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Microfacies Analysis and Depositional Environment of the Middle Eocene Avanah Formation in Haibat Sultan Area, Iraqi Kurdistan Region

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ABSTRACT

The Avanah Formation (Middle Eocene) was studied in the Haibat sultan section at Bina Bawi Anticline, Northeast of Erbil city within the Iraqi Kurdistan region. The field observation indicated that the formation occurs as Carbonate interbeds within the lower and middle parts of the Gercus Formation, which consists mainly of light yellowish to creamy color, well-bedded, marly, and dolomitic limestone with some intercalations of sandstones and marls reaching about 32 m thick characterized by lateral variations in facies and thicknesses. A petrographic study of 16 thin slices of carbonate rocks indicated that most of the matrix is composed of micrite, with a few microspars. Foraminifers, dasycladacean green alge, and Ostracods make up the skeleton grains. Non-skeletal grains mainly include peloids, intraclasts, and extraclasts. Depending on detailed microfacies analysis in the current study, five main microfacies and fourteen submicrofacies were discovered. The total of all petrographic, facies and textural investigations indicates that the Avanah Formation in the Haibat Sultan area was deposited in the shallow marine inner platform within subtidal, intertidal, and supratidal environments.

تحليل الكائنات الدقيقة وبيئة الترسيب لتكوين الأيوسين الأوسط أفانا في منطقة هيبة سلطان، إقليم كردستان العراق

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الملخص

تمت دراسة تكوين أفانا (الأيوسين الأوسط) طبقيًا، وتم تحليل بيئاتها الترسيبية في مقطع هيبه سلطان في طية بنا باوي، شمال شرق مدينة أربيل ضمن إقليم كردستان العراق. الملاحظة الميدانية تدل إلى أن التكوين يضهرعلى شكل طبقات كربونية فى الأجزاء السفلية والمتوسطة من تكوين جركس، والتي تتكون أساسًا من اللون الأصفر الفاتح إلى الكريمي، وحجر الجير المارلي والدولوميت مع بعض تداخلات الأحجار الرملية والمارل التي تصل سمكه إلى حوالي 32 مترًا، تتميز بالتغيرات الجانبية في السحنات و السماكه. أظهرت دراسة بتروغرافية على 15 شريحة رقيقة تدل بأن غالبيه صخور الكربوناتيه تتكون من ميكرايت مع قليل من مايكوسبارايت، تشكل. الفورامنيفيرا و الطحالب الخضراء و الأستراكوا تشكل الحبيات الهيكليه.والحبيبات الغيرهيكلية تشمل الدمالق والحبيبات الداخلية . والحبيبات الخارجية. اعتمادا على تحليل التفصيلي تبين خمس سحنات رئيسية واربعة عشرة سحنة ثانوية . الدراسة البتروغرافية والسحنات والنسيج اثبت بإن التكوين الافانة في منطقة هيبة سلطان قد ترسبت في بيئة بحرية ضحلة ضمن المصطبة الداخلية والتي تشمل البيئات تحت المدية وبين المدية وفوق المدية .

1. Introduction

The Avanah Formation was first described by [1] in Kirkuk well no.116 located on the Avanah dome at Low Folded Zone. The formation comprises 210 m thick limestone, generally dolomitized limestone, and recrystallized limestone of shoal facies with occasional beds of lagoonal dolomitized limestone. Laterally the Avanah Formation interfingers with Jaddala and Gercus formations. The age of the Avanah Formation at the type locality was suggested from the middle to late Eocene, depending on fossil assemblages [2-3] The formation was deposited in an along belt at the boundary of the Low Folded and High Folded Zones and is incredibly thick in the area of the Low Folded Zone of North Iraq [3] The records of sedimentary infill in the foreland basins interact between the thrust wedge development, isostatic adjustments of the cratonic lithosphere to thrust loading and additional bending moments, eustasy, and the surface processes redistribute sediments from the paleo-high into the surrounding basin [4] The abrupt change from the fluviatile facies of the Gercus Formation to the shoal facies of the Avanah Formation within the foreland basin is probably associated with the sea-level transgression and local tectonic block movement due to the lithospheric shortening adjustments throughout continental collision and closing of the Neo-Tethys Ocean. Uppermost Middle Eocene sediments represented by Gercus and Pila Spi formations usually overlie the Avanah Formation. The present study aims to clarify the lithostratigraphy, facie analysis and depositional environment of the Avanah Formation using field observations and petrographic investigations.

2. Location of the studied Area

The studied section is located in the northeast of Iraq, Erbil Governorate at the Haibat Sultan mountain, about three kilometers northeast of Koysnjaq district northeast of Iraq (Fig.1), with latitude (36^{o} 06' 40" N) and longitude (44^{o} 39' 21" E).

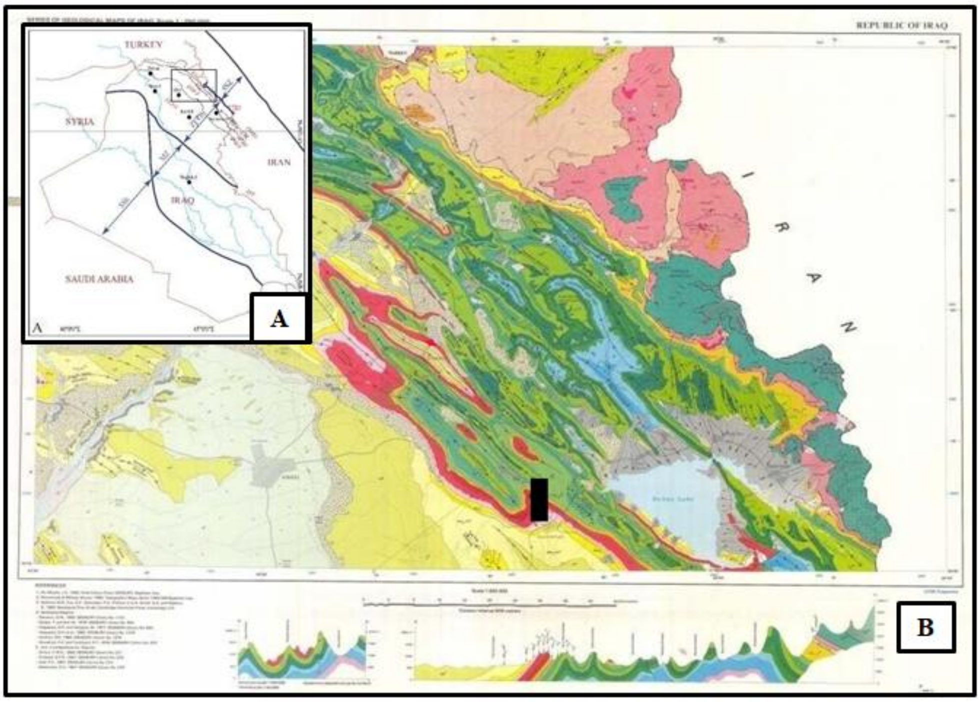

Fig. 1: Location Maps: (A) Tectonic map of Iraq showing the tectonic subdivision zones. (SSZ: Sanandaj-Sirjan Zone; ZFTB: Zagros Fold–Thrust Belt; MZ: Mesopotamian Zone; SSh: Stable Shelf (after [5-6- 7]), B- Geological map of northeast Iraq showing the location of studied section (Haibat Sultan).

3. Methods

The study methods were divided into two parts: fieldwork and laboratory work; the outcrop was measured and described, providing information on its lithology and sedimentology. The formations are visible, with close outcroppings along the ridges. The lithology of the Avanah Formation in the Haibat sultan section at Bina Bawi Anticline includes dolomitic limestone and marly limestone, as well as clastic with marls intercalations, which were sampled from the outcrops. Twenty-seven samples were collected from the area, and 16 thin-sectioned samples were equipped.

4. Geological Setting

The Avanah Formation is exposed as a belt in several areas of the High Folded Zone, especially near the border of the Low Folded Zone and commonly interbedding or intertonguing with Gercus and Jaddala formations. The formation is a part of the tectonostratigraphic Megasequence AP10 [8] belongs to the Middle-Late Eocene sequence, which originated during the latter stages of the subduction and closing of the Neo-Tethys Ocean and was deposited southwest of the emergent uplift [9].

The additional units in this sequence include the Gercus fluviatile, the Pila Spi lagoonal, the Retag fore slope, the Dammam platform, and the Jaddala deep basin deposits [10] The Avanah Formation was deposited as an isolated carbonate shoal associated with a paleo-ridge along the NE shoreline of the basin during a high stand of sea level. This barrier separated the molasse basin of the Gercus Formation in the N and NE from the open sea basin of the Jaddala Formation to the S and SW [10].

5. Stratigraphy

The stratigraphy and sedimentology of the Avanah Formation were examined according to field observations in the well-exposed sedimentary succession. The Middle to Late Eocene sequence in the studied section is composed mainly of Gercus, and Pila Spi formations, with the occurrence of Avanh Formation in the lower and middle parts of the Gercus Formation as carbonate rock interbeds. The sequence is underlain conformably by the Paleocene to lower Eocene Khurmala Formation and overlain unconformably by Lower Fars (Fatha) Formation. The Avanah Formation is lithologically composed of even-bedded pale creamy to yellowish dolomitized, fossiliferous, and marly limestone intercalated with thin layers of siltstone and sandstone occurring at irregular intervals. The well-bedded limestone's become partly dolomitized, especially in the upper part. Friable thin interbedded of greenish-grey color marl occasionally interbedded with reddish clay layers compensate the middle and lower units of the section. The formation age in the studied section is supposed to be Middle Eocene, depending on stratigraphic position and fossil investigation. Generally, the Avanah Formation is characterized by lateral variation in thicknesses [11] which reduced away to the northeast direction far from the boundary between Low Folded Zone and High Folded Zone. A variety of diagenetic factors affected the formation, such as cementation, compaction, neomorphism, dolomitization, and silicification (Table,1).

Fig. 2: a Field photograph of the studied stratigraphic section showing carbonate rock interbeds of the Avanah Formation in the lower and middle parts of the Gercus Formation. B- Close up field photograph of the Avanah interbeds.

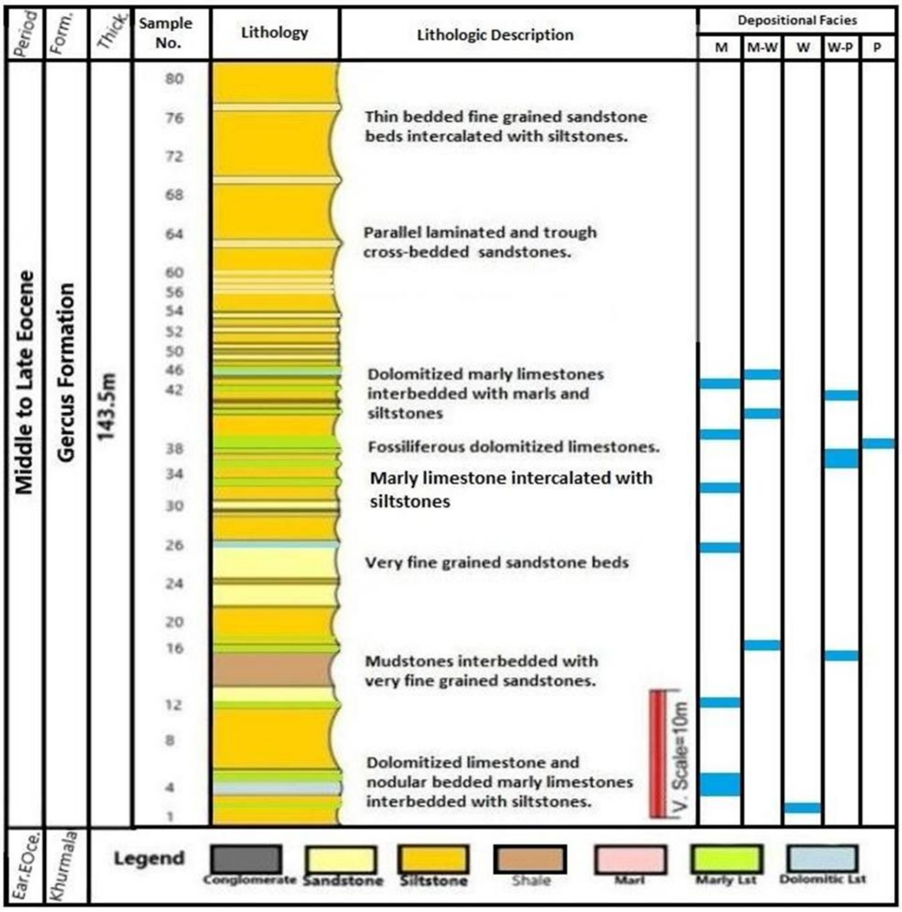

Fig. 3: Geologic column showing lithologic descriptions and depositional facies of the Avanah carbonate rock interbeds within the lower and middle parts of the Gercus Formation at Haibat Sultan section.

6. Results

6.1. Petrographic components

Petrographic components comprise grains and groundmass, and the grains are divided into two types which are represented by skeletal grains and non-skeletal grains. The skeletal grains in the studied rock samples mainly include foraminifers and dasycladacean green algae with some occurrence of ostracods in addition to a few bioclasts of bryozoans and pelecypods. The non-skeletal grains are mainly represented by peloids with some appearance of oncoids.

The groundmass is composed of micrite and is slightly affected by the dolomitization process, which leads to the development of fine crystalline subhedral to euhedral dolomite crystals. Based on our investigation, the following types of skeletal and non-skeletal grains have been identified.

6.1.1. Foraminifera: Avanah Formations in the studied section contain a range of small and larger benthonic foraminifera, including, Miliolids (Fig 6, a, f), Rotaliid, (Fig 6, c)

and Nummulites Miliolids and Rotaliid are excellent paleo-environmental indicators, and their diversity is commonly distributed in the shallow marine inner platform. The Eocene Nummulitic Limestone commonly accumulates the distal part of the carbonate ramp at the Alpine foreland basin and is generally organized in distinct shallowing-upward cycles, separated by surfaces of rapid deepening The new benthonic foram named *Dictyoconus aydimi* (Fig. b, b), belonging to Middle Eocene (Bartonian) age, has been found in the middle part of Avanah Formation and very abundant in the time equivalent rocks at neighboring countries according to and distributed at the northernmost portion of the Arabia [12]

6.1.2. Green Algae: Dasycladacea green algae are the most critical fossil calcareous algae used in microfacies analysis and interpreting ancient shallow shelf carbonates [12] Dasycladacean green algae are the second more abundant skeletal grains in the studied section, especially in the middle parts (Fig.5, f).

6.1.3. Ostracods: Ostracods are rarely occurred in relation to other types of skeletal grains and observed at both the middle and upper parts of the Avanah Formations in Haibat Sultan sections. Ostracods are tiny crustaceans that range in size from 0.2 to 30 mm and have been found in the Ordovician through modern times, making them one of the longest fossil records of any extant crustacean order [13]The pelagic forms have thin shells and range in shape from oval to sub-circular in lateral profile views [14] The bulk of the ostracods in the investigated portions are articulated; some have different types of cement developed inside the shells, while others have been influenced by dissolution (Fig.4, d).

6.1.4. Peloids: The Pellets are typically tiny, rounded to oval, and uniform in size, a Peloid is a microcrystalline carbonate structure less than the size of a grain of sand. They often have rounded or subrounded edges and are spherical, ellipsoidal, or irregular in shape [15] Peloids are fecal pellets formed by animals after they ingest calcium carbonate and expel undigested mud. Peloids have several origins and environmental relationships (Fig.4, a, 5, c).

6.1.5. Oncoid: The Oncoids were created by the trapping and binding of sedimentary grains (quartz silt, tiny bioclasts). Contrast the evident structural variations between oncoids produced in subtidal normal-marine ecosystems [16] This was discovered in the uppermost part of the Avanah Formation in the Haibat- Sultan section (Fig.6, e)

6.1.6. Extraclasts: include any carbonate and non-carbonate particles transported from beyond the sedimentary basin, and their grain size can be used to determine the proximity of shorelines to depositional settings [17]. These grains prevail and are mainly composed of quartz because the depositional basin (foreland basin) was near the Paleogene's positive area or paleoheight, which was covered by Gercus and Pila Spi formations. Layer this form of grain was carrying terrigenous to the Avanah basin. The grains were made up of quartz, chert, pieces of skeletal grain, and other rock fragments (Fig, 4, e).

6.1.7. Intraclasts: Intraclasts are fragments of poorly consolidated carbonate sediment removed and re-deposited, typically within the same depositional basin. Intraclasts are found in the middle and upper portions of the Avanah Formation (Fig. 4, a, e). Intraclasts are common in shallow-marine environments and can be caused by waves, currents, and organic activity [18].

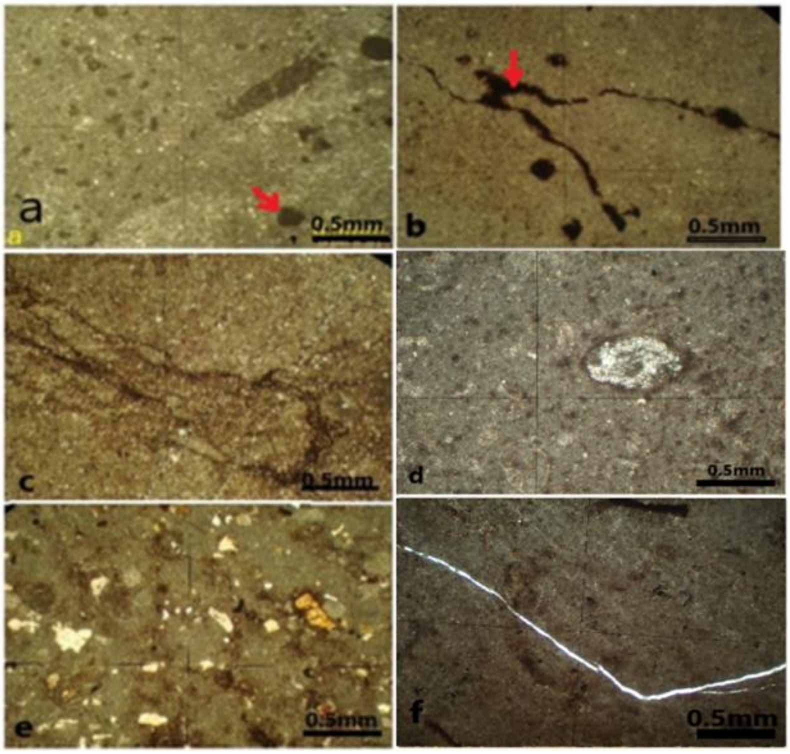

Fig. 4: Photomicrograph showing a-Peloids in Peloidal wackestone (Red arrow), b-Bituminous Mudstone. c- Brecciated mudstone. d- Ostracode in micritic matrix. e- Extraclasts Mudstone. f-Laminated Mudstone to wackestone.

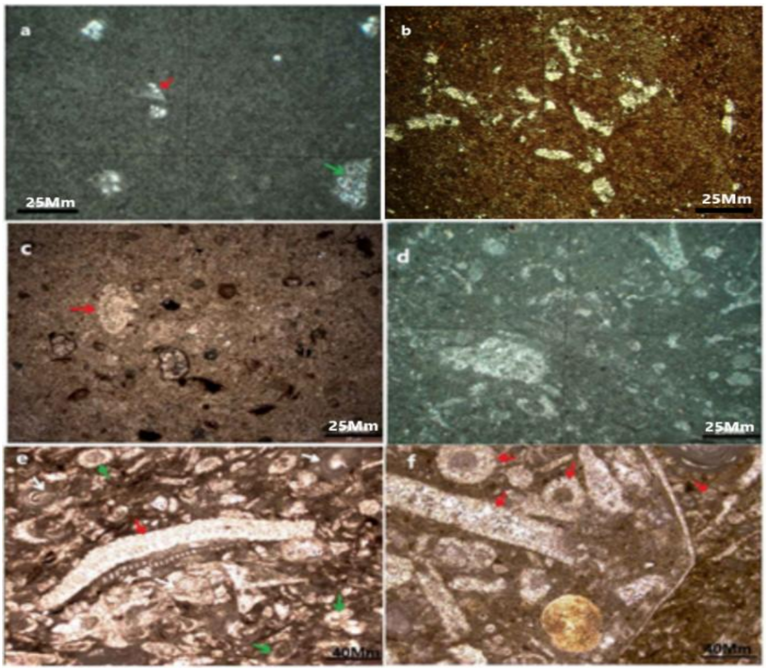

Fig. 5: Photomicrograph a- Fossiliferous mudstone, b- Argillaceous Mudstone with grains of dolomite. c- Peloidal fossiliferous wackestone to packstone (Rotaliid). d – Bioclastic fossiliferous wackestone to packstone. e- Fossiliferous packstone showing *Orbitolites* sp. (red arrow). f- Fossiliferous packstone showing dasycladacean green algae (red arrows).

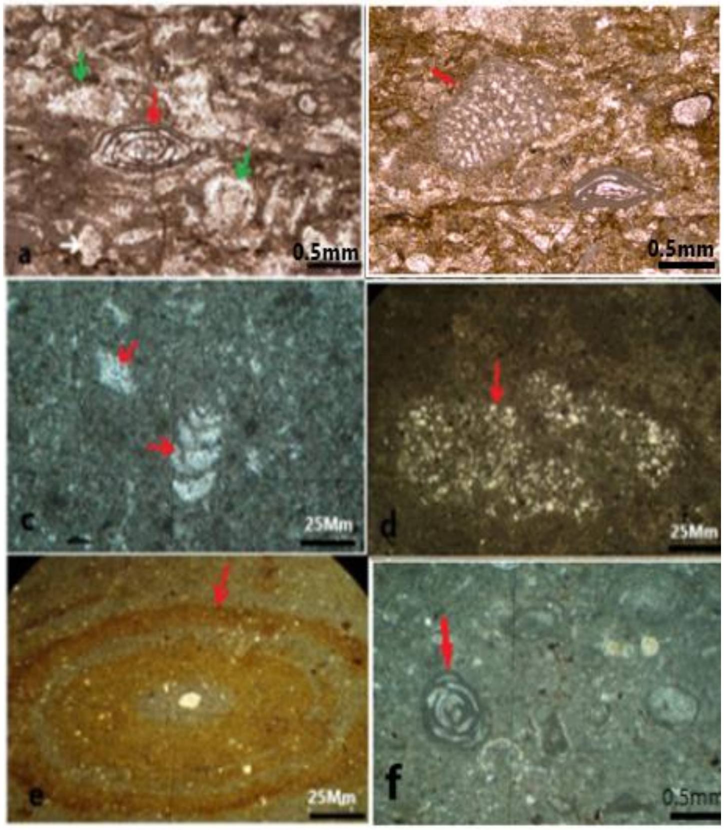

Fig. 6: Photomicrograph a Fossiliferous packstone showing deformed Miliolid due to compaction process, b- Dictyoconus aidymi in fossiliferous packstone (red arrow). c- Fossiliferous Mudstone to wackestone showing small benthic foram, *Textularia* sp. is affected by the micitization processing, and *Rotalia* sp. is affected by neomorphism. d – Burrowed Mudstone to wackestone showing the burrows filled by skeletal and non-skeletal grains. E- Oncoidal wackestone to packstone. f- Fossiliferous wackestone showing Miliolid (red arrow).

6.2. Microfacies Analysis

Microfacies are sedimentary facies that can be investigated and classified into tiny rock sections. A microfacies is defined as the sum of all paleontological and sedimentological data that may be characterized and identified in thin sections, peeling and polished slabs, or rock samples [19]. The paleotopography and paleobathymetry at the distal edge of foreland basins, which strongly influence the distribution of carbonate facies, are affected by a number of local controls in addition to flexural subsidence. According to the classification of [20]in the studied thin sections, five major microfacies types were discovered in the carbonate rocks of the Avanah interbeds. Based on the exceptional petrological components and diagenetic processes, each facies was separated into multiple sub-microfacies (Table, 1). The main microfacies recognized in the petrographic study of the carbonates are Mudstone, Mudstone to wackestone, wackestone, wackestone to packstone, and packstone microfacies.

6.2.1. Mudstone Microfacies

Mudstone microfacies are the most common and abundant in the studied carbonate rocks, which are dominated by micrite with uncommon (less than 10%) grains in contact [20].The grains are mainly represented by silt to sand-sized extraclasts with few skeletal grains of small benthic forams. This microfacies is subdivided into six submicrofacies; bituminous Mudstone, brecciated Mudstone, fossiliferous Mudstone, dolomitized Mudstone, extraclastic Mudstone, and argillaceous submicrofacies. Dolomitization is the more characteristic diagenetic process in these submicrofacies (Fig.5, a, b). The dolomitization process leads to develop fine crystalline euhedral to subhedral dolomite crystals. Other diagenetic processes involve pyritization, silicification, dissolution, and neomorphism.

6.2.2. Mudstone to Wackestone Microfacies

These microfacies are relatively common microfacies in the studied thin sections (fig.,7d) and are subdivided into three submicrofacies, represented by fossiliferous Mudstone to wackestone, burrowed Mudstone to wackestone, and laminated Mudstone to wackestone submicrofacies (Table, 1). The main diagenetic processes in these facies include dolomitization, silicification, and neomorphism. The ghost of benthic foraminifera is found in the micritic matrix; grains; therefore, the Peloidal wackestone is the main submicrofacies in carbonate rocks of the Avanah inter beaded (Fig.6 c and d). The genetic differentiation of the peloids offers essential information on the depositional setting, palaeoenvironmental conditions, and diagenetic features [21]. These microfacies were observed in the lowermost part of the studied section, and diagenetic processes altered it due to micritization and pyritization (Fig.3b)

6.2.3. Wackestone Microfacies

The petrographic investing shows non-skeletal grains increases by up to 40% in the studied wackestone microfacies. The sand-sized, angular to subangular (Fig.3e).

6.2.4 Wackestone to Packstone Microfacies

This microfacies is also common in the studied thin sections, which are dominated by more than 40% non-skeletal grains imprinted in the slightly dolomitized micritic matrix (Fig.5d). The non-skeletal grains are mainly composed of non-skeletal grains of peloid and oncoids with some skeletal grains of foraminifers constituting peloidal wackestone to packstone, bioclastic wackestone to packstone, oncoidal wackestone to packstone submicrofacies.

6.2.5 Packstone Microfacies

This microfacies is less abundant in relation to other studied thin sections, which consists mainly of skeletal grains of small and larger benthic forams with a moderate occurrence of green algae. This microfacies is observed in the upper parts of the Carbonate interbeds of the Avanah Formation. These facies are affected by micritization, cementation, and compaction processes. The compaction process leads to develop clay seems and the deformation of some skeletal grains. This facie is represented by fossiliferous packstone submicrofacies, probably representing Rotaliids (Fig.6c).

Table 1: Microfacies types, diagenetic features, abundant grains, and facies zones of the Avanah interbeds in the studied section

Microfacies	Submicrofacies	Diagenetic features Skeletal and non-skeletal grains	SMF Flugel (2010)	Facies Zone
Mudstone	**Bituminous Mudstone**	Dolomitization & Pyritization	**23**	**9 Supratidal**
	Brecciated Mudstone	Dissolution, Dolomitization& Compaction	**23**	**9 Supratidal**
	Fossiliferous Mudstone	Dolomitization, Micrtization & Neomorphism	**8**	**7 Subtidal**
	Dolomitized Mudstone	Dolomitization & Compaction	**23**	**8 Intertidal**
	Extraclastic Mudstone	Dolomitization & Pyritization	**24**	**8 Intertidal**
	Argillaceous Mudstone	Dolomitization & Dissolution	**23**	**9 Supratidal**
Mudstone to Wackestone	**Fossiliferous Mudstone to Wackestone**	Dolomitization, Neomorphism & Pyritization	**8**	**7 Subtidal**
	Burrowed Mudstone to Wackestone	Dolomitization & Cementation	**9**	**7 Subtidal**
	Laminated Mudstone to Wackestone	Dolomitization, Dissolution & Cementation	**19**	**8 Intertidal**
Wackestone	**Peloidal Wackestone**	Dolomitization	**16**	**7 Subtidal**
Wackestone to Packstone	**Peloidal Wackestone to Packstone**	Dolomitization & Pyritization	**16**	**7 Subtidal**
	Bioclastic Wackestone to Packstone	Dolomitization & Neomorphism	**9**	**7 Subtidal**
	Oncoidal Wackestone to Packstone	Dolomitization & Pyritization	**22**	**8 Intertidal**
Packstone	**Fossiliferous Packstone**	Cementation & Neomorphism	**8**	**7 Subtidal**

7. Depositional Environments

Carbonate sediments produced in warm marine tropical environments are under the control of tectonics, climate, eustatic sea-level fluctuations, hydrology, organic composition, and substrate character. Combinations of these parameters control degrees of depth, water agitation, circulation, salinity, and frequency of subaerial exposure and greatly influence depositional facies, sediment types, and platform [22]. Depositional environments of the Avanah interbeds in the Haibat Sultan area are discovered depending on the carbonate rocks' petrographic components and depositional textures. The following environments were observed throughout our investigation.

7.1 Open Marine Platform (Subtidal)

Geographically such environments are located in open lagoons behind the outer platform edge. The general term lagoon is applicable; water is shallow, generally a few meters to tens of meters deep. Salinity varies from normal marine to somewhat higher; circulation is very moderate or limited. Water conditions are favorable for organisms and texturally varied but contain considerable amounts of lime mud Sediments are made up of mudstones or wackestone, frequently with a lot of dolomite; peloids are the most prevalent. The organisms may be abundant locally, but their variety is often entirely restricted. Most of them are gastropods, algae, foraminifera, and ostracods [22]. The petrographic investigation of the Avanh carbonate rocks reveals that they are composed of peloidal wackestone, fossiliferous Mudstone to wackestone, peloidal fossiliferous wackestone to packstone, bioclastic fossiliferous wackestone to packstone, fossiliferous packstone, and burrowed mudstone to wackestone subfacies.

7.2 Restricted Marine Platform (Intertidal)

This belt also includes highly diverse and well-known intertidal environments. The facies in this environment has mostly fine sediment in very shallow and restricted circulation water. The muddy lime sediment is characteristic of such an environment, and diagenetic effects are strongly marked in the resulting sediment. Tidal channels contain coarser grain, lithoclastic sediment, and peloidal Mudstone; wackestone is the most common. Mudstone is more laminated, and the channel sands show cross-bedding. Very limited fauna and flora, mainly gastropods, algae, foraminifera (miliolids), and ostracods. These organisms may occur locally in great abundance [23]. The petrographic investigation of the Avanh carbonate rocks reveals that they are composed of peloidal Mudstone, dolomitized Mudstone, fossiliferous Mudstone, oncoidal wackestone to packstone, and laminated wackestone to packstone.

7.3 Supratidal Environment

The environment is characterized by tense heat; aridity is common, at least seasonally, and marine flooding is sporadic. Very fine-grain carbonate sediment and terrigenous clastics may be very common in such an environment. The petrographic investigation of the studied carbonate rocks reveals that these facies are relatively less typical and composed mainly of bituminous Mudstone and brecciated Mudstone.

The greenhouse ramp cycle consists of low-energy subtidal facies capped by flat tidal facies and commonly composed of laminated dolomitic limestone; such low-energy tidal flat-capped cycles appear to be the signature of the interiors of tropical ramps. The flat tidal facies typically are composed of interlayered Peloidal sand-mud facies, reflecting shallow-water depth. This cycle grades into an upward coarsening cycle of burrowed wackestone and argillaceous wackestone capped by skeletal packstone), Peloids are common in shallow-marine tidal and subtidal shelf carbonates [24]. The tropical environment supported by conical Middle Eocene foraminifera, *Dictyoconus aidymi*, is strictly tropical and was discovered in the studied section's upper interbeds of the Avanah Formation.

The Middle Eocene carbonate rocks in the Haibat Sultan section were deposited in a platform at foreland basins due to the rising sea level and tectonic subduction of the Arabian Plate. Petrography, facies, and textural investigations of the interbed Carbonate of Avanah indicate it to be formed in a shallow marine inner platform ramp setting involving a subtidal lagoon, tidal flat and supratidal environments comprising mainly of repeated cycles of low-energy subtidal facies capped by tidal flat facies.

8. Conclusions

1- Avanah Formation is lithologically composed of even-bedded pale creamy to yellowish dolomitized, fossiliferous, and marly limestone intercalated with thin layers of siltstone and sandstone occurring at irregular intervals.

2- Petrographic components comprise grains and groundmass; the grains are divided into two types: skeletal grains and non-skeletal grains. The skeletal grains in the studied rock samples mainly include foraminifers and dasycladacean green algae with some occurrence of ostracods in addition to a few bioclasts of bryozoans and pelecypods. The non-skeletal grains are primarily represented by peloids with some appearance of oncoids.

3- The Avanah interbeds in the studied thin sections five major microfacies types were discovered in the carbonate rocks on the exceptional petrological components and diagenetic processes; each facies was then separated into multiple sub-microfacies

4- Based on petrography, facies, and textural investigations, the Avanah Formation was deposited in a shallow marine inner platform ramp setting involving a subtidal lagoon, tidal flat and supratidal environments comprising mainly of repeated cycles of low-energy subtidal facies capped by tidal flat facies.

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