/wackestone, Mollusks-bioclastic wackestone/ packestone, Echinoderm-peloidal-bioclastic wackestone, Peloidal-planktonic foraminifera-bioclastic wackestone/packestone, Bioclastic wackestone, Benthic foraminifera bioclastic wackestone, Peloidal-bioclastic wackestone/packestone, Peloidal-bioclastic mudstone/wackestone, and Benthic foraminifera mudstone.

### 5.3. Depositional Environments

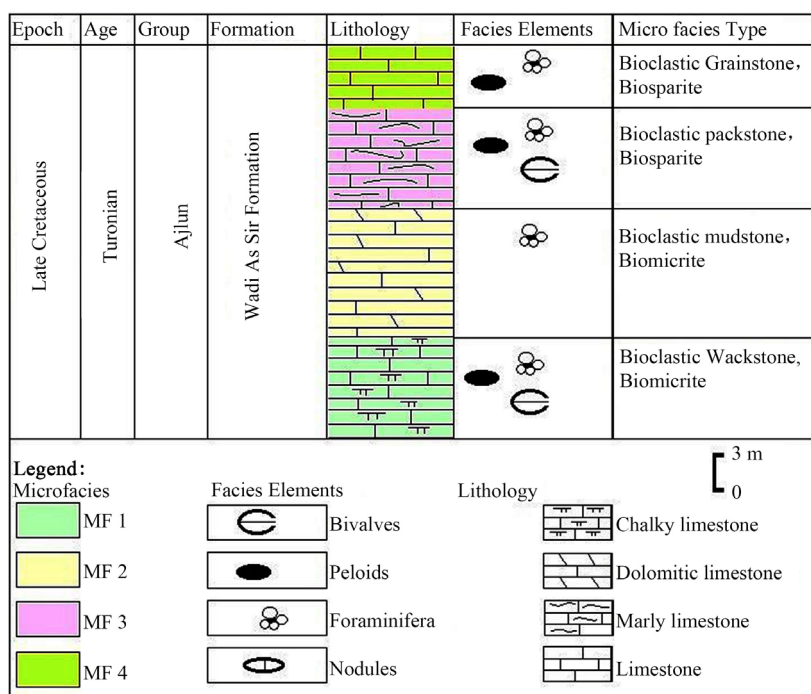
Microfacies analysis of the Turonian succession in the study area (Wadi As Sir Limestone Formation) led to the recognition of four types of microfacies, namely the Bioclastic Wackestone-Biomicroite, Bioclastic Mudstone-Biomicroite, Bioclastic Packestone-Biosparite, and Bioclastic Grainstone-Biosparite (Figure 11) that change laterally as well as vertically. Based on the grain composition (mainly fossil types) and the content of the matrix. Paleoenvironmental interpretation of each microfacies as follows;

Starting with the base of Wadi As Sir Limestone Formation (in the study area), the lowermost 7.7 m thickness consists of Bioclastic Wackestone microfacies, including bivalves, gastropods, echinoderms, pelecypods, peloids, and fossil ostracodes. Wackestone facies, stromatolites, rudist fragments, and other fossils suggest deposition under low energy conditions, salinity, as well as oxygenation, are subject to highly variable, restricted circulation shelves, most likely lagoon environments. The lagoon is a shallow coastal water body separated from the ocean by a barrier, intermittently connected to an ocean exchange by one or more restricted inlets, usually oriented parallel-shore [24]. In general, relatively shallow environments are approximately 50 meters deep and moderate in water energy, temperature, and salinity.

Bioclastic packestone microfacies found in the third part of the section with a thickness of 7.6 m. This type of microfacies is widespread in the Middle East in strata of different geological ages [25], and the type of fossils in this facies suggest that deposition was in shallow, warm, and restricted environments.

The top of the section was a microfacies of Bioclastic grainstone, 4.8 m thick, consisting mainly of fossils, suggesting that it is a result of relatively high energy environments. Current activity is responsible for reworking the underlying sediments, and for creating new grains of sediments.

The findings in the present study identified various types of Microfacies, such variations represent a shift in the environmental deposition. Several variables influence the sedimentary environment as a whole, such as water energy, depth, temperature, and salinity. The Wadi as Sir Limestone Formation deposited in shallow shelf environments-back reef (lagoon), moderate saline, and varying energy levels based on the present study [26]. This may mean that a sea level fluctuation during the period of deposition was possibly causing upliftment and subsidence.



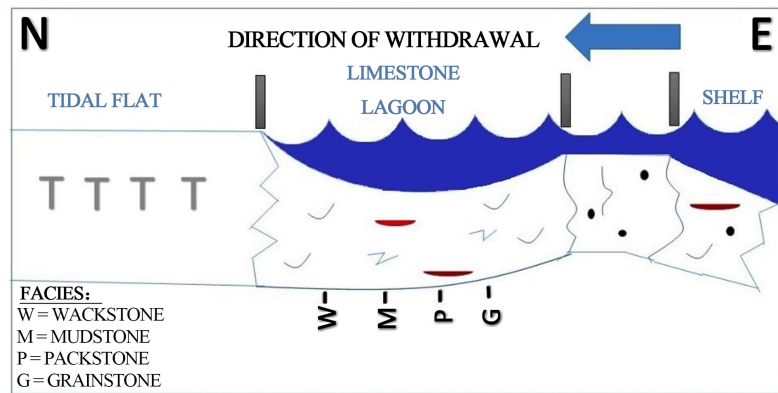
**Figure 11.** Lithological columnar section of the area of study including the types of microfacies.

The second part of the section in Wadi As Sir Limestone Formation was a bioclastic mudstone microfacies with a thickness of 9.9 m, it indicates deposition in shallow water environments, and a large amount of micrite suggested deposition in low energy conditions and restricted circulation.

Depositional models usually derived from sedimentary environments and can be used for comparison with other ecosystems or systems. Vertical and lateral microfacies and fossil changes in the study area indicated the initiation of the deposition of Wadi as Sir Limestone Formation in the lagoon environment as a consequence of the withdrawal of the sea from the northern part of the study area and its retreat from the east; (Figure 12).

This assumption confirmed by the existence of peloid, microfossils, gastropods, bivalves, pelecypods, echinoderms, and ostracods. Peloids in some varieties of microfacies indicate a shift from low to high energy environments [27]. The lateral distribution of depositional facies relies on the depositional setting, whereas their vertical piling determined by the fluctuation of the sea level, shown in the stratigraphic sequence [28].

The variability of microfacies types in the study area correlated with previous studies showing that the Tethys Ocean has spread and filled both of these areas. The paleodepositional environment in the present study is in accordance with [4] who proposed that the Wadi as Sir Formation (Upper Cretaceous) depositional environment was lagoonal but towards the end of the period in which open shelf conditions prevailed. Correspond to [5] who suggested that the depositional environment of Wadi as Sir Formation was in a shallow marine environment except for the lower part deposited in the outer open sea shelf.



**Figure 12.** Depositional model of the study area, modified [23].

Ref. [1] [19] who proposed that the Wadi As Sir Formation deposited in shallow epicontinental seas and wide shallow carbonate platform. The aforementioned general interpretation may usually agree with, in the case that they used it on a basis for deposition in shallow neritic shelf seas on a platform.

## 6. Conclusions

- The four main microfacies types distinguished and described are; Bioclastic Wackestone-Biomicrite, Bioclastic Mudstone-Biomicrite, Bioclastic Packestone-Biosparite, and Bioclastic Grainstone-Biosparite.
- The recognized micro- and macrofossils in the present study are; Bivalves, Gastropods, Echinoderms, Pelecypods, Ostracods, Brachiopods, Cephalopods, Foraminifera, Radiolarian, Peloids, Serpulids worm tubes, Stromatoporoids, Calcareous algae, Cortoids grains, and Crinoid.
- Microfacies analysis indicated that the Wadi As Sir limestone formation was deposited dominantly in lagoonal environment occasionally influenced by shallow carbonate shelf.
- The study of benthic foraminiferal shells confirmed the presence of deformations or decalcification which hinders the process of accurately identifying them.
- Three matrix categories can be distinguished; Micrite, Microsparite, and Sparite.

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## Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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