

Lithostratigraphy & microfacies analysis of Avanah Formation (Middle Eocene) in Gomaspan section northeast Erbil City, Kurdistan region, Iraq

Irfan Sh. Asaad

*Dept. of Earth Sciences and Petroleum, College of Science,
Salahaddin University-Erbil, Erbil Kurdistan Region, Iraq.*

Corresponding author: irfan.asaad@su.edu.krd

Abstract

Lithostratigraphy and microfacies analysis of the Avanah Formation (Middle Eocene) were studied in the Gomaspan section in the Bina Bawi anticline, northeast of Erbil city, Kurdistan Region, Iraq. The field observations refer that the formation attains 56 m of medium to thick-bedded yellow limestone, grey dolomitic limestone, and blue marly dolomitic limestone interbedded with thin beds of blue marl and dark grey shale with an interval of sandy limestone in the middle part and thin to medium bedded limestone interbedded with red mudstone. The petrographic study of 29 thin sections of Avanah carbonates revealed that most of the matrix is carbonate mud (micrite) with few microspar. The skeletal grains include benthic foraminifera, dasycladacean green algae, ostracods, calcispheres, pelecypods, rare planktonic foraminifera, and bryozoa, in addition to bioclasts. Non-skeletal grains encompass peloids, oncoids, intraclasts, and extraclasts with common monocrystalline quartz. Three different lithostratigraphic units were identified based on field observation and petrographic analysis. They are in ascending order: A-Thick bedded dolomitic marly limestone interbedded with shale. B- Bedded dolomitic limestone interbedded with shale and marl. C- Thin to medium bedded limestone interbedded with red mudstone. Depending on detailed microfacies analysis of carbonate rocks, three main microfacies and 12 submicrofacies are recognized. From the sum of all petrographic, facies, and textural analyses, it is concluded that Avanah Formation in the Gomaspan section was deposited in the shallow marine environment, semi-restricted lagoon, in lower and upper parts, and open lagoon environment in the middle part interval.

Keywords: Avanah; Iraq; lithostratigraphy; microfacies analysis; middle eocene.

1. Introduction

Mc Ginty first described the Avanah Formation in 1953 (Bellen *et al.*, 1959) from well Kirkuk 116 on the Avanah dome of the Kirkuk anticline in the low folded Zone. In its type section, the Avana Formation comprises 210 m of dolomitized and recrystallized limestones of shoal facies with occasional beds of lagoonal dolomitized limestone. Its thicknesses in subsurface sections in northern Iraq are as follows: Kirkuk-117 (159 m), Butmah-I (503 m), Alan-I (154 m), Atshan-1 (138 m), and Mushorah-I (550 m). Laterally the Avanah Formation interfingers with Jaddala Formations in wells Sufaya-A2 and Najmah-30 (Jassim & Buday, 2006). The Avanah Formation belonging to the late Lower Eocene- Upper Eocene cycle (Buday, 1980) and distributed in a belt

along the boundary of the Foothill and High Folded Zones, and is thick in the area of the Foothill Zone of northern Iraq as an isolated carbonate shoal associated with a palaeoridge along the northeastern shoreline of the basin during a highstand of sea level (Jassim & Buday, 2006). On the other hand, the Avanah Formation is characterized by the dominance of macro and microfossils and high porosity and permeability ratio, making its lower and middle parts a good hydrocarbon reservoir (Al-Hamdany & Sulaiman, 2014).

Since the first description of the formation in Bellen *et al.* (1959), several studies have dealt with the Avanah Formation in terms of sedimentology, stratigraphy, and paleontology; these are the studies of Al-Omeri & Sadek (1975), Sharbazheri & Abawi. (1987), Al-Banna & Al-Mutwali (2005), Barzani (2016) and Abdullah *et al.* (2020). The present study aims to clarify lithostratigraphy and comprehension of the depositional environment of the Avanah Formation in the Gomaspan section by using integrations of field, petrographic observations, and microfacies analysis.

2. Location

The studied area is located in the northeast of Erbil city in the Kurdistan Region of northern Iraq (Figure 1). The studied section, which was not covered by any previous works, is located about 300 m northeast of Gomaspan village and about 30 km northeast of Erbil city on the main road of Erbil-Dolly Smaqli area, in the southwestern limb of Bna Bawi Anticline (36° 16' 48" N and 44° 20' 07" E) (Figure 2).

3. Geologic Setting

Avanah Formation is exposed in different areas of the High Folded Zone as a belt close to the boundary with the Low Folded Zone (Figure 1). The High Folded Zone is characterized by numerous folds and faults with major trending northwest-southeast (Al-Qayim *et al.*, 2020). The Avanah Formation is located in the middle part of the tectonostratigraphic AP 10 mega sequence of Sharland *et al.* (2001). This mega sequence was split into two subsequences: The Paleocene – Early Eocene sequence and the Middle to Late Eocene sequence (Jassim & Buday, 2006). The Avanah Formation belongs to the Middle-Late Eocene subsequences, which is deposited in the SW of the emergent uplift along with the final phase of the subduction and closing of the remnant part of the Neo-Tethys Ocean. The other carbonate units of this subsequences are Dammam platform, Ratga fore slope, Jaddala deep basin and Pila Spi lagoonal formations (Al-Hashimi & Amer, 1985).

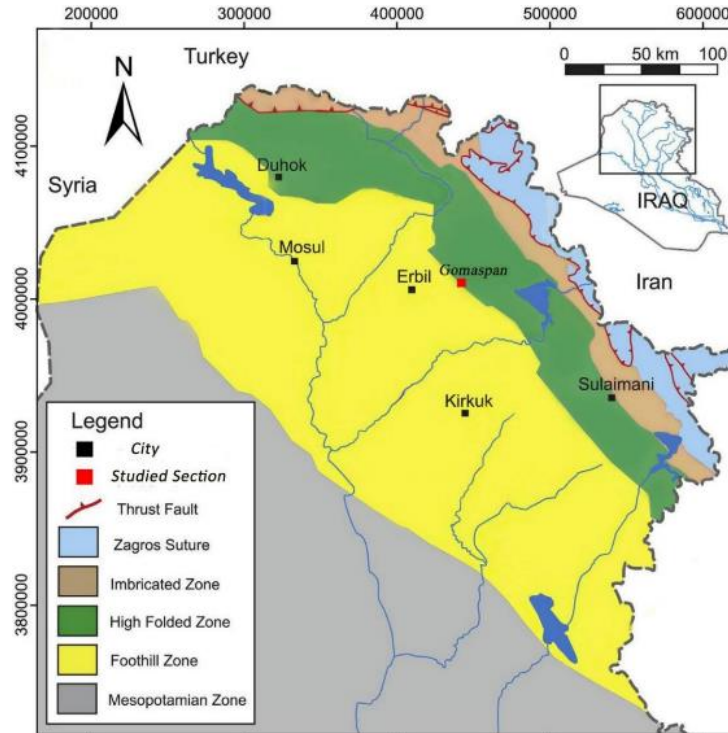


Fig. 1. Location and tectonic map of the studied area (after Jassim & Goff, 2006).

Generally, the Avanah Formation in the eastern Erbil, from Koya in the east to Shaqlawa in the northeast, occurs as a tongue within the Gercus Formation and characterizing by lateral variation thickness (AL-Sakry, 1999). The Avanah Formation in the Gomaspan section crops out at the southwestern limb of the Bina Bawi anticline, which is characterized by NW-SE trending and verges to the SW (Awdal *et al.*, 2013), which is linked to the NW with Pirmam anticline and latter proposed by Omer (2005) as NW continuation of Bina Bawi anticline which together may form one gigantic anticline that is over 75 km long (Figure 2). The stratigraphic successions around the studied area include Bekhme, Shiranish, and Tanjero formations from the Upper Cretaceous age; the latter is overlain by Tertiary units involving Kolosh, Khurmala, Gercus, Avanah, Pilaspi, Fatha (Lower Fars), Injana (Upper Fars), and further away Mukdadiya (Lower Bakhtiari) and Bai Hassan (Upper Bakhtiari) formations. The Avanah Formation in the studied section exists as a tongue within the red mudstone of the Gercus Formation (Figure 3a).

4. Materials and methods

To select a suitable section for the present study, comprehensive fieldwork was done between High Folded and Low Folded Zones, which involved the study of general geology and structural relationships of the Tertiary succession in the surrounding area. The Gomaspan area was chosen for the present study since it is characterized by well-exposed fresh beds due to cutting their surface by shovel vehicle machines and removing the sedimentary covers because it will be a part of the

proposed earth dam in that area. The outcrop was described and measured in detail, logging the lithology and mineralogy. The primary lithologies of the studied outcrop are limestone, dolomitic limestone, marly limestone, sandy limestone, marl, and shale.

A total of 29 fresh samples were collected from the carbonate beds. The samples were collected at every change in lithology or color (random sampling). All samples were taken along a line perpendicular to the bedding plane. The upper and lower parts of each sample were also marked and detailed description of samples (Macroscopic study) using a hand lens and dilute HCl acid was performed. The sum of 29 thin sections was prepared at Salahaddin University –Erbil. At least one thin section for each sample was prepared. The thin sections were oriented and stained with the Alizarin Red Solution (ARS) following the procedure of Friedman (1959) for the identification of calcite and dolomite.

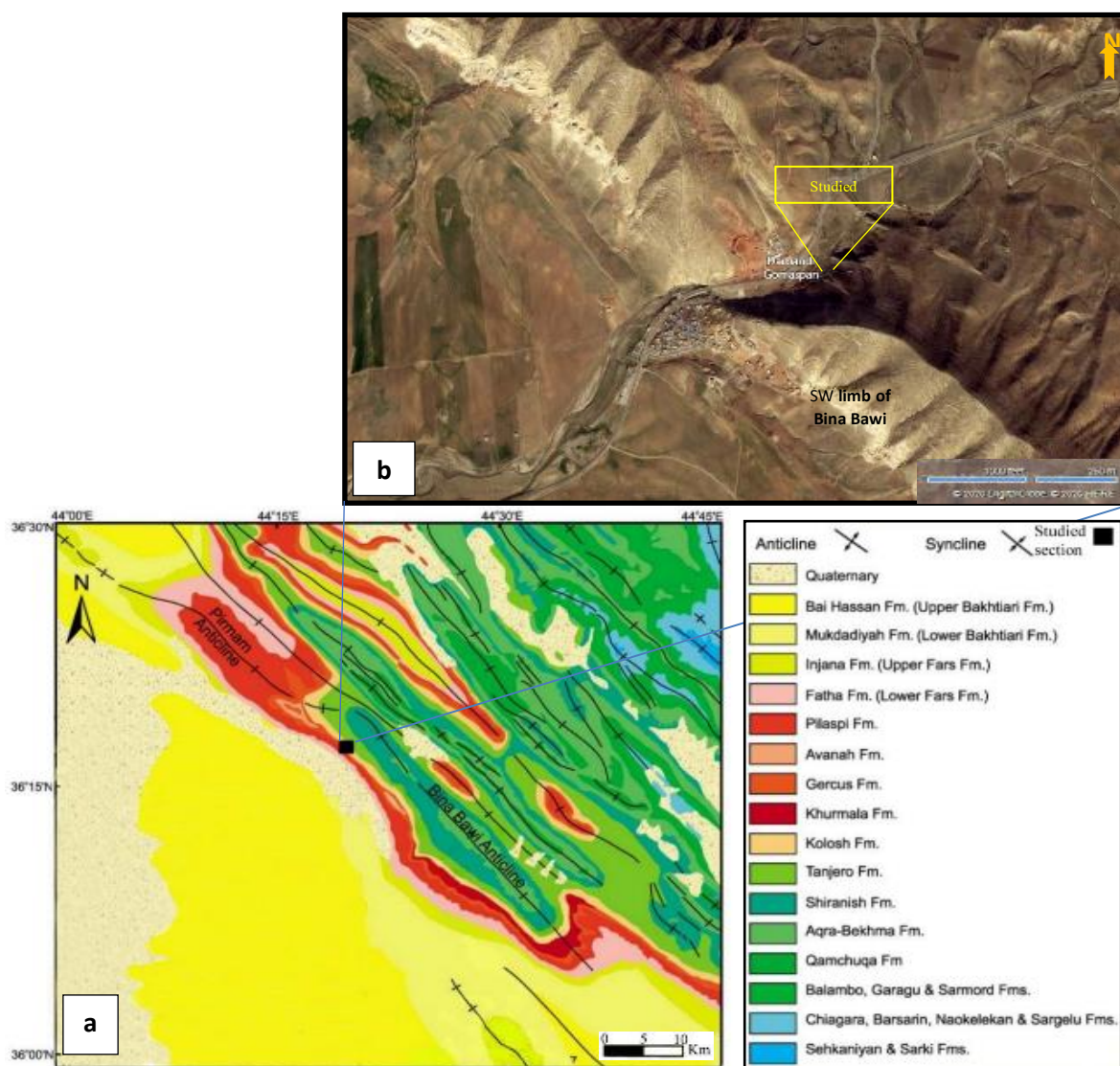


Fig. 2. (a) Geological and structural map of Bina Bawi and Pirmam anticlines showing studied section (after Awdal *et al.*, 2013). (b) Satellite image of Gomaspan section (from Bing Map).

5. Lithostratigraphy

The total thickness of the Avahah Formation in the Gomaspan section is about 56 meters. Based on field inspection and petrographic analysis, the Avahah Formation in the studied area can be divided into three units, which are in ascending order (Figure 3a):

5.1 Thick bedded marly dolomitic limestone interbedded with shale (Unit A)

This unit occupies the base of the Avahah Formation in the studied section and is underlain by thin beds of red mudstone of the Gercus Formation (Figure 3b). It comprises 9.5 m of thick (50-100 cm) bedded of grey marly dolomitic limestone interbedded with laminated (less than 1cm wide) brown to grey shale (Figures 3b &c). The sedimentary structure of this unit is thin horizontal (planar) millimeter-thick laminations. The carbonate beds of this unit are characterized by calcite (Figure 3d) and sulphur geodes (Figure 3e), bearing macrofossils (pelecypods) (Figure 4a), and bituminous (Figure 4b). The macrostylolitic porosity observed on the carbonate beds of the unit (Figure 3d) is formed by chemical compaction diagenesis when the created stylolites contribute to making some pores around their sutures due to the passing of CO₂- rich solution along with them (Carrozi and Bergen, 1987). Sedimentary structures of this unit are thin horizontal (planar) millimeter-thick laminations and burrowing (Figure 4a).

5.2 Bedded marly dolomitic limestone interbedded with shale and marl (Unit B)

The total thickness is about 30 m. The lower 3.8 m is composed of medium (30-50cm) bedded of grey marly limestone and fossiliferous dolomitic limestone interbedded with thin beds of grey shale and blue marl (Figure 4c), followed by 30 cm of intraformational conglomerate (Figures 4d & e). The middle 2.3 m comprises thick (50-100) bedded dolomitic limestone interbedded with thin beds of grey shale. Subsequently, 1m consists of yellowish-grey of medium to thick-bedded sandy limestone (Figure 4f). The upper 22.5 m comprise of alternation of thin to medium (10-50 cm) and medium to thick (50-100 cm) bedded of fractured grey marly dolomitic limestone interbedded with narrow beds of grey shale and blue marl (Figure 5a).

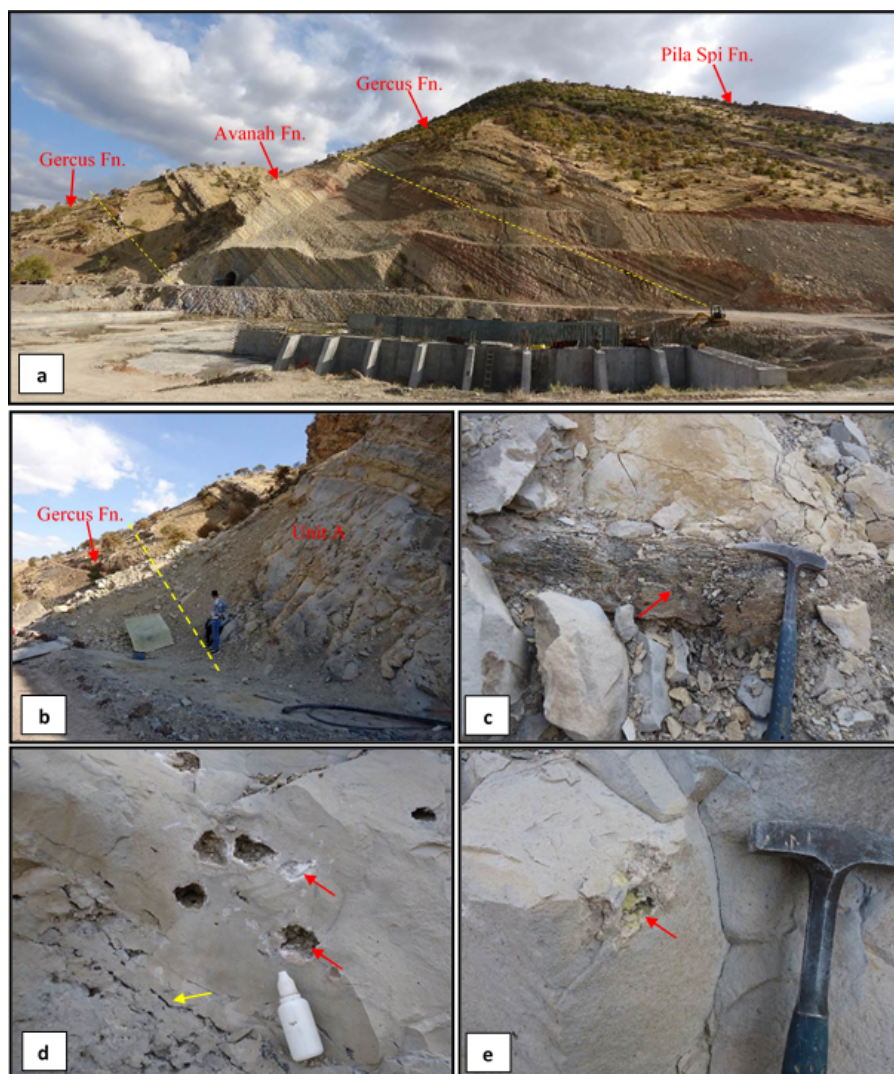


Fig. 3. Field photographs showing: (a) Avanah Formation inter tongue within red mudstones of Gercus Formation which overlain by Late Eocene Pila Spi Formation in Gomaspan section. (b) Thick bedded dolomitic marly limestone interbedded with shale (unit A) overlain red mudstone beds of Gercus Formation. (c) Laminated brown to grey shale (red arrow) interbedded within thick yellow to grey dolomitic limestone. (d) Calcite geodes (red arrows) in the fractured dolomitic limestone affected by chemical compaction formed Macrostylolitic porosity (yellow arrow). (e) Sulphur geodes (red arrow) characterized by yellow color and had rotten eggs smell on the thick dolomitic limestone of Unit A.

Generally, different sedimentary structures were observed in this unit, including horizontal planar lamination, bending (Figure 4f), symmetrical ripple marks (Figures 5a & b), and slump structure which is post depositional structure supposed to be formed by tectonic activity related to the final phase of the subduction and closing of the remnant part of the Neo-Tethys Ocean (Figure 5d). Calcite geodes and veins (Figure 4f), besides pyrite nodules, also occurred on the carbonate beds of this unit (Figure 5e).

5.3 Thin to medium bedded limestone interbedded with red mudstone (Unit C)

This unit overlain unit B and is regarded as a transition zone between Carbonates of Avanah Formation and clastics of Gercus Formation. It comprises 16.5 m of thin to medium bedded (10-50 cm) yellow to white marly limestone interbedded with calcareous red mudstone and yellow marl (Figure 5f). The sedimentary structures of this unit are thin horizontal (planar) millimeter-thick laminations.

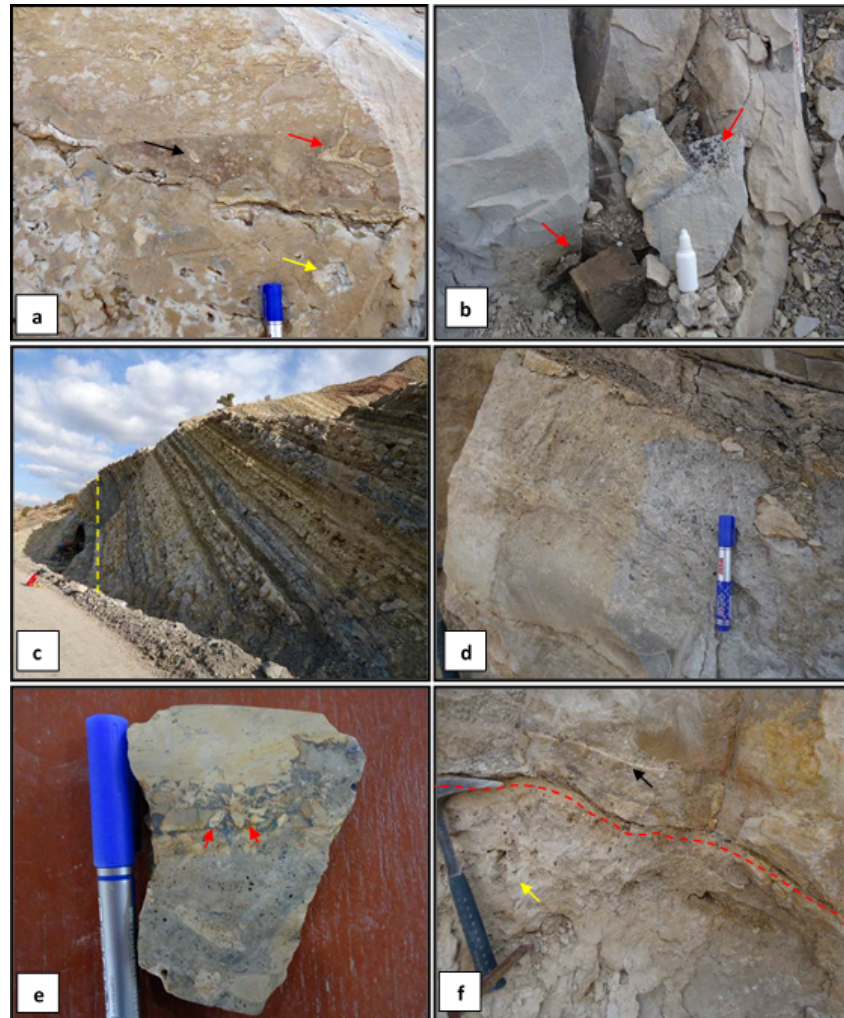


Fig. 4. Field photographs showing: (a) Burrowing (red arrow), bivalves (black arrow) and calcite concretion (yellow arrow) filled the molluscan mold on the dolomitic limestone beds of Avanah Formation, calcite concretion (yellow arrow). (b) Bituminous limestone bed (red arrow). (c) Bedded dolomitic limestone interbedded with shale and marl overlain unit A. (d) Intraformational conglomerate (30 cm) overlain dolomitic limestone and underlain grey shale. (e) Slabs of conglomerate bed show intraclasts (red arrows). (f) Bending in (red dash-line) in the Sandy limestone beds of Avanah Formation affected by bioturbation (yellow arrow) and has calcite veins (black arrow).

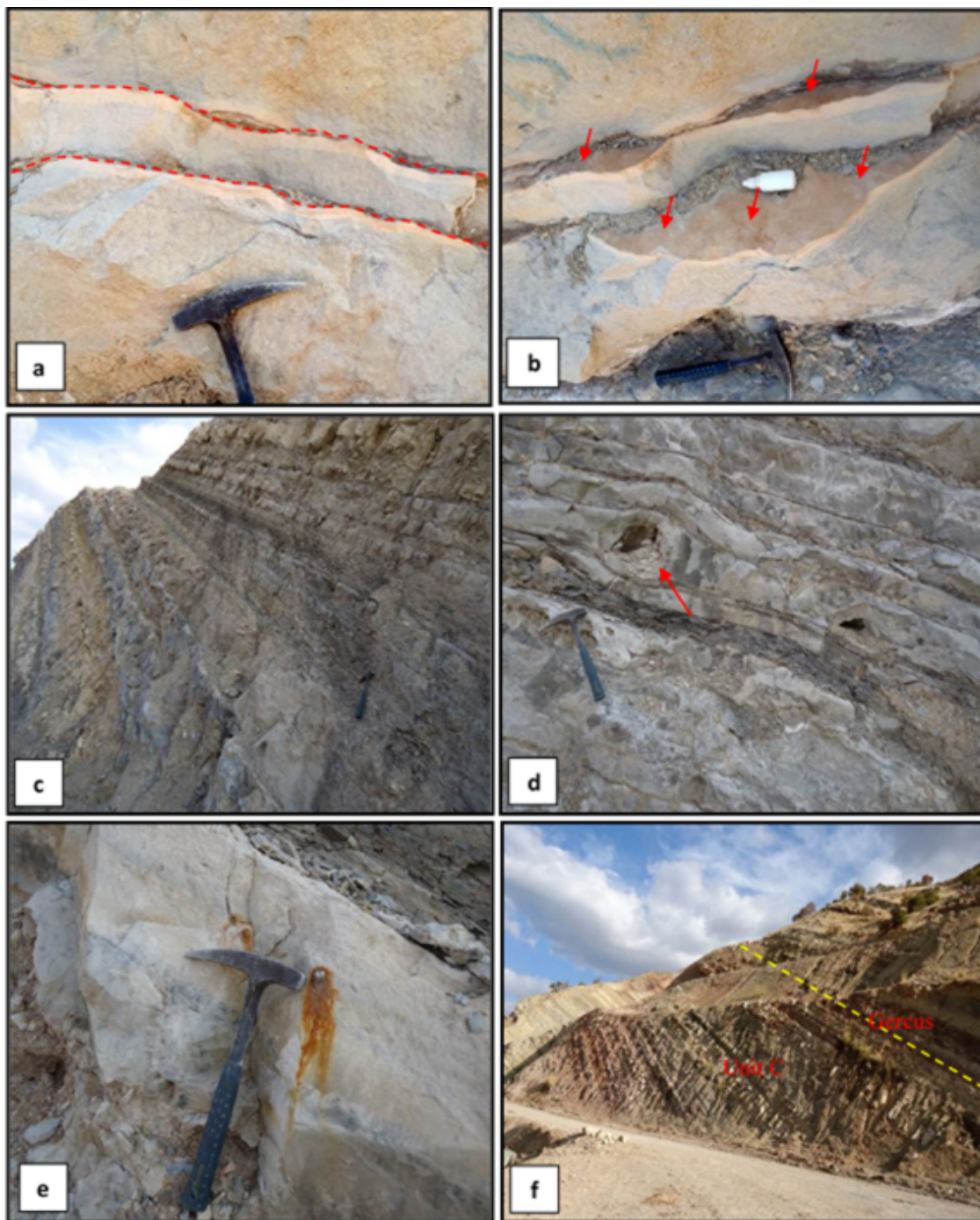


Fig.5. Field photographs showing: (a) Symmetrical ripple marks formed in sandy limestone beds (red dash line). (b) Surface of ripple marks in the sandy limestone beds (red arrows). (c) Thin to medium bedded grey dolomitic marly limestone interbedded with grey shale and blue marl in the upper part of unit B. (d) Slump sedimentary structure formed on the medium to thick dolomitic limestone beds of Avanah Formation (red arrow). (e) Pyrite nodules in the fractured dolomitic limestone beds. (f) Thin to medium bedded limestone interbedded with red mudstone and yellow marl overlain by red mudstone of Gercus Formation.

6. Microfacies types

According to the classification of Dunham (1962), three main microfacies types were identified in the carbonate rocks of the Avanah Formation in the studied section. Each was subdivided into several submicrofacies on the remarkable fossil type and diagenetic processes. Table (1) manifests the main and submicrofacies recognized in the petrographic study of the formation.

Table 1. Microfacies types of the Avanah Formation in the Gomaspan section

Main microfacies Dunham (1962)	Subdivision of Dunham (1962)	Diagnostic features (main skeletal grain + common diagenetic process)	SMF Flügel (1982)	Environment of deposition
Lime Mudstone	Dolomitized lime mudstone	-Dolomitization+ Pyritization	23	Restricted platform (lagoon)
	Benthic foraminiferal lime mudstone	- <i>Textularia plummerae</i> - Neomorphism+ Dolomitization	9	Shallow lagoon with open circulation
	Dasycladacean lime mudstone	-Dasycladacean green algae -Silicification+ Ferruginous material + Organic matter.	8	Shelf lagoons with circulation
Lime Wackestone	Sandy-miliolid lime wackestone	-Miliolid+ Monocrystalline quartz -Dissolution+ Pyritization+ Micritization	8	Shelf lagoon with circulation
	Alveolina lime wackestone	-Alveolina -Micritization+ Dolomitization	9	Shallow lagoon with open circulation
	Planktonic foraminifera - intraclasts lime wackestone	- <i>Globigerina</i> + intraclasts -Dolomitization+ Micritization	9	Shallow lagoon with open circulation
	Sandy-Peloidal lime wackestone	-Monocrystalline quartz+ peloids -Dolomitization+ Dissolution	8	Shelf lagoons with circulation
	Sandy-benthic foraminifera lime wackestone	- <i>Valvulina</i> -Dissolution + Micritization	18	Shelf lagoons with open circulation
Lime Packstone	Ostracoda- <i>Calcispheres</i> lime packstone	-Ostracods+ Calcispheres -Neomorphism+ Dissolution	9	Shallow lagoon with open circulation
	Bryozoan-ostracoda-intraclasts lime packstone	-Bryozoa +Ostracods -Neomorphism+ Dolomitization	9	Shallow lagoon with open circulation
	Benthic foraminifera-bioclasm-dasycladacean lime packstone	Rotaliid+ <i>Spirloculina</i> + Dasycladacean green algae + Bioclasts -Dolomitization+ Cementation	18	shelf lagoons with open circulation
	Oncoid lime wackestone	-Oncoids -Cementation+ Pyritization	22	Subtidal (lagoon)

6.1 Lime mudstone microfacies

Mudstone microfacies are widespread in the studied section but less common than the lime wackestone microfacies. It is characterized by the dominance of micrite with rare (generally less than 10%) grains content (Dunham, 1962). The identified skeletal grains in this microfacies are benthic foraminifera (*Valvulina* sp. and *Textularia plummerae*.) (Figure 6b) with dasycladacean green algae (Figure 7c). It is observed within the unit (A) in the lower part of the formation and unit (C) in the upper part of the studied section. The characteristic diagenetic process in these facies is dolomitization (Figure 6a). Other diagenetic types involve pyritization, micritization, and silicification.

6.2 Lime wackestone microfacies

This microfacies is considered the most common among other microfacies of Avanah carbonate. It is commonly found in different parts of the Gomaspan section, particularly in the middle part (Unit B). It is defined by involving grains ranging between 10 to 50 % in the micritic matrix (Dunham, 1962). Skeletal grains include benthic foraminifera (Miliolids (*Quinqueloculina* sp.) (Figure 6d), *Alveolina* sp. (Figure 6e), and *Textularia* sp.) and planktonic foraminifera (*Globigerina* sp.) (Figure 6f). While non-skeletal grains involve peloids (Figure 7a) and extraclasts, mainly monocrystalline quartz (Figures 6d & 7b). It is subjected to diagenetic processes such as dolomitization, pyritization, dissolution, silicification, micritization, and neomorphism.

6.3 Lime packstone microfacies

Packstone microfacies are less common than other microfacies and are observed in the lower and middle parts of the studied section of the Avanah Formation. In this microfacies, skeletal grains increase up to 60% in the packstone, leaving minor micrite between grains-supported limestones (Dunham, 1962). The petrographic investigation of these microfacies lead to recognize the Ostracoda- calcispheres lime packstone submicrofacies (Figure 7c), bryozoan - Ostracoda-intraclasts lime packstone submicrofacies (Figure 7d), Rotaliid-bioclats-dasycladacean lime packstone submicrofacies (Figure 7e) and Oncoid lime packstone submicrofacies (Figure 7f). The common diagenetic processes that affected it are neomorphism, cementation, and pyritization.

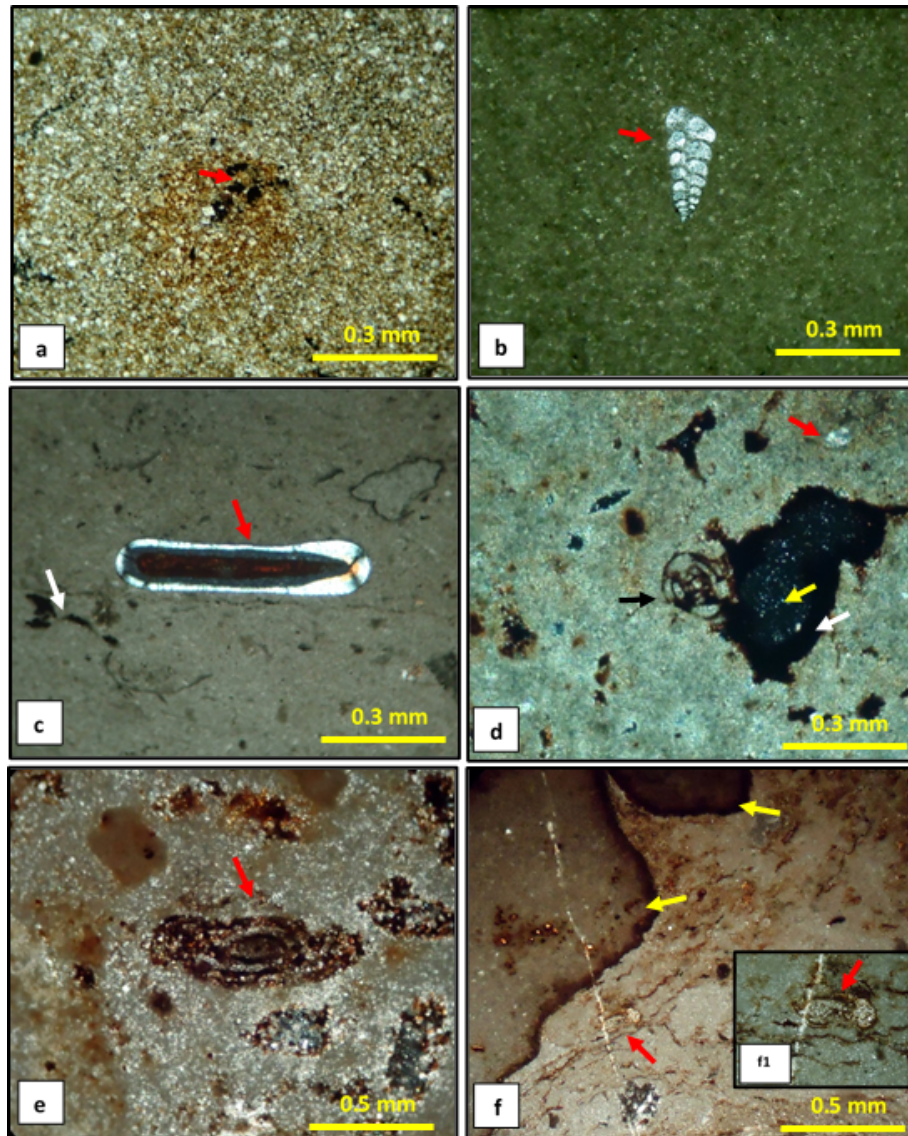


Fig. 6. Photomicrographs showing microfacies types of Avanah Formation in Gomaspan section: (a) Dolomitized lime mudstone submicrofacies subjected to pyritization (red arrow). GA1., P.P. (b) Benthic foraminifera (*Textularia plummerae* (red arrow)) lime mudstone submicrofacies. GA9., P.P. (c) Dasycladacean lime mudstone submicrofacies, dasycladacean shell filled by ferruginous material in the center and affected by silicification in the outer layers (red arrow), the groundmass affected by organic matter (white arrow). GA26., X.N. (d) Sandy (red arrow)-miliolid (black arrow) wackestone submicrofacies, a mold of undefined shell subjected to affected by pyritization (white arrow) and dissolution (yellow arrow). GA2., X.N. (e) Alveolina (red arrow) lime wackestone submicrofacies. GA14., X.N. (f) Planktonic foraminifera (*Globigerina*) (red arrow)-intraclasts (yellow arrow) wackestone submicrofacies. GA11., P.P. (f1) enlarged photomicrographs of *Globigerina* sp. GA11., X.N.

Key= AG: Avanah-Gomaspan, P.P: Plane polarized light, X.N: Crossed Nicoles.

7. Facies associations

Based on the integration of the recognized microfacies analysis and field observations of the Avanah Formation in the Gomaspan section, two basic types of facies associations were identified according to their environmental interpretation, which is as follows (Figure 8).

7.1 Semi-restricted lagoon Facies Association (FA1)

This association is equivalent to standard facies zone 7 and 8 of Wilson (1975) and Standard Microfacies 8, 22, and 23 of Flügel (1982). It is observed in the lower 9.5 m and upper 39 m of the Avanah Formation. The lower 9.5 m, which occupies unit (A), consists of 9.3 m of thick-bedded grey dolomitic marly limestone-rich lime mudstone to wackestone with rare packstone interbedded with laminated brown to grey shale. It shows thin horizontal (planar) millimeter-thick lamination, burrowing, brecciation and bioturbation. The pelecypod macrofossils with molds of mollusks are also observed. While the upper part of the association comprises 22.5 m of thin to medium and medium to thick-bedded fractured grey marly dolomitic limestone rich in lime mudstone to wackestone interbedded with narrow beds of grey shale and blue marl and 16.5 m of thin to medium bedded yellow to white marly limestone-rich lime mudstone to wackestone interbedded with calcareous red mudstone and yellow marl. Horizontal planar lamination, slump sedimentary structure, burrowing, and calcite geodes and veins, and pyrite nodules are seen on the carbonate beds of this association. Petrographically, the association, contains skeletal grains, including benthic foraminifera (*Textularia plummerae*, *Quinqueloculina sp.* and *Valvulina sp.*), Dasycladacean green algae and bioclasts. While non-skeletal grains involve peloids, oncoids, and extraclasts, mainly monocrystalline quartz grains. The groundmass is mainly lithified carbonate mud (micrite) which is occasionally transformed to microspar by neomorphism. Dolomitization is a characterized diagenetic process of this association, particularly in mudstone microfacies. Other significant diagenetic processes include pyritization, dissolution, cementation, silicification, and micritization.

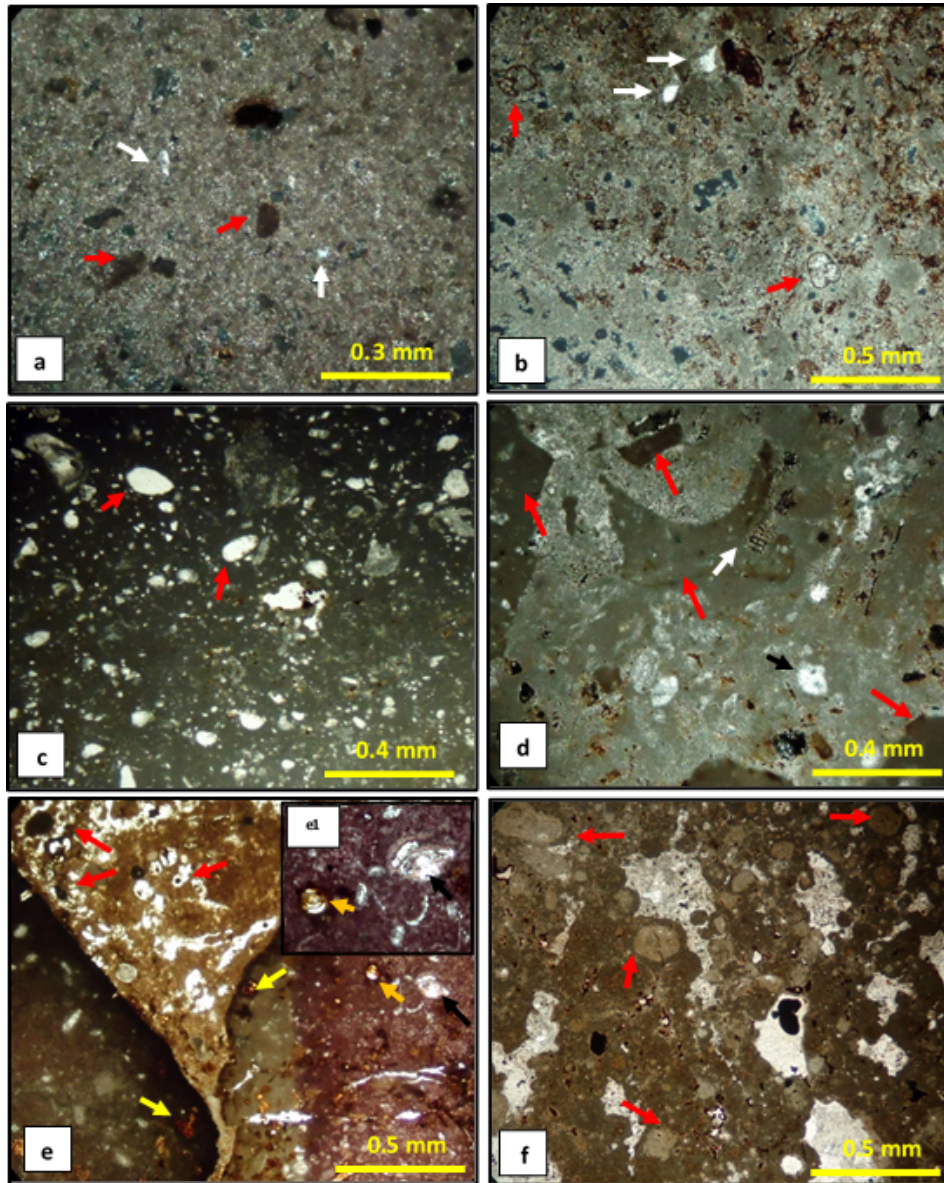


Fig. 7. Photomicrographs showing microfacies types of Avanah Formation in Gomaspan section: (a) Sandy (white arrows)-peloidal (red arrows) lime wackestone.GA9., X.N. (b) Sandy (white arrows)-benthic foraminifera (*Valvulina* (red arrows))- lime wackestone submicrofacies which is characterized by high porous and the foraminiferal test affected by micritization envelop. GA16., X.N. (c) Ostracoda (red arrows)- *calcispheres* lime packstone submicrofacies. GA10., P.P. (d) Bryozoan (white arrow)-ostracoda (black arrow)-intraclasts (red arrows) lime packstone submicrofacies.GA15., P.P. (e) Benthic foraminifera (Rotaliid (black arrow), *Spirloculina* sp. (orange arrow))-bioclasts (yellow arrows)-dasycladacean (red arrows) lime packstone submicrofacies formed in intraformational conglomerate grains .GA15., P.P. (e1) enlarged photomicrographs of part of (e) displaying Rotaliid (black arrow) and *Spirloculina* sp. (orange arrow). (f) Oncoid (red arrows) lime wackestone submicrofacies subjected to cementation and pyritization GA2., P.P.

Key= AG: Avanah-Gomaspan, P.P: Plane polarized light, X.N: Crossed Nicoles.

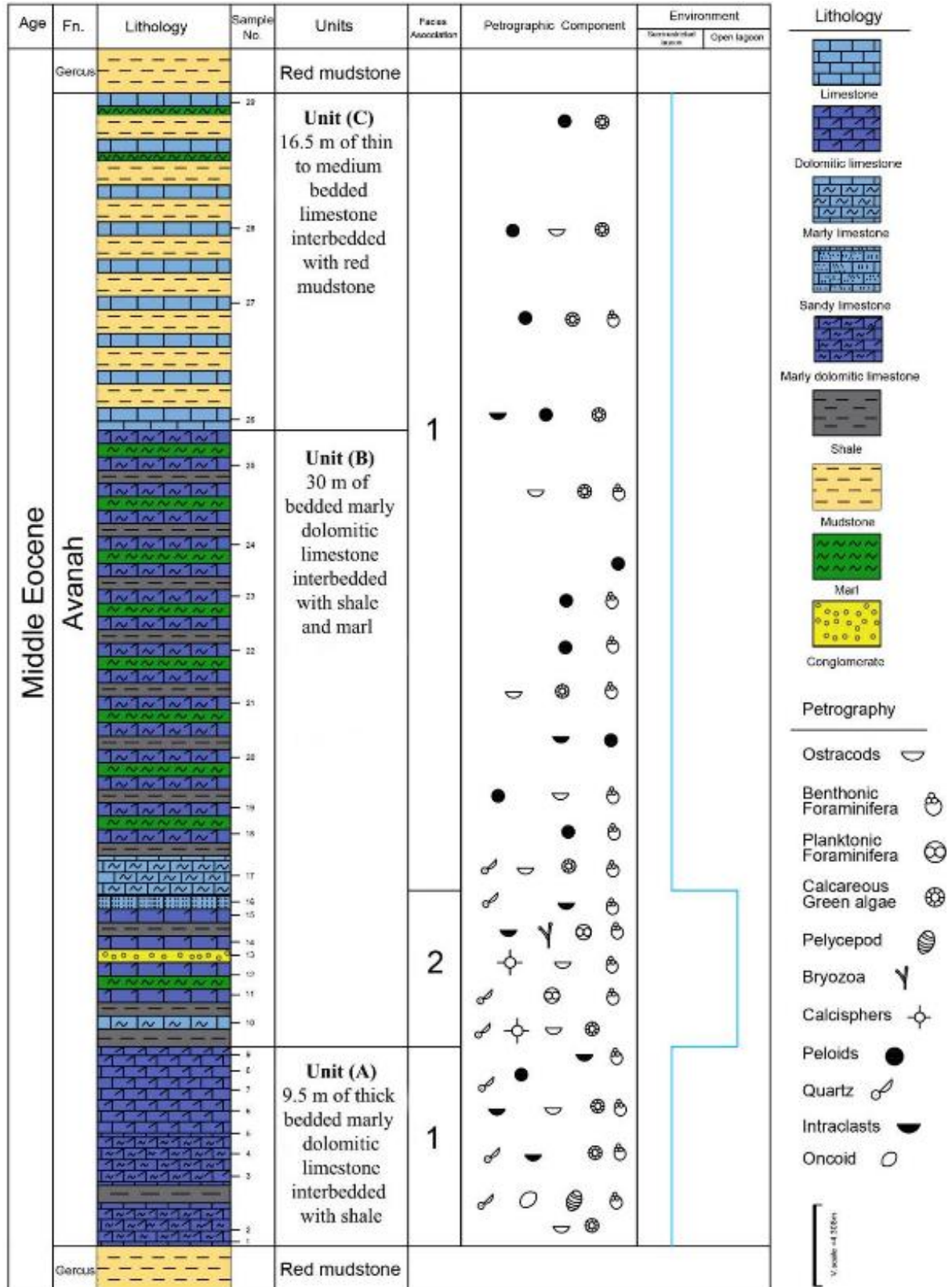


Fig. 8. Columnar sections and Facies Associations of the Avanah Formation in Gomaspan Section.

Interpretation: This facies association is rich in dolomitized lime mudstone followed by lime mudstone and lime wackestone. The dominance of the micrite matrix microfacies within this association indicates that the sea bottom was stagnant and calms enough for lime mud to accumulate (Boggs, 2006). Dolomitized lime mudstone is expected in the restricted platforms (Wilson, 1975; Flügel, 1982). The porcelaneous imperforate miliolids (*Quinqueloculina sp.*) dominate in the restricted lagoon with hypersaline water (Murray, 2006). The presence of *Textularia plummerae* represents a shallow marine environment with semi-restricted conditions (Asaad and Balaky, 2018). The dominance of dasycladacean algae reflects a shallow water environment of less than 10 m deep (Aguirre *et al.*, 2000). The occurrence of peloids within this association indicates shallow warm waters (Flügel, 2010). Oncoidal lime packstone, which occurred at the base of the studied section, indicates an Inner-platform environment (shallow subtidal lagoon) (Flügel, 2010; Pleş *et al.*, 2019). Monocrystalline quartz is believed that it deposited in low energy, restricted intertidal, supratidal, and subtidal environments (Nowrouzi *et al.*, 2015), and its association with benthic foraminifera in lime wackestone microfacies reflects restricted lagoon setting (Ameen *et al.*, 2019). Pelecypods have a wide environmental range, from near-shore to off-shore environments (Clarkson, 1998), but existing as association with mentioned fossils supposed to be deposited in a lagoonal environment. The laminated dark grey shale is thought to be deposited in a shallow lagoon environment with very slow-moving water (Blatt & Tracy, 1996). Calcite and sulphur geodes are diagenetic products that are supposed to be formed by minerals precipitation from aqueous solution filling the dissolved nodules in the rock, mainly composed of evaporates (Milliken, 2003). Burrowing is common in low-energy, shelf lagoons with a circulation environment (Flügel, 2010).

7.2 Open Lagoon Facies Association (FA2)

The association is equivalent to Faces Zone 7 of Wilson (1975) and Standard Microfacies 9 and 18 of Flügel (1982). It is equipped with the lower 7.5 m of unit (B). It consists of medium to thick-bedded grey to blue marly limestone and fossiliferous dolomitic limestone rich in lime wackestone to packstone with rare mudstone interbedded with thin beds of grey shale and blue marl and medium to thick-bedded yellowish-grey sandy limestone rich in lime packstone with 30 cm interval of intraformational conglomerate in the middle part of the facies association. The obvious sedimentary structures of this facies are horizontal planner lamination and symmetrical ripple marks in addition to calcite geodes and veins.

The microscopic investigation of thin sections revealed that the skeletal grains of this association involves benthic foraminifera (Miliolids (*Spirloculina sp.*), *Rotalia sp.*, *Textularia sp.* and *Valvulina sp.*), planktonic foraminifera (*Globigerina sp.*), ostracods, bryozoa, dasycladacean green algae, calcispheres, and bioclasts. Non-Skeletal grains consist of peloids, intraclasts, and extraclasts. The main groundmass is micrite which tentatively changed to microspar. The main diagenetic processes upon the beds of these facies are cementation, micritization, pyritization, dissolution, and neomorphism.

Interpretation: The appearance of planktonic foraminifera (Globigerinid) with benthic fauna indicates a lagoonal environment connecting with open marine (Open shelf) (Ahmad *et al.*, 2020). The occurrence of calcispheres in a shallow water environment with planktonic foraminifera represents deposition toward the deep basin (Al-Haj, 2020). Bryozoa is found in a shallow lagoon with open circulation (Flügel, 2010). The dominance of ostracod fragments reflects an open-marine lagoon across the platform (Flügel, 2010). Intraclasts can create in many environments but most typically are formed in regimes with intermittently high energy conditions (Scholle *and* Scholle, 2003); therefore, are supposed to be developed in an open lagoon setting with high energy conditions in Avanah Formation. Intraformational lime conglomerates are commonly deposited below the storm wave base in the inner shelf environment (Scholle *et al.*, 1983). They are supposed to be created from the reworking of subtidal sediments by storms (Dravis, 1979) in occasional subsiding in the open lagoon basin. Sandy-benthic foraminifera lime wackestone is common in the mixed energy part of the lagoon (Soleimani *et al.*, 2014) in the shallow lagoon with open circulation (Flügel, 2010). The symmetrical ripple marks on sandy limestone beds of the Avanah Formation are thought to be formed in shallow water in the in and out motion of bidirectional waves of sandy size particles bottom in inner shelf environments (Wilson & Jordan, 1983). Highly bioturbated carbonates are inferred to be shallow-marine environments with a low sedimentation rate (Strasser *et al.*, 1999).

Thus, from above observations and interpretations of both facies' associations indicated that the Avanah Formation was deposited in a semi-restricted lagoonal environment with an interval of the open lagoonal setting in the middle part.

A schematic block diagram was drawn to imply all these interpretations and the updated vision of the Avanah environment in the Gomaspan section (Figure 9). This figure illustrates the inferred paleoenvironmental conditions and elements of the Avanah Formation in the Gomaspan section in the Kurdistan region-Northern Iraq.

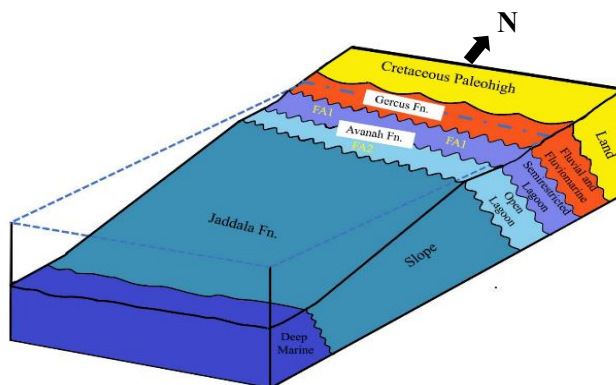


Fig. 9. Schematic Model of Avanah Depositional Environment (Middle Eocene) in Gomaspan section. (FA1: Semi-restricted lagoon Facies Association, FA2: Open Lagoon Facies Association).

8. Conclusions

8.1 The Avanah Formation in the Gomaspan section consists of 56 m medium to thick-bedded yellow limestone, grey dolomitic limestone, dolomitic marly limestone interbedded with thin beds of marl and dark grey shale with an interval of sandy limestone in the middle part and thin to medium bedded limestone interbedded with red mudstone. It is inter-tongue within Gercus Formation.

8.2 Based on field observation and petrographic analysis, three different lithostratigraphic units were identified in the Avanah Formation in the studied section. They are in ascending orders:

- a. Thick bedded dolomitic marly limestone interbedded with shale.
- b. Bedded dolomitic limestone interbedded with shale and marl.
- c. Thin to medium bedded limestone interbedded with red mudstone.

8.3 The petrographic components of Avanah carbonate are as follows:

- a. Matrix composed mainly of micrite with little recrystallized microspar.
- b. Non-skeletal grains involve peloids, oncoids, intraclasts, and extraclasts, commonly monocrystalline quartz.
- c. Skeletal grains include benthic foraminifera, dasycladacean green algae, ostracods, calcispheres, pelecypods, rare planktonic foraminifera, and bryozoa, in addition to bioclasts.

8.4 Depending on detailed microfacies analysis of limestone following Dunham (1962), three main microfacies and twelve submicrofacies are recognized in the studied thin sections of Avanah Formation in the studied area. These facies were subdivided according to their environmental interpretation, vertical and lateral transitions into two basic types of facies associations: semi-restricted and open lagoonal environment

8.5 The study of petrography, facies, and textural analyses, concluded that Avanah Formation in the Gomaspan section was deposited in the shallow marine environment, semi-restricted lagoon, in the lower and upper part, and open lagoon environment in the intervals in the middle part.

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