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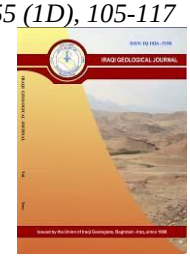

Microfacies Analysis and Depositional Environment of Khurmala Formation (Paleocene-Early Eocene) in Kalati Section, Akre Area, Kurdistan Region, Iraq

Aland M. Ahmed[1,*]

[1] Survey Department, Technical Institute-Akre, Duhok Polytechnic University, Duhok, Iraq

[*] **Correspondence**: aland.ahmed@dpu.edu.krd

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Abstract

The depositional environment of the Khurmala Formation (Paleocene-Early Eocene) in the Kalati village, Akre area, northern Kurdistan region of Iraq was carried out from its microfacies analysis. The total thickness of the formation in studied section is about 220 m and it is divided into three lithostratigraphic units: Brecciated dolomitic limestone unit, Medium to thick bedded dolomitic limestone unit and Thin to medium bedded limestone unit. Based on the detailed microfacies studies of 33 thin sections, three microfacies and ten sub microfacies were distinguished in the carbonate rocks of Khurmala Formation and they are subdivided depending on their environmental interpretation, into two facies association: back reef /lagoon and intertidal. Field observation and microfacies studies suggest that the Khurmala Formation in Kalati outcrop was deposited in the back reef lagoonal environment in the lower part and intervals of the middle part and changed to an intertidal environment toward the upper part.

Keywords: Microfacies; Depositional environment; Paleocene-Eocene; Kalati; Northern Iraq

1. Introduction

The Paleogene Khurmala Formation has significant economic value because is regarded as a hydrocarbon reservoir in some oil fields in northern Iraq (Al-Dabagh, 2010). It was firstly defined by Bellen (1953 in Bellen et al., 1959) from its type locality (well Kirkuk-114) which is comprised mainly of dolomite (pseudoplastic in parts) and finely recrystallized limestone. Ditmar and the Iraqi-Soviet Team (1971) mentioned that the Khurmala Formation consists of recrystallized limestones, with occasional argillaceous beds, and beds of anhydrite and gypsum in well Chemchemal-2. In some surface section such as Koi Sanjak, Surdash and Sirwan, contains argillaceous limestone and marls (Bellen et al., 1959).

The Khurmala Formation is occupied the middle part of the tectonostratigraphic megasequences (AP 10) of Sharland et al. (2001) and belongs to Paleocene-Early Eocene age depending on its stratigraphic relationship to other dated formations (Bellen et al., 1959; Jassim and Buday, 2006). The thickness of the formation in its type locality about 185 m and reaches to 262m in well Atshan-1. Whereas, in surface sections which is mainly occurred in High Folded Zone, it is thickness varies

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between several meters to 90 m and reaches to 90.7 m in Spindar section in Gara anticline Northern Iraq (Barzani, 2020).The Khurmala Formation in northern Iraq was described by Bellen et al., (1959), then many researchers were studied sedimentology, stratigraphy and paleontology: e.g. Buday (1980), Al-Eisa (1983), Al-Berzanji (1989), Al-Qayim (1995), Lawa (2004), Karim (2009), Al-Dabagh (2010), Salih (2010), Salih (2013), Omer et al. (2014), Tamar-Agha et al. (2015), Asaad and Balaky (2018), Karim et al. (2018) Barzani and Al-Qayim (2019), Barzani (2020), Daoud (2020) and Al-Qayim and Barzani (2021).However, some of them designed the depositional environment of the formation, but no one studied the formation in the present section. The main aim of this paper is to study petrographic description and microfacies distribution, to clarify the depositional environment of the Khurmala Formation in Kalati section, Akre area, Kurdistan region, Northern Iraq.

2. Geologic Setting

The Khurmala Formation occupied the restricted belt between Chemchemal-Qizil Dagh in the southeast to Bashiqa-Jabal Maqlub area in the northwest (Bellen et al., 1959). It is regarded as lagoonal carbonate unit equivalent of the Paleocene- lower Eocene Sinjar reefal Limestone Formation (Bellen et al., 1959). The studied section is located in High Folded Zone (Fig. 1a), 30 m north of the Kalati Village, in the outlet of the Kalati Valley 6.5 km and 17 km east of Bjeel and Akre towns respectively near to the main road between Qandil-Akre in Duhok Governorate, almost on Lat. 36° 43' 52" N and Long. 44° 05' 16" E. Structurally, the Kalati section is located in the western segment of the southern limb of Berat anticline which is characterized by E-W trends of anticline axis in the area while it has NW-SE trending in the S and SE parts. The change of the trend of the axis of Berat anticline is associated with the collision and convergent zone along the Taurus–Zagros Mountain system (Al-Ma´amar and Obaidi, 2016). The exposed rocks at the core of the anticline are belong to Cretaceous period, whereas, the Cenozoic rocks manifested toward the limbs of the anticline (Zebari, 2013) (Fig.1b).

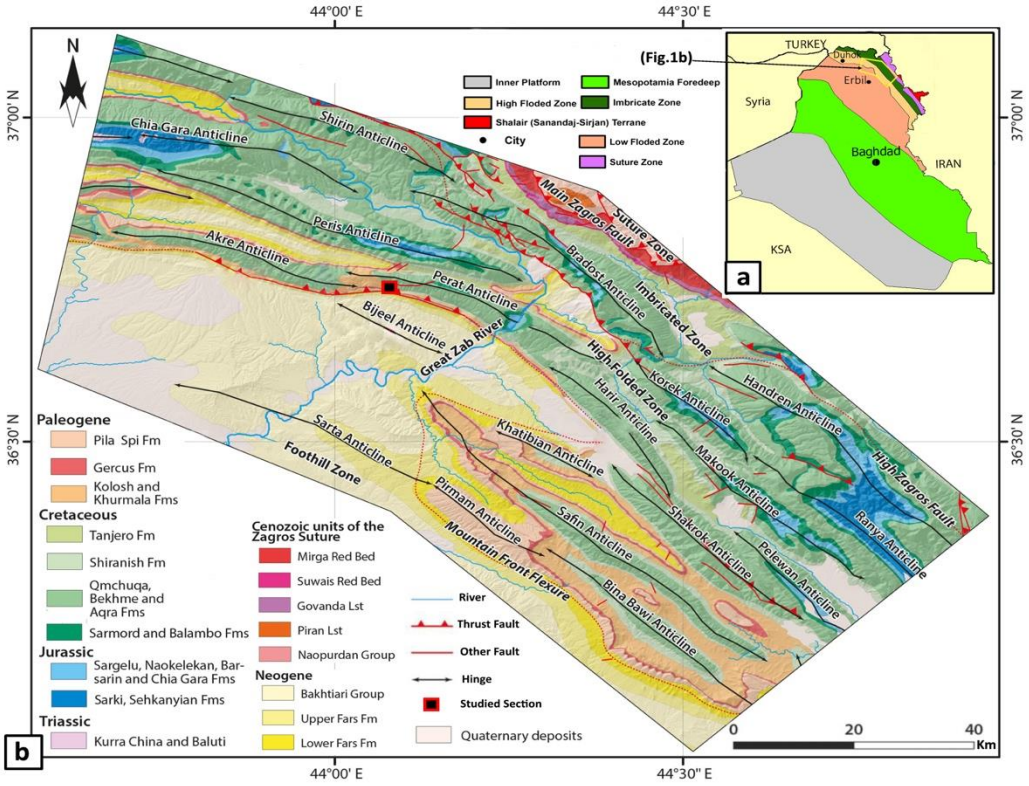

Fig.1. a) Location of studied area with tectonic divisions of Iraq after (Fouad, 2015); b) Geological and structural map of studied area (Modified from Zebari et al., 2019)

Stratigraphically, Berat anticline comprised of Cretaceous Qamchuqa and Bekhma formations in the core of anticline and Shiranish (Cretaceous) (Znad et al., 2020), Kolosh, Khurmala, Gercus, Avanah, Pila Spi, Fatha (Lower Fars), Injana (Upper Fars), and further away Mukdadya (Lower Bakhtiari) and Bai hasan (Upper Bakhtiari) formations of (Tertiary) toward the southern limb of the anticline (Asaad, 2022) (Fig. 1b). The nature of the contact with underlaying grey Shale of Kolosh Formation is unclear due to covering by about 100m of recent sediments. Whereas, it sets gradational and conformable with the overlying red mudstone of Gercus Formation (Fig.2a).

3. Materials and Methods

The field works of the current study started with a recording of all field characteristics in the studied outcrop, which encompasses measuring the thickness of the beds and logging a lithology. Although, the nature of the boundaries of the studied formation is assigned. A sum of 33 fresh samples from carbonate rocks of the Khurmala Formation in Kalati section were collected and the upper and lower surface of each sample are marked.

Later, the lab works includes the preparing of 33 thin sections at least one thin section of each collected sample. Thin sections were done at the workshop of the Earth Sciences and Petroleum Department in Salahaddin University –Erbil. All thin sections are stained by the Alizarin Red Solution (ARS) according to Friedman (1959) procedure for the identification between calcite and dolomite. The detailed petrographic and microfacies study were examined by using a polarized microscope and depending on the classification of Dunham (1962).

4. Results

4.1. Lithostratigraphy

The overall thickness of the Khurmala Formation in Kalati section reaches 220 m (Fig. 2a). The Khurmala Formation in the Kalati section can be divided into three units according to the field observation and lithologic description which are in ascending order:

4.1.1. Brecciated dolomitic limestone unit (Unit A)

The thickness of this unit is 105 m overline 100 m of recent sediments which sets on the grey shale of Kolosh Formation (Fig. 2a). It is overlain by medium to thick bedded dolomitic limestone unit. This unit comprised of 6 m of thick to massive (>100 cm) grey brecciated dolomitic limestone, followed by 2 m of thick yellow marly limestone interbedded with yellow marl (Fig. 2b) bearing molds of mollusks (Fig. 2c). Subsequently, it consists of 35 m of massive grey brecciated dolomitic limestone. Then it covers by 18 m of sedimentary materials followed by 44 m of thick to massive grey brecciated dolomitic limestone (Fig. 2d).

4.1.2. Medium to thick bedded dolomitic limestone unit (Unit B)

This unit is underlain by unit (A) and overline by thin to medium bedded limestone unit (Unit C). It had 60 m thickness. It is comprised of 18 m of thick bedded (50-100 cm) white to grey limestone (Fig. 2e) subsequent by 32 m of medium (30-50 cm) to thick (50-100 cm) bedded grey to yellow dolomitic limestone overlined by 10m of thick bedded (50-100 cm) white dolomitic limestone having chert nodules (Fig. 3a).

4.1.2. Thin to medium bedded limestone unit (Unit C)

It overlain the unit (B) and underline the red mudstone of Gercus Formation (Fig. 3d). The thickness of this unit is about 55 m. It is mainly comprised of 3 m of thin (10-30 cm) to medium (30-50 cm) of white to yellow limestone. It overlined by 14 m of medium bedded (30-50 cm) grey dolomitic limestone have a joint (Fig. 3b). Then it formed of 7 m of thin to medium bedded fractured limestone include joints followed by 31 m of thin to medium white to grey limestone interbedded in the upper part with red mudstone of Gercus Formation (Figs. 3c and d).

4.2. Microfacies Analysis

Based on the classification of Dunham (1962), three microfacies types were found out in the Khurmala carbonates in Kalati section. Each of them is subdivided into several submicrofacies depending on significant fossils type content and groundmass (Table 1), They are as following:

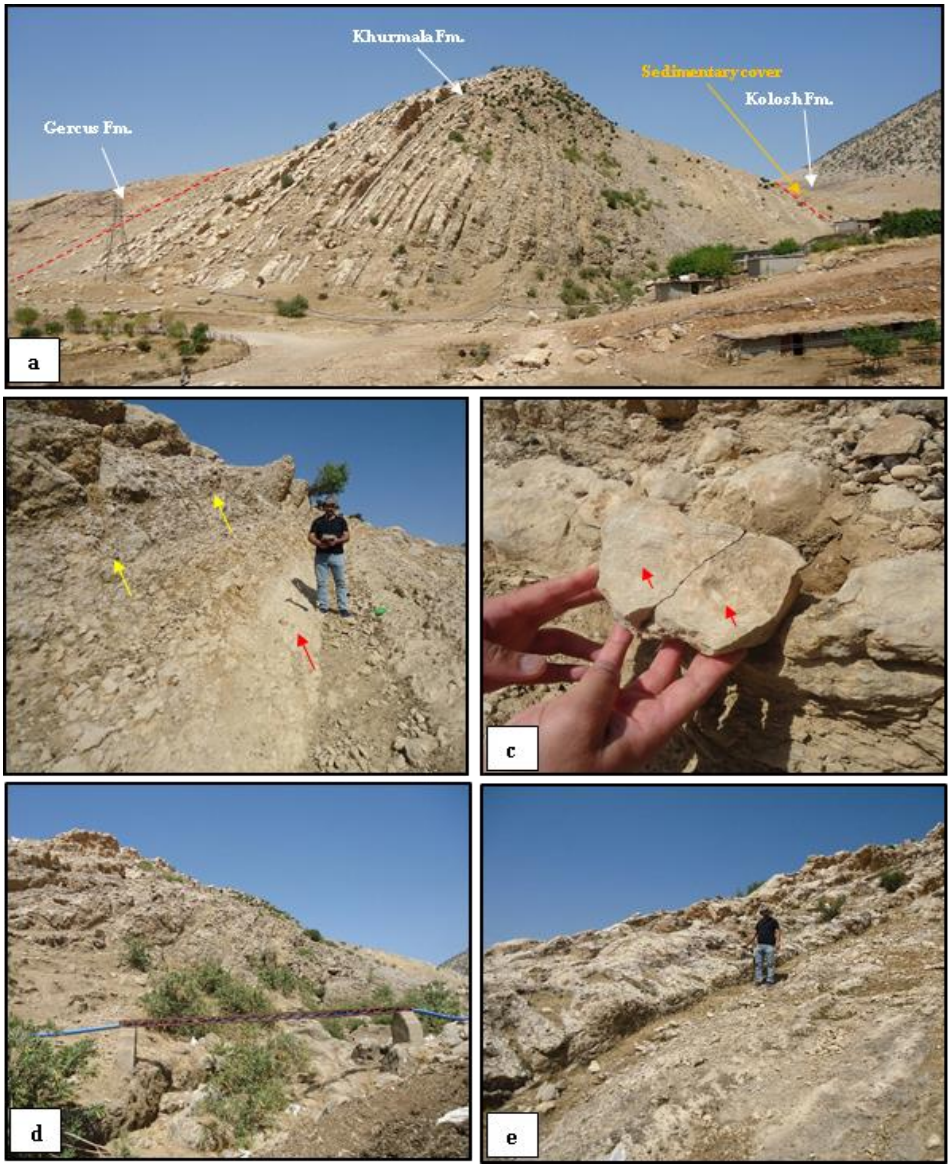

Fig.2. Field photographs of Khurmala Formation in studied section showing: a) Khurmala Formation with underlying and overlying formations; b) Bedded marly limestone interbedded with yellow marl (red arrow) overlying by thick bedded brecciated dolomitic limestone (yellow arrows); c) Molds of mollusks in the bedded marly limestone rocks (red arrows); d) Grey brecciated dolomitic limestone beds underlying unit B; e) Thick bedded white to grey limestone in the unit B.

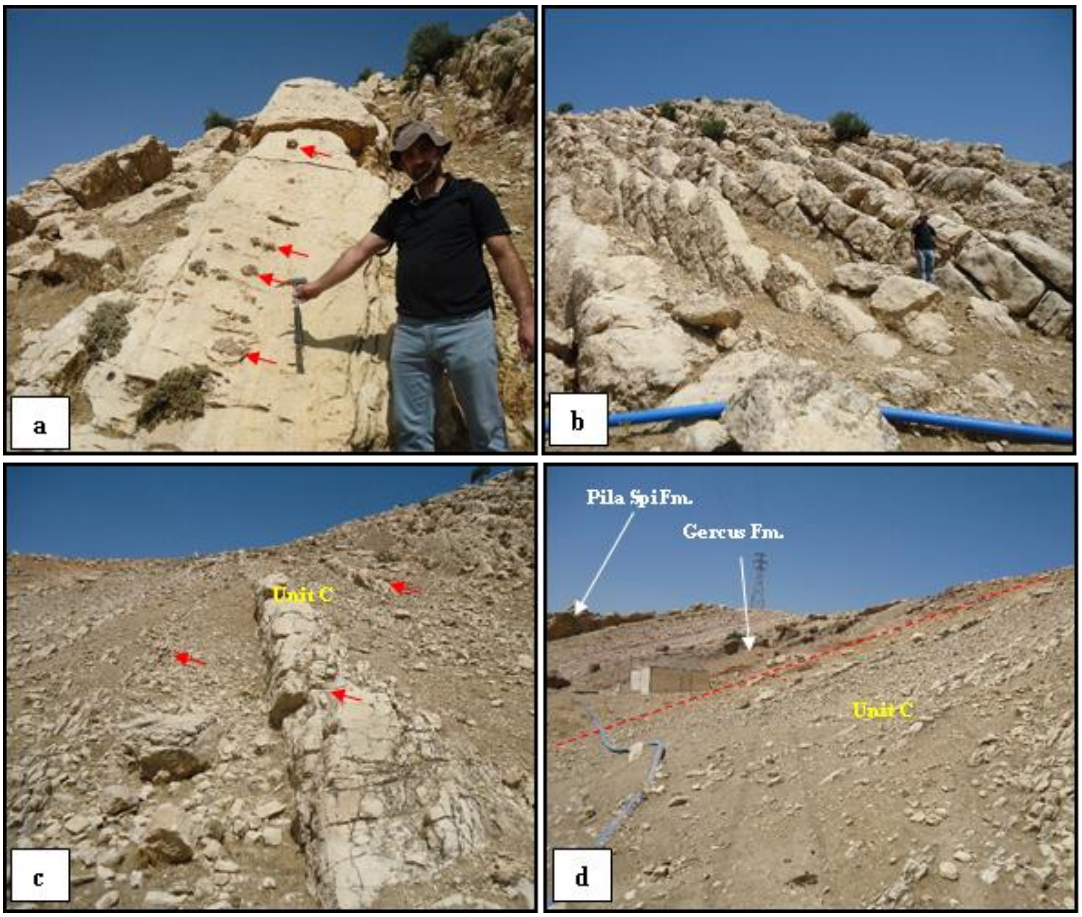

Fig.3. Field photographs of Khurmala Formation in studied section showing: a) Thick bedded white dolomitic limestone bearing chert nodules (red arrows); b) Medium bedded dolomitic limestone characterized by joints in the unit C; c) Fractured limestone interbedded with mudstone in unit C; d) Gradational contact between limestone beds of Khurmala Formation and red mudstone of Gercus Formation.

4.2.1. Lime mudstone microfacies

This microfacies is common in the middle and upper parts of studied section. It is characterized by comprising of micrite groundmass with few grains less than 10 % (Dunham, 1962). It includes four sub microfacies in studied rocks of the Khurmala Formation which are sandy dolomitized lime mudstone (Fig.4a), fenestral dolomitized lime mudstone (Fig. 4b), laminated dolomitized lime mudstone (Fig. 4c), and dasycladacean dolomitized lime mudstone sub microfacies (Fig. 4d). They consisting of dasycladacean green algae, intraclasts and extraclasts (mainly monocrystalline quartz grains) in addition to molds of ostracods. It mainly exhibits fine to medium crystalline dolomite texture and characterized by fenestral pores. The first three sub microfacies are comparable to the standard microfacies (SMF) 20,21 and 23 of Flügel (1982) and facies zone (FZ) 8 of Wilson (1975). While the last one is equivalent to SMF 8 and FZ 7.

Table 1. The main microfacies and subdivisions of the Khurmala Formation in Kalati section

Main Microfacies Dunham (1962)	Subdivision of Dunham's (1962) terms	Diagnostic features (Main skeletal grain +common diagenetic process)	SMF of (Flügel, 1982)	Environment of deposition
Lime Mudstone	Sandy dolomitized lime mudstone	-*Monocrystalline quartz grain* -Dolomitization+ Neomorphism	23	Intertidal
	Fenestral dolomitized lime mudstone	-Rare ostracods molds -Fenestral pores+ dolomitization	21	intertidal
	Laminated dolomitized lime mudstone	--Dolomitization+ neomorphism	20	intertidal
Lime Wackestone	Dasycladacean dolomitized lime mudstone	-Dasycladacean green algae -dolomitization+ neomorphism	8	Shelf lagoon with circulation
	Miliolid-peloidal dolomitized lime wackestone	-Miliolids + peloids -Dolomitization	8	Shelf lagoon with circulation
Lime Packstone	Gastropods-intraclasts dolomitized lime packstone	-Gastropods+ intraclasts -Dolomitization+ organic matter	9	Shallow lagoon with open circulation
	Fossiliferous lime packstone	-Orbitolites+ miliolids+ rotaliids+ bivalves+ bryozoa - Fracturing+ Neomorphism	18	Back reef/lagoon
	Echinoids-dacycladacean-larger foraminifera lime packstone	-Orbitolites+ Dasycladacean green algae+ Echinoid spines -Neomorphism+ Compaction	18	Back reef
	Mollusca-ostracods- orbitolites lime packstone	-Orbitolites+ Ostracods+ mollusks - Cementation+ neomorphism	18	Back reef
	Larger foraminifera lime packstone	-Orbitolites+ monocrystalline quartz + echinoids -Neomorphism+ silicification+ pyritization	18	Back reef

4.2.2.67 Lime wackestone microfacies

It is commonly had grains between 10-50% in the micritic groundmass (Dunham, 1962). This microfacies occurred in the middle part of the Khurmala Formation in Kalati locality. It is skeletal grains are mainly miliolids and non-skeletal grains are peloids (Fig. 4e). The main diagentic processes affecting this microfacies are dolomitization. The miliolid-peloidal lime wackestone corresponds to SMF 8 of Flügel (1982) and FZ 7 of Wilson (1975).

4.2.3 Lime packstone microfacies

This microfacies is the second common microfacies of the carbonate rocks of the Khurmala Formation and mainly occurs in the lower part of the studied section. It is grain dominant microfacies (50-90%) with minor micrite groundmass (Dunham, 1962). It is involved gastropods-intraclasts dolomitized lime packstone sub microfacies (Fig. 4f) which equivalent to SMF 18 of Flügel (1982) and 7 of Wilson (1975) and fossiliferous lime packstone (Figs. 5a, b and c), echinoids-dasycladacean- larger foraminifera lime packstone (Fig.5d), Mollusca-ostracods- orbitolites lime packstone (Fig. 5e) and larger foraminifera lime packstone (Fig. 5f) sub microfacies which they belong to SMF 18 and FZ 7. The common diagenetic processes in this microfacies are neomorphism (Fig.5a), cementation, pyritization (Fig. 5f), compaction and organic matters (Fig. 4f). The micrite groundmass changed to microspar due to neomorphism.

4.3. Facies Associations

Two facies' associations (F.A.) were established from integration of the recognized sub microfacies of Khurmala Formation depending on its environmental interpretation (Fig.6), which are:

4.3.1 Lagoonal back reef facies association

This F.A. occupied the whole unit A and 46 m intervals in unit B (Fig. 6). In the unit A it is consist of 105 m of thick to massive grey brecciated dolomitic limestone, thick yellow marly limestone interbedded with yellow marl bearing molds of mollusks within lime packstone microfacies. While the in the unit B, it is comprising of 14 m of thick bedded white to grey limestone dominated by lime mudstone microfacies in the lower part of the unit and 32 m of medium to thick bedded yellow to grey dolomitic limestone and thick bedded white dolomitic limestone bearing chert nodules within lime mudstone and wackestone microfacies in the upper part of the unit. The microscopic investigations of this FA revealed that it comprises mainly of lime packstone microfacies with less abundant of lime mudstone, wackestone microfacies. The main skeletal grains are larger benthonic foraminifera (orbitolites and discosyclina), small benthonic foraminifera (miliolids and rotaliids), echinoids, ostracods, mollusca, dasycladacean green algae and bioclasts. Whereas, non-skeletal grains are intraclasts and peloids. The groundmass is composed of micrite and microspar. Most of microspar are created by neomorphism processes. This facies association is subjected to many diagenetic processes eg. dolomitization, neomorphism, pyritization, cementation and organic matter.

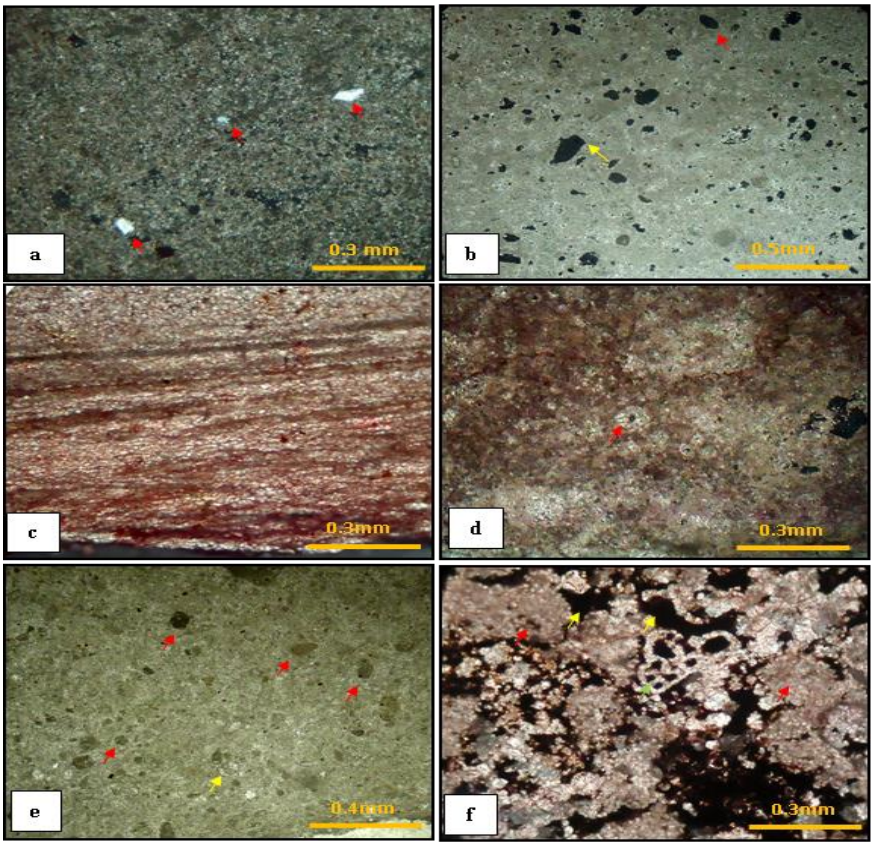

Fig.4. Photomicrographs of carbonate rocks of Khurmala Formation in Kalati section showing: a) Sandy dolomitized lime mudstone submicrofacies include monocrystalline quartz grains (red arrows). KK19. X.N; b) Fenestral dolomitized lime mudstone submicrofacies having ostracods molds (red arrow) and birds eyes shape pores (yellow arrows). KK26. X.N; c) Laminated dolomitized lime mudstone microfacies submicrofacies. KK27., P.P., A.S; d) Dasycladacean (red arrow) dolomitized lime mudstone submicrofacies. KK20. X.N; e) Miliolid (yellow arrow)- peloidal (red arrows) dolomitized lime wackestone submicrofacies. KK24., P.P; f) Gastropods (green arrow)-intraclasts (red arrow) dolomitized lime packstone submicrofacies the groundmass and pores within the allochems were filled by organic matter (yellow arrows). KK15., P.P. Key: KK = Khurmala Kalati, P.P.= Plane Polarized, X.N.= Crossed Nichols. A. S= Alizarine stained

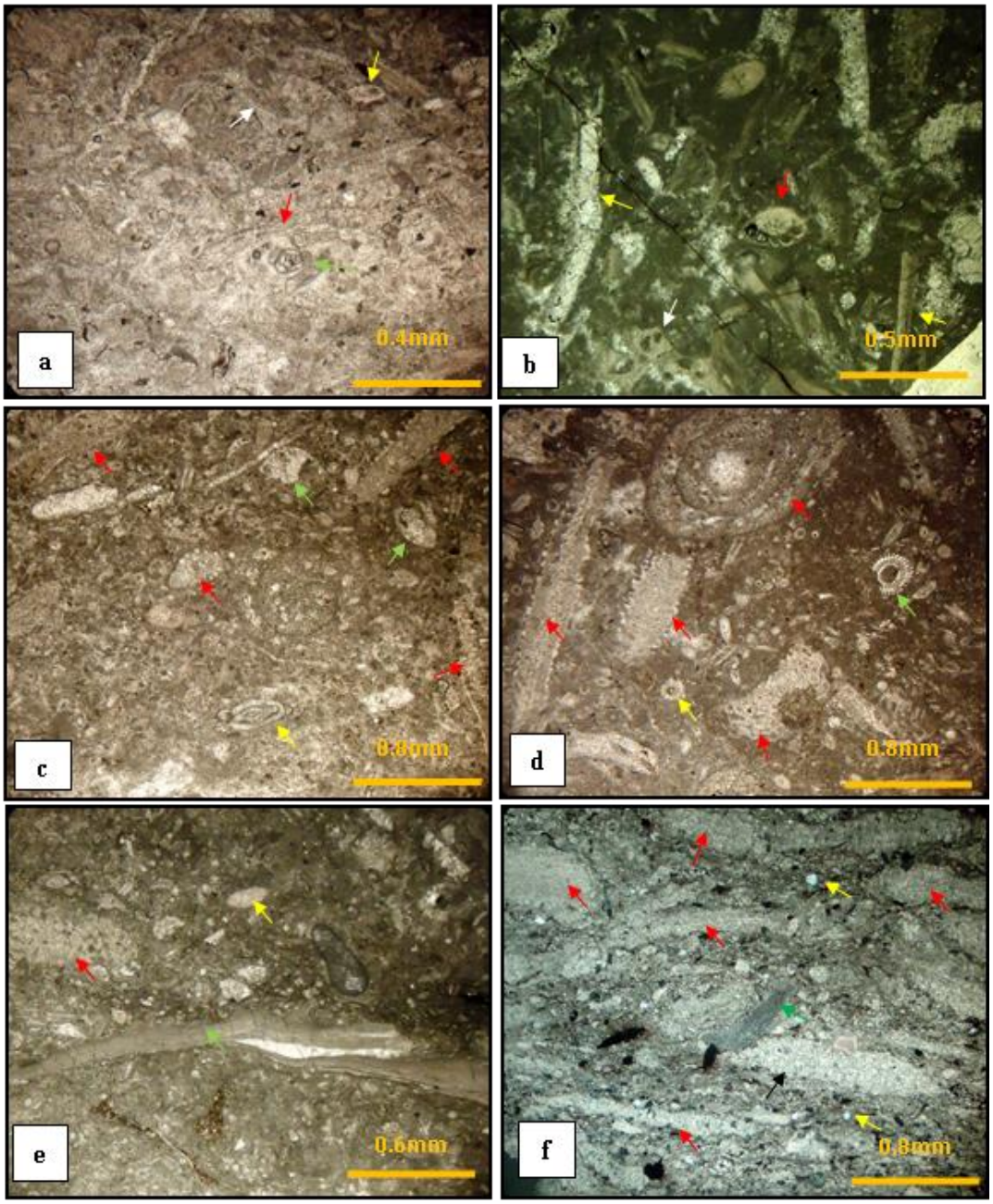

Fig.5. Photomicrographs of carbonate rocks of Khurmala Formation in Kalati section showing: a) Fossiliferous lime packstone submicrofacies including benthonic foraminifera (rotaliids (yellow arrow), miliolids (green arrow), Orbitolites sp. (red arrow)) and bivalves (white arrow) and subjected to neomorphism. KK.8., P.P; b) Fossiliferous lime packstone submicrofacies involving rotaliids (red arrow), mollusks (yellow arrows) and bryozoa white arrow. KK.2., P.P; c) Fossiliferous lime packstone submicrofacies include miliolid (yellow arrow)-orbitolites (red arrows) and rotaliid (green arrows). KK.6., P.P; d) Echinoids (green arrow)-dacycladacean (yellow arrow)- larger foraminifera (orbitlolites (red arrows) lime packstone submicrofacies. KK.5., P.P; e) Mollusca (green arrow)-ostracods (yellow arrow) – orbitolites (red arrow) lime packstone submicrofacies. KK.1., P.P; f) Larger foraminifera lime packstone submicrofacies mostly orbitolites (red arrows) and dycosyclina sp. (black arrow) including echinoids fragment (green arrow) monocrystalline grains (yellow arrows) and pyrite (black patches) KK.9., X.N.

4.3.2 Intertidal facies association

This F.A. occupied intervals in the unit B with the whole unit C (Fig.6). In the unit B it is consist of 14 m thick bedded white to grey limestone and medium to thick bedded yellow to grey dolomitic limestone within lime dolomitized mudstone. While, in the unit C it is comprises of 55m of thin to medium white to yellow limestone, medium bedded grey dolomitic and thin to medium bedded fractured limestone characterized by joints and thin bedded white to grey limestone interbedding with red mudstone of Gercus Formation and all beds formed within lime dolomitized mudstone microfacies. The petrographic study shows that the FA is characterized by rare skeletal grains includes the molds of ostracods. Whereas, the identified non skeletal grains are intraclasts and extraclasts that is mainly monocrystalline quartz grain. The main microfacies in this association are lime mudstone microfacies characterized by dolomitization and fenestral pores in addition to occurrence of ghost lamination in the upper part of the studied section. The groundmass of it is mainly micrite and affected by dolomitization, neomorphism and dissolution processes.

5. Discussion

The depositional framework of the Khurmala Formation in the Kalati area is lagoonal/back reef in the lower part and intervals in the middle part. This is equivalent to SMF 8,9 and 18 of Flügel (1982) and FZ 7 of Wilson (1975). The occurrence of larger foraminifera (orbitolites and discosyclina) lime packstone microfacies inferred to back reef setting as orbitolites founds in the shallowest parts of carbonate platforms (inner lagoonal part of a carbonate ramp) (Scheibner et al. 2007), whereas, discocyclinids commonly occurs in the back reef shallow inner platform (Flügel, 2010). The porcelaneous imperforate small benthonic foraminifera (miliolids) indicate to the restricted lagoonal (Murray, 2006). The dominance of rotaliids in the carbonate rocks of the section refers a shallow marine environment (Vršič et al., 2021). Echinoid spines that are noticed in the lower part of the studied formation, are found in depths ranging from tide line to deep marines (Brusca and Brusca, 2003). Peloidal, intraclasts and bioclasts mudstone and wackestone microfacies are dominant in the lagoonal environment (Asaad et al., 2021). The dasycladacean green algae is commonly occurs in the depth less than 10 m in shallow water environment (Aguirre et al., 2000). The occurrence of mollusks, bivalves and ostracods which inhabit different depositional setting with the above-mentioned skeletal grains refer to shallow marine environment. Gastropods also observed in the thin section of Khurmala Formation and it is association with ostracods indicates brackish-lagoonal environment in Tertiary carbonates (Clarkson, 1998). Rare bryozoan and echinoderms fragments with benthonic foraminifera can be found in shallow lagoon with open circulation (Flügel, 2010). The organic matter rich facies of the platform common in lagoonal-microbial-tidal flat (Mikołajewski et al. 2019). While, the depositional setting of the upper part and intervals of the middle part of Khurmala Formation in the studied outcrop is intertidal. It is confirmed by corresponds to SMF 20,21 and 23 of Flügel (1982) and FZ8 of Wilson (1975). The dolomitized lime mudstone that is characterized by fenestral porosity structure and ghost lamination indicate to intertidal facies (Photiades et al. 2010). This lamination supposed to be microbiolite and formed by cyanobacterial activity in the tidal zone (Kendall and Alsharhan 2013; Al-Qayim and Barzani, 2021). Monocrystalline quartz in lime mudstone microfacies supposed to be deposited in low energy, restricted intertidal, supratidal and subtidal environments (Wilmsen et al. 2010; Nowrouzi et al. 2015). Thus, from the above interpretation, the depositional environment of the Khurmala Formation in the Kalati section was determined as a back reef/lagoonal environment in the lower part and intervals in the middle part and changed to an intertidal environment toward the upper part (Fig.7).

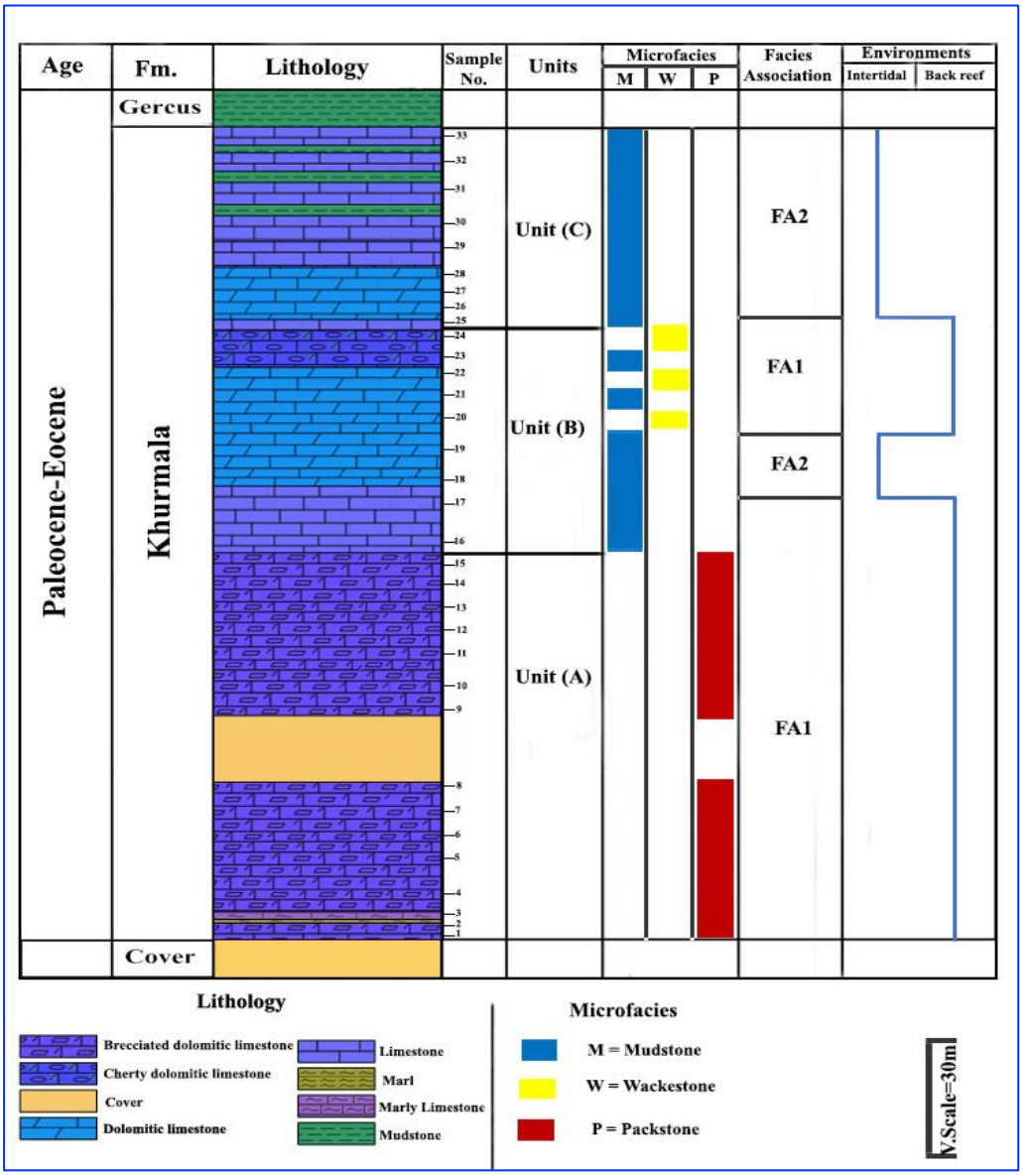

Fig.6. Columnar sections with microfacies and depositional environments of the Khurmala Formation in Kalati section. High Folded Zone, Northern Iraq

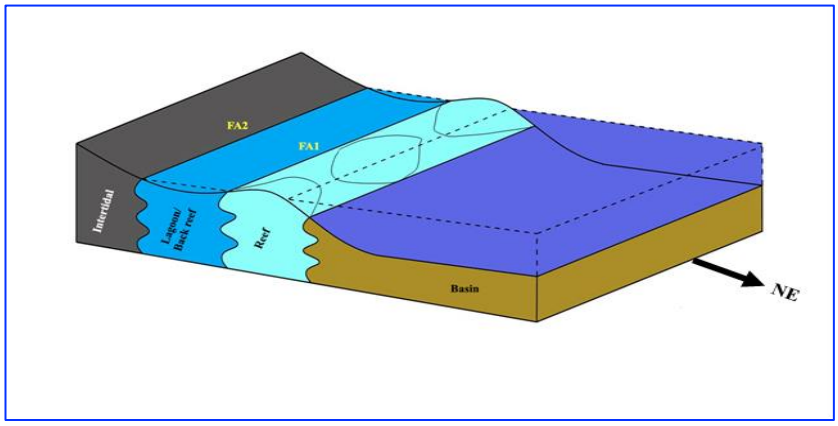

Fig.7. Depositional model of the Khurmala Formation in Kalati section, Akre area, Northern Iraq.

6. Conclusions

- The Khurmala Formation in the Kalati section was subdivided into three lithological units that are, from lower to upper parts: unit A brecciated dolomitic limestone, Unit B medium to thick bedded dolomitic limestone and unit C thin to medium bedded limestone.
- Based on the classification of Dunham (1962), the carbonate rocks of the Khurmala Formation are subdivided into three microfacies and 10 sub microfacies which are grouped together depending on their environmental interpretation into two facies associations: back reef/lagoon and intertidal.
- According to the petrographic and microfacies analysis, the Khurmala Formation in the Kalati outcrop was deposited in a back reef/ lagoonal environment in the lower part and intervals of the middle part and changed to an intertidal environment toward the upper part.

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