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البيئة الترسيبية والميكروسحنة في تتابعات الأولجوسين الأعلى والميوسين الأسفل في إقليم كردستان العراقي

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الملخص

يوضح البحث أن تتابعات الأولجوسين الأعلى والميوسين الأسفل في حدود مناطق الدسّر المطوية العالية/ المنخفضة في حي السليمانية، إقليم كردستان، شمال شرق العراق تتجلى في تكوينات Bajwan, Anah and Jeribe. غالباً ما تتسم المناطق محل الدراسة بعدم المطابقة، فوق كربونات الأيوسين (تكوين Pila Spi) التي يعلوها بشكل غير منتظم ترسيبات الميوسين الأوسط Fatha تكوين (فارس Fars الأسفل). يشير البحث إلى أن المناطق الثلاث محل الدراسة (البصرة، زامشا، الوزيارة) تم اختيارها بسبب بيئتها الترسيبية والميكروسحنة. ومن ثم تم تحديد 11 ميكروسحنة. كما تم تمثيل البيئات الترسيبية الأساسية بموضع المنحدر الداخلي الذي تحول إلى منحدر متوسط أثناء الأوجوسين الأعلى (تكوين باجوان) بينما تغير وضع المنزلق الداخلي إلى شبه مُغلق مثل البيئة البحيرية الشاطئية أثناء الميوسين الأسفل (تكوينات Anah و/ أو Jeribe).

Microfacies and depositional environment of the upper oligocene and lower miocene successions from the Iraqi Kurdistan Region

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Abstract

Upper Oligocene and Lower Miocene successions in the High/Low Folded Thrust Zones boundary from the Sulaimani District, Kurdistan region, northeast Iraq, are manifested by the Bajwan, Anah and Jeribe formations. Studied sections are mostly underlain by unconformity, above the Eocene carbonates (Pila Spi Formation) and unconformably overlain by the Middle Miocene deposits of Fatha (Lower Fars) Formation. Three studied sections (Basara, Xamsha and Wazyara) have been investigated for their microfacies and depositional environments. Accordingly, eleven submicrofacies are identified. Main depositional environments are represented by the inner ramp setting that is changed to middle ramp during the Upper Oligocene (Bajwan Formation), while inner ramp setting is changed to semi-closed as lagoonal environment during the Lower Miocene (Anah and/or Jeribe formations).

Keywords: Depositional environment; Kurdistan; lower miocene; microfacies; upper Oligocene.

1. Geological setting

The three studied sections are located at the boundary between the high and low folded thrust zones. This boundary geograpically extends from the Sirwan River to the Little Zab River (Figure 1). This study aims to clarify the stratigraphic and sedimentological properties of the new recorded Upper Oligocene and Lower Miocene stratigraphic units. The predominant microfacies of each stratigraphic unit have been determined, in addition to their depositional environments. The carapace of the studied structures (Qaradagh, Sagerma, and Basara anticlines) is manifested by the Pila Spi Formation and their core by the Kolosh Formation (Paleocene). Al- Khdhimi *et al*. (1998), Aqrawi *et al*. (2010), Fouad (2012) and Lawa (2004) placed the boundary of the high and low folded thrust zones in front of the southwestern limb of the Qaradagh, Basara, and Sagerma anticlines (Figure 1). Basara and Xamsha sections are measured from the southwestern limb of the Basara and Sagerma anticlines, while the Wazyara section is located on the Northeastern limb of Qaradagh anticline (Figure 1). The general stratigraphic column of the studied area is well-illustrated by Figures 2, 3 and 4.

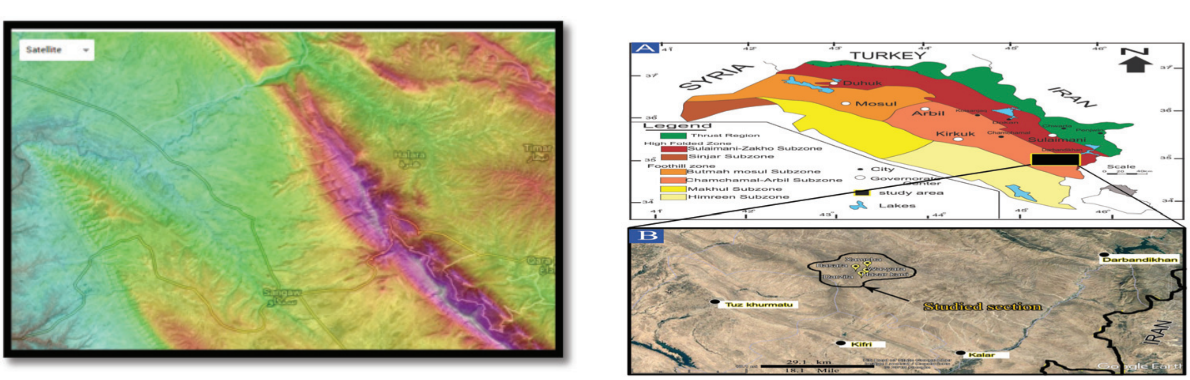

Fig. 1. Location & geological setting of the studied sections, A (Tectonic zones- boundary, after Fouad 2012), B (Demo & satellite image of the studied area).

2. Methodology

Detailed fieldwork was carried out at the high/low folded thrust zones boundary, in term of detailed sedimentology and stratigraphic concepts. Out of 110 rock samples, one hundred (100) thin sections were prepared by using polarized microscope to define microfacies types. Thin sections were stained to distinguish between calcite and dolomite components. Carbonate rock classification followed the nomenclature system of Dunham (1962), Embry & Klovan (1971), Flugel (2010), and Wilson (1975).

3. Microfacies

Six major microfacies have been identified and subdivided into eleven (11) submicrofacies. Figures (5 & 6), Table (1).

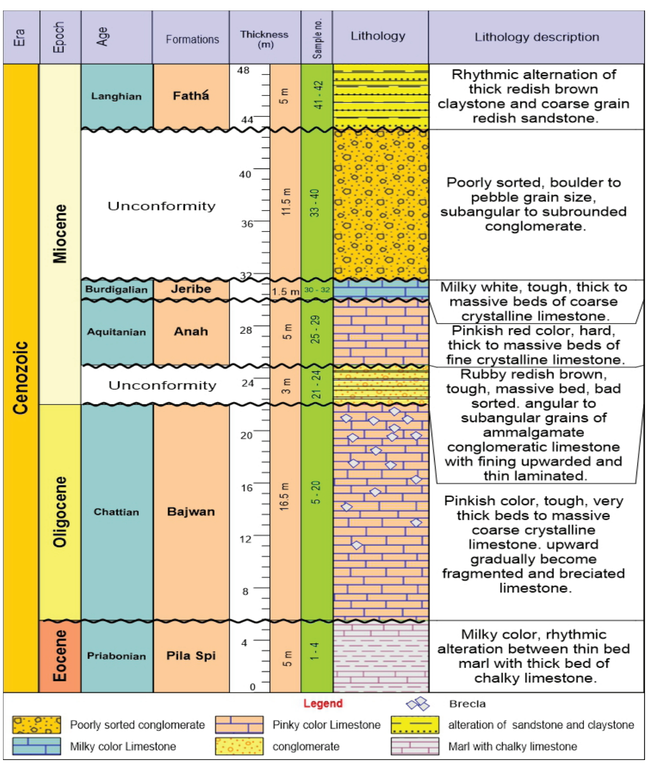

Fig. 2. Stratigraphic column of Basara section.

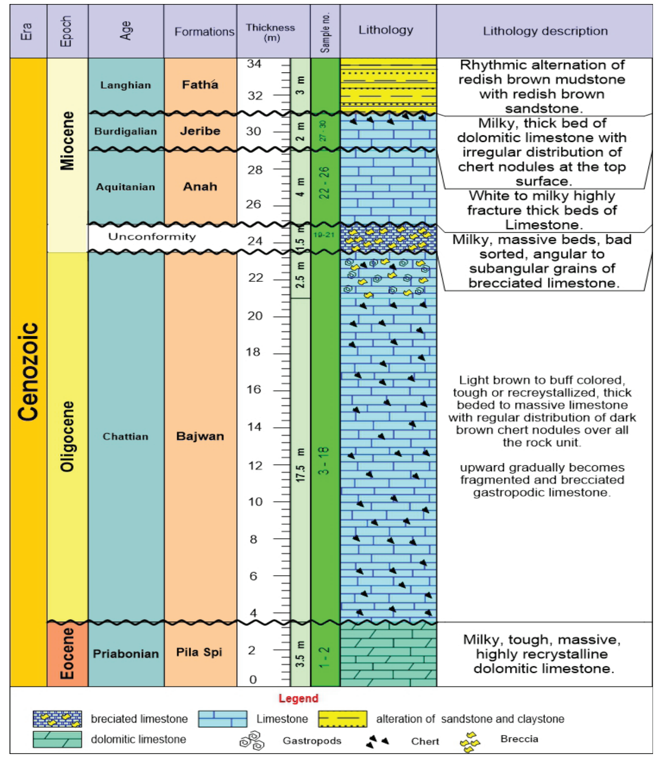

Fig. 3. Stratigraphic column of Wazyara section.

3.1 Microfacies types of Bajwan Formation (B)

3.1.1 Extraclasts Wackestone submicrofacies: B1 (Figures 5a, b). This submicrofacies type overlies the dolomudstone submicrofacies of the Pila Spi Formation and underlies the extraclasts rudstone submicrofacies of the Fatha Formation.

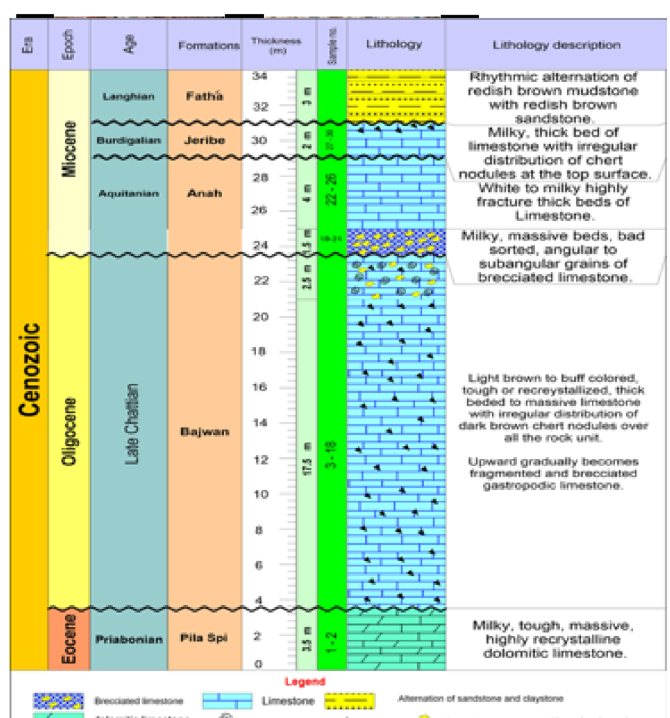

Fig. 4. Stratigraphic column of Xamsha section.

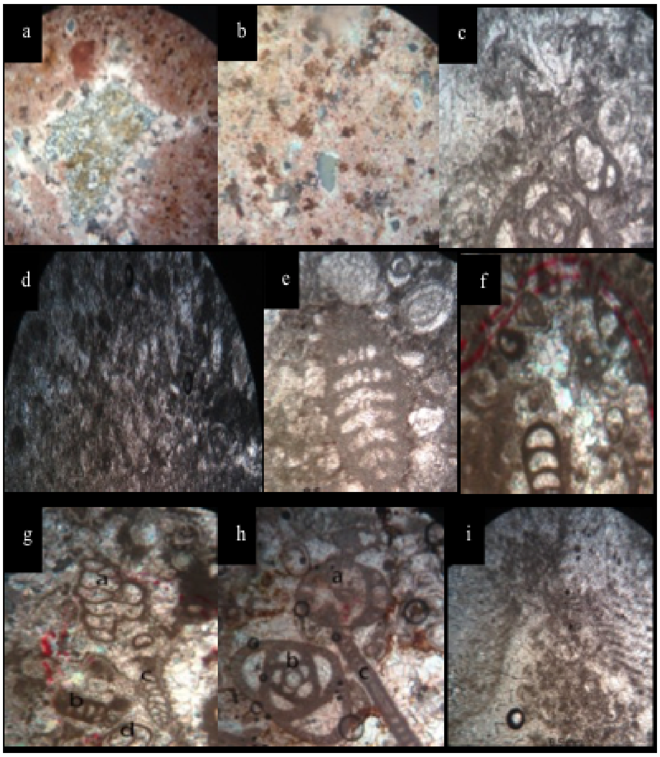

Fig. 5. B1 (a, b) Extraclasts wackestone, BA, S.NO 12, 15, XP, B2 (c, d) Milliolids Soritoids packstone, XA, S.No 5, 6, XP, B3 (e) *Praerhapydionina* packstone, WZ, S. No 8, XP, B4 (f, g, h) Milliolids -Valvulinids grainstone, WZ, S.No 5, 7, 13, & B5 (i) Dasycladacea & Coral Framestone, WZ, S. No 26, XP.

The thickness of this submicrofacies is (14m) and only observed at the Basara section. The extraclasts grains are of different sizes (2mm-20cm), and sources (carbonate rock, chert, mudrocks, and fine quartz grains), while bioclasts and skeletal grains belong to benthic foraminifera such as *Rotallids*, *Valvulinids, Miliolid and Praerhapydionina delicata Henson*, with low diversity. All of these components are distributed within a dark micritic groundmass. This microfacies is highly porous and rich in organic matter towards the upper parts of the formation. Recrystallization, dissolution, compaction, and stylolite features are common digenetic features.

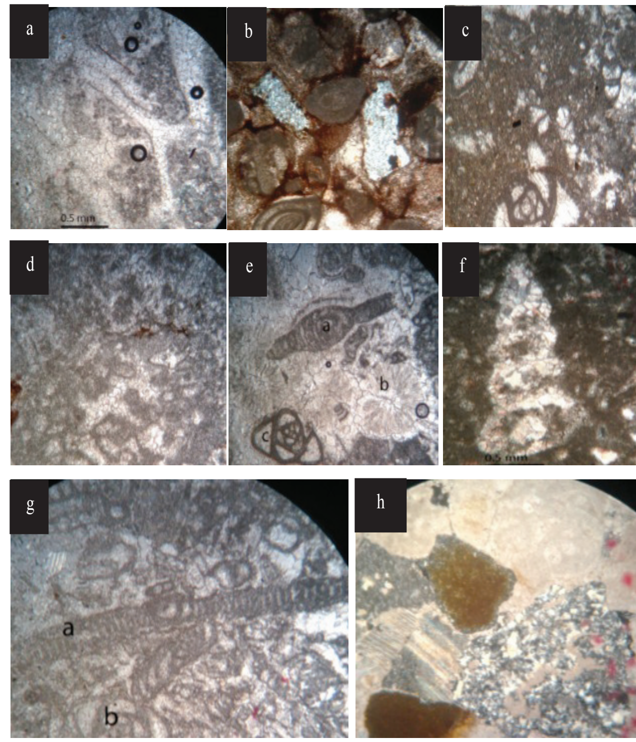

Fig. 6. B5 (a) Dasycladacea & Coral Framestone, WZ, S. No 28, XP, A1 (b) Exraclasts Rudstone WZ, XA, & S. No 26, 14, XP, A2 (c) *Austrotrilina* packstone, XA, S. No 17, XP, A3 (d, e) Coralline algal Framestone, WZ, XA S. No 27, 28, XP. J1 (f) Gastropoda wackestone,WZ, S. No 22, XP, J2 (g) *Peneroplis* packstone- grainstone, XA, S. No 23, XP, & F1 (h) Extraclasts Rudstone, BA, S. No 14, XP.

Interpretation: The presence of multisource and size extraclasts grains are indications of the proximity of the source. The subangular to subrounded rock fragments emphasized the unconformity boundary. The benthic foramninferal associations mostly represent lagoonal facies of an inner ramp setting according to Brandano *et al*. (2008). According to Brasier (1980) and to Hallock and Glenn (1986), the occurrence of rotaliids represents hypersaline conditions of the restricted lagoon (internal ramp) depositional environments.

Table 1. Main microfacies & submicrofacies type, composition, diagenesis processes & depositional environment of different Formations from study sections.

Formations	Sections	Main microfacies type	Submicrofacies types	Code	Thickness (meter)	Compostion of the microfacies	Diagenesis	Depositional environment
Fatha	Wazyara	Rudstone	Extraclasts rudstone	F1	11.5	Extraclasts carbonate rock fragments %50- %55,chert %40- 45 , mud rock fragments%7, quartz grains%5) & radiolarian chert %1	Recrystallization, dissolution, silicification and compaction	Tidal flat inner ramp
	Basara	Rudstone	Extraclasts rudstone	F1	3	Extraclasts carbonate rock fragments %55-%60 with few chert rock fragments %30, mud rock fragments %5 & quartz grains %2	Recrystallization, dissolution, compaction and silicification	Tidal flat inner ramp
Jeribe	Wazyara	Wackestone	Gastropoda wackestone	J1	1.5	Gastropoda%5, Rotallids %3, *Praerhapydionina sp* %2, green algae %2 and Bolivina %1	Recrystallization	Restricted lagooon (inner ramp)
	Xamsha	Packstone-grainstone	Peneroplis packstone-grainstone	J2	2	Peneroplis %25,Milliolids %15, Pelecypoda %5, *Praerhapydionina* %1, *Dendritina rangi* %3, green algae %5, Gastropda %1, Valvulinids %2, extraclast %3 and Textularia %1	Dissolution, cementation and silicification	Shoal environment (inner ramp)
Anah	Wazyara	Boundstone	Coralline algal Framestone	A3	5	Coral %25,Milliolids (*Austratrillina* %15), *Praerhapydionina* %10, Peneroplis %5, *Archaias* %5, Valvulinids %5, green algae %2, Bolivina %1 and *Dendritin* %1	Compaction, Micritization and cementation	Reef environment (middle ramp)
		Rudstone	Extraclasts rudstone	A1	3	Extraclasts carbonate rock fragments %60- %75,chert %13 radiolarian chert %10, mud rock fragments %5 & quartz grains%2)	Recrystallization, dissolution, silicification and compaction	Tidal flat inner ramp
	Xamsha	Boundstone	Coralline algal Framestone	A3	1	Coral%35, Milliolids %15, Peneroplis %10, Valvulinids %5 and *Dendritina rangi* %3	Cementation, micritization and dissolution	Reef environment (middle ramp)
		packstone	Austrotrilina packstone	A2	3	Milliolids (*Austratrillina* %20), other Milliolids %10, Peneroplis %10, Valvulinids %7, *Dendritina* %5 and *Praerhapydionina delicata* %5	Cementation, micritization and dissolution	Open lagoon (inner ramp)
		Rudstone	Extraclasts rudstone	A1	1.5	Extraclasts carbonate rock fragments %75-80, quartz grains %5 and chert %2	Recrystallization, dissolution, compaction and silicification	Tidal flat inner ramp
Bajwan	Wazyara	Boundstone	Dasycladacea and coral Framestone	B5	3.5	Green algae %35, patch reef coral %25, Miliolids %3, Rotalids %4, *Dendritina rangi* %5, *Austrotrillina howchini* %3, *Praerhapydionina delicata* %1	recrystallization and dissolution	Reef (middle ramp)
		Packstone	prarephydionina packstone	B3	3	*Praerhapydionina* sp %17, Miliolids %10, Peneroplis %5, Valvulinids %3, Echinoid %2, Rotallids %2, dendritina %2, Gastropoda %2	micritization, silicification, recrystallization and dissolution	Open lagoon (inner ramp)
		grainstone	Miliolids Valvulinids Grainstone	B4	10	Milliolids (*Austrotrillina*) %35, Valvulinids %20,Soritoid (Peneroplis %10, *Praerhapydionina delicata* %15,*Archaias sp* %2), *Spiroplactammina* %5, Algae %3, Bolivina%2 *Dendritina rangi* %1, Echinoids %1, Valvulinids %1, , Rotalia %1	recrystallization, micritization, cementation, dissolution and silicification	sand shoal (inner ramp)
	Xamsha	Packstone	Miliolids Soritoids packstone	B2	20	Milliolids % 30, Soritoids (*Archaias* %15,, *Praerhpydionina delicata* %7, peneroplis), Echinoid %5, *Rotalia viennoti* %3, Gastropoda %2, green algae %2, Pelecypoda %3, Bryozoa %1 and peloids %3	recrystallization, dissolution and silicification	restricted lagoon (inner ramp)
	Basara	Wackestone	Extraclasts wackestone	B1	14	Extraclasts (carbonate rock fragments %5, chert %3, %quartz %3 and mud rocks fragments %2) , Rotalids %5 and Valvulinids %3 with small amount of *Prarephydionina* %2 and Milliolids %1 and bioclasts %1	recrystallization, dissolution and silicification	restricted lagoon (inner ramp)

3.1.2 Miliolids-Soritoids Packstone:

B2 (Figs. 5c, d). This submicrofacies overlies the dolomudstone of Pila Spi Formation and underlies the extraclastic rudstone of Anah Formation. This submicrofacies was observed along the wholy part of the Bajwan Formation at Xamsha section and its thickness reaches 20 m. Different species of *Miliolids* are recorded *(Austrotrilina howchini Schlumberger, Pyrgo sp, Quinqueloculina sp, and Triloculina sp)* and *Soritoids* (*Archaias sp. Peneroplis sp. Praerhapydioninadelicate Henson*). The occurrence of *Rotalia viennoti Greig,* bioclasts of echinoids, gastropoda, green algae, pelecypods, and bryozoans are less abundant. All these components are embedded within a dark gray micritic groundmass. Silicification, dissolution, and recrystallization partially affect the groundmass and some of the skeletal grains.

Interpretation**:** According to Farhan *et al*. (2016), such microfacies deposited in restricted shallow sub-tidal environments with relatively low energy, since it is enriched with a high number of benthic foraminifera (Miliolids, Archaias, and *Praerhapydionina*). Buxton and Pedly (1989) and Al- Qayim *et al*. (2015) mentioned that the occurrence of benthic foraminifera such as Archaias sp. indicates that the deposition is of tropical and subtropical shallow-water environmental conditions of the lagoon type, whereas the presence of benthic fauna is referring to lagoonal facies and an inner ramp platform (Brandano *et al*. 2008; Flugel, 2010). The larger amount and high variety of imperforate benthic fauna (miliolids) is a good indicator of the shallow restricted lagoonal environment (Hallook & Glenn, 1986). According to Rafi *et al*. (2012) miliolids prefer to live in a lagoon and in restricted marine environments. Based on the above data, this submicrofacies is deposited in an inner ramp setting. Al-Enezi *et al*. (2019) recorded several porcelaneous and hyaline tests of recent foraminifera on Umm AL Maradim Island associated with the coral reef body south of Kuwait. She also mentioned that the high dominance of porcelaneous tests might be explained by the peculiar physiographic setting and the presence of coral reef around the Island.

3.1.3 *Praerhapydionina* Packstone:

B3 (Figure 5e). This submicrofacies type overlies the Miliolids- Valvulinids grainstone and underlies the Dasycladacea and Coral Framestone submicrofacies of the Bajwan Formation. It is about (3m) thick and identified from the middle part of the Bajwan Formation from the Wazyara section only. The major constituents are skeletal grains of *Praerhapydionina delicate Henson*. Other grains such as *Miliolids*, *Valvulinids, Peneprolis, Archaias, Dendritina, Rotallids,* and shell fragments of echinoids and gastropoda are less common.

Interpretation: The co-existence of larger benthic foraminifera with *Miliolids, Peneroplis,* and *Archaias* together with *Dendritina,* Rotallids, and Valvulinids, indicates a back reef environment (Farhan *et al*. 2016). However, the high occurrence of the *Praerhapydionina delicata* is common in water at a depth of 8-10m with a temperature of 11^0c- 33^0c at the back reef area (Othman, 2007). Consequently, this facies is deposited in shallow waters with open circulation within the inner ramp.

3.1.4 Miliolids-Valvulinids Grainstone:

B4 (Figures 5f, g&h). This submicrofacies type overlies the dolomudstone of the Pila Spi Formation and underlies the Praerhapydionina packstone of the Bajwan Formation, about 10m thick and recorded at the lower part of the Bajwan Formation from the Wazyara section only. It is composed of *Miliolids (Austrotrilina sp, Quinqueloculina, Pyrgo sp, Spiroloculina sp,*and *Spirolina cylindreca*), *Spiroplactammina* and *Valvulinids* with *Soritoids* (*Peneroplid evolutus Henson, thomasi Henson* and *farsensis Henson*), *Archaias sp*, and *Praerhapydionina delicata Henson*. Others such as *Bolivina, Dendritina, Rotallids,* bioclasts of *Echinoids* and algae are also observed. Few *Miliolids* are coated by a dark gray micritic envelope. All the grains are embedded in sparry calcite cement. The common diagenesis processes are micritization, silicification, recrystallization, neomorphism, and dissolution.

Interpretation: *Miliolids* mostly exist in a variety of very shallow, hyposaline to hypersaline environments and is also common in sand shoal environments of normal salinity (Rashid *et al*. 2015). This microfacies of grainstone fabric, a low amount of micrite, and the occurrence of sparry calcite cement indicate the deposition in a high energy shoal environment. The faunal association of miliolids, soritoid, rotaliids and echinoids characterizes an inner part of the platform (Corda & Brandano, 2003). This submicrofacies was deposited in a high energy sand shoals or bars environment (Tucker, 2001; Yazdani, 2014). Accordinly, this facies is deposited in an inner ramp setting.

3.1.5 Dasycladacea and coral Framestone:

B5 (Figures 5i & 6a). This submicrofacies overlies the *Praerhapydionina* Packstone of the Bajwan Formation and underlies the extraclasts rudstone of the Anah Formation. This microfacies is about 3.5m in thickness and recorded at the upper part of the Bajwan Formation from the Wazyara section only. It is predominantly composed of green algae (>2mm size) and coral. Other components like miliolids, rotalids, *Dendritina, Praerhapydionina delicate* HENSON, *Austrotrillina howchini* (SHLUMBERGER) and bioclasts of echinoids were observed as well. The bioturbation feature was also noted within the facies. The commonly recognized diagenesis was partially recrystallization and dissolution. Accordinly, this facies is deposited in a middle ramp setting.

3.2 Microfacies type of Anah Formation (A)

3.2.1 Extraclasts rudstone:

A1 (Figure 6b). This submicrofacies overlies the miliolid-soritoid-packstone of the Bajwan Formation and underlies the *Austrotrilina* packstone of the Anah Formation at the Xamsha section, but at the Wazyara section it overlies the Dasycladacea and coral framestone of the Bajwan Formation and underlies the Coralline algal framestone of the Anah Formation. The thickness of this facies ranges between 1.5m-3m and represents an unconformable boundary between the Bajwan and Anah formations. The main components are represented by carbonate fragments of Oligocene with radiolarian chert, mudrocks and polycrystalline quartz fragments at the Wazyara section, whereas at the Xamsha section, the extraclasts of radiolarian chert and mudrocks are not recorded. The groundmass is rich in clay material and/or reddish-brown iron oxides. The clasts are mostly poorly sorted and angular to subangular with various sizes (0.2-40 cm). Dissolution and compaction affected the groundmass and clasts. This microfacies with very compacted grain supported conglomerate and showed concavo-convex and suture contact types.

Interpretation: The mixed extraclasts (carbonate and siliciclastic) with different size and shape can be common in near-shore environments. The input of extraclasts into the carbonate environment by erosion of the underlying sediments indicates a tidal depositional setting (Flugel, 2010). Most of the main components of this microfacies were driven by the erosion of various Oligocene and older stratal unit fragments. Accordingly, this facies was deposited in an algal tidal channel and restricted shelf-lagoon environments.

3.2.2 Austrotrilina packstone:

A2 (Figure 6c). This submicrofacies overlies the extraclasts rudstone of the Anah Formation and underlies the coralline framestone of the Anah Formation. It is recorded only at the middle part of the Anah Formation from the Xamsha section and is about 3m thick. The major components are skeletal grains of benthic foraminifera *(Austrotrilina howchini Shlumberger)* and others miliolids *(Pyrgo sp, Quinqueloculina sp*, and *Triloculina sp), Peneropilids (Peneroplis thomasi Henson, Peneroplis evolutus Henson*, and *Peneroplis sp*.) with *Dendritina sp, Valvulinids* and *Praerhapydionina delicata Henson*. The forams are embedded in calcite cement groundmass. Types of diagenetic processes that affected this microfacies are dissolution, micritization, and cementation.

Interpretation: The occurrences of larger, imperforate foraminifera indicate deposition in a shelf-lagoon setting, inner ramp (Al- Ghreri *et al*. 2013). According to Yazdani (2014) this type of facies is deposited in an inner ramp setting and points to a nutrient-rich and slightly hypersaline and warm euphotic condition.

3.2.3 Coralline algal framestone:

A3 (Figures 6d & e). This submicrofacies overlies the Austrotrilina packstone of the Anah Formation and underlies the Peneroplis packstone-grainstone of the Jeribe Formation at the Xamsha section and is about 1m thick, while, at the Wazyara section, about 5m thick. The facies mostly overlies the extraclasts rudstone of the Anah Formation and underlies the gastropoda wackestone of the Jeribe Formation. The main components are a reef coral colony having radiating septa. The associated foraminifera are *(Pyrgo sp, Quinqueloculina sp* and *Triloculina sp), (Peneroplis thomasi Henson,* and *Peneroplis evolutus Henson*), *Dendritina rangi d'Orbigny* and valvulinids at the Xamsha section, while, at the

Wazyara section, there is a patchy reef associated with *Austrotrilina howchini* Shlumberger*, Praerhapydionina delicate* Enson, peneroplid*s*, Archaias, Valvulinids, *Dendritina rangi d·Orbigny,* with a few green calcareous algae. Diagenetic processes such as dissolution, re-crystallization, cementation, and micritization have affected groundmass and skeletal grains.

Interpretation: The coral reef patches refer to the upper part of a carbonate slope environment in an oligotrophic condition (Flugel, 2010; Wilson, 1975) or as mid-ramp environment (Buxton & Pedly, 1989). Consequently, this submicrofacies is formed within a carbonate middle ramp setting.

3.3 Microfacies type of Jeribe Formation (J)

3.3.1 Gastropoda wackestone:

J1 (Figure 6f). This submicrofacies overlies the Coralline framestone of Anah and underlies the Fatha Formation. It is about 1.5m thick and recorded from the Wazyara section. The constituents are gastropods with rotalids, *Praerhapydionina delicata Henson,* dasycladeca and pelecypods. The diagenesis is represented only by recrystallization.

Interpretation**:** Erfani *et al.* (2016) concluded that the gastropoda are attributed to low erosion and movement, implying an oxidized, low-energy, restricted lagoon environment. This microfacies marked sedimentation in the restricted lagoon environment of the inner ramp (Flugel, 2010; Wilson, 1975). It is mostly deposited in a low-energy environment and represented by protected embayment in a shallow subtidal ramp.

3.3.3. *Peneroplis* packstone-grainstone:

J2 (Figure 6g). This submicrofacies overlies the coralline algae framestone of the Anah Formation and underlies the facies of the Quaternary deposits. The thickness is about 2m at the Xamsha section. The benthic fauna includes peneropilid*s*, *Austrotrilina howchini Shlumberger, Pyrgo* sp, *Quinqueloculina* sp*, Dendritina rangi d'Orbigny, Praerhapydionina delicata Henson,* and *Textularia, Valviulina).* The bivalves, green algae, gastropoda, and a few quartz and chert grains are recognized, too. Diagenetic processes like dissolution, cementation and silicification are mostly affected on groundmass and skeletal grains.

Interpretation: The association of *Peneroplis* miliolids mostly indicates shallow warm tropical environments. The presence of sparry calcite cement almost refers to the photic zone of a high energy environment (Flugel, 2010). Accordingly, this submicrofacies was deposited in a shoal environment.

3.4 Microfacies type of Fatha Formation (F)

3.4.1 Extraclasts rudstone:

F1 (Figure 6h). This submicrofacies overlies the extraclasts wackestone of the Bajwan Formation and underlies the Oyster wackestone microfacies of the Fatha Formation at the Basara section, but at Wazyara section it overlies the gastropoda wackestone of the Jeribe Formation and underlies the sandstone submicrofacies of the Fatha Formation. Their thickness ranges between 3 and 11.5m. The main components are represented by extraclasts of different sources and sizes (boulders of carbonates and poorly sorted, subangular siliciclastic). The groundmass of this submicrofacies is rich in clay and reddish to brown iron oxide materials. Dissolution and compaction affected the groundmass and clasts.

Interpretation: The mixed extraclastic rock fragments of different sizes and shapes can be common in near-coast environments. Most of the components were derived from the erosion of various gravel particles which had been re-deposited due to marine transgression of the sea caused by the sedimentation at the beginning of the new sedimentary cycle at the Middle Miocene This type of facies was formed as a lag deposit in tidal channels and restricted shelf-lagoon environments (Flugel, 2010; Wilson, 1975).

4. Depositional environment model

Several carbonate systems in marine environments are defined and represented by lagoon, shoal and reef environments (Figure 7).

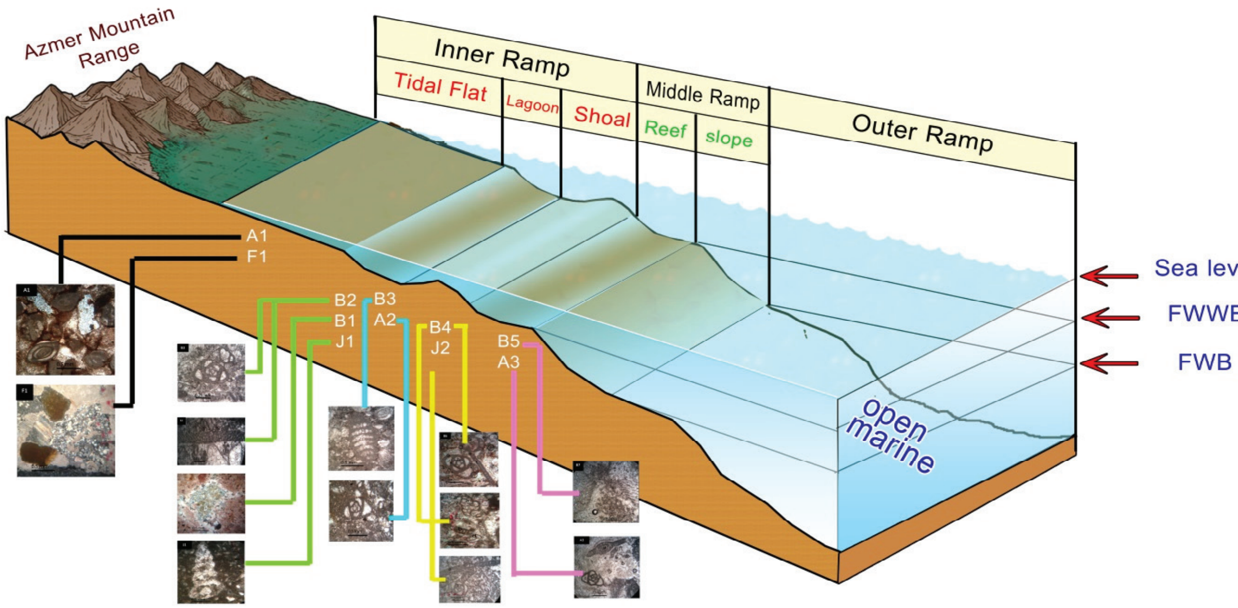

Fig. 7. Facies distribution & depositional models during Late Oligocene- Early Miocene.

The most dominated microfacies are widely distributed in the inner (lagoon and shoal environments) and middle (reef environment) ramps (Burchette and Wright, 1992). The submicrofacies B1, B2 (Bajwan Fn.) are deposited in restricted shallow subtidal environment with relatively low energy lagoon facies. Also, the characters of these submicrofacies suggested a restriction to a slightly hypersaline stressful low energy shallow water environment in a near- shore setting (Kakemen, 2016). The B3 submicrofacies is proposed as an open circulation lagoon environment, while Microfacies type deposited within sand shoal facies is represented by B4. The patchy reef facies, (B5) composed mainly of coral and algae, refers to an organic reef. The Anah Formation was deposited in an inner ramp setting. The Jeribe Formation was deposited in restricted lagoon and shoal environments based on microfacies types J1 and J2. Moreover, the lowermost part of the Fatha Formation was deposited in a tidal flat setting (inner ramp) represented by F1 submicrofacies. Consequently, the Bajwan Formation was deposited in the inner and middle ramp environments, while the Anah Formation was deposited in the inner ramp and upper part deposited in the middle ramp environment. The sedimentation of Jeribe facies took place in the inner ramp environment only, while the Fatha Formation was deposited in semi-restricted depositional lagoon environments.

5. Conclusions

The microfacies types of the Bajwan Formation (Chattian) are extraclasts ackestone, miliolids-soritoids packstone, *Praerhapydionina* packstone, miliolids-valvulinids grainstone and dasycladacea and coral framestone and the depositional environment is of inner and middle ramp. Extraclasts rudstone, *Austrotrilina* packstone, and coralline algal framestone submicrofacies are the microfacies types of the Anah Formation (Aquitanian) that was deposited in the inner ramp and grading upwards to a middle ramp environment at the Wazyara and Xamsha sections. Microfacies types at the Jeribe Formation (Burdigalian) are gastropod wackestone and Peneroplis packstone-grainstone submicrofacies and deposited in an inner ramp environment, particularly at the Wazyara and Xamsha sections. The extraclastic rudstone submicrofacies type was observed in the Fatha Formation almost overlying the Anah Formation and determined as semi-restricted depositional lagoon environments at the Wazyara and Basara sections.

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