Depositional Setting of Khurmala Formation (Paleocene-Early Eocene) in Nerwa section, Berat Anticline, Kurdistan Region, Northern Iraq

Irfan Sh. Asaad1*, Mohammed A. Al-Haj2 and Zaid A. Malak2

1 Department of Earth Sciences and Petroleum, College of Science, Salahaddin University-Erbil, Kurdistan Region, Iraq
2 Geology Department, College of Science, University of Mosul, Mosul, Iraq

* Correspondence: irfan.asaad@su.edu.krd

Abstract

The depositional environment of the Khurmala Formation (Paleocene-Early Eocene) has been investigated in the Nerwa section, the southern limb of the Berat anticline in the High Folded Zone of Iraq. The thickness of the formation in the studied section was about 113m and can be divided into three units; fossiliferous bedded limestone unit (Unit A), massive dolomitic limestone unit (Unit B) and bedded marly dolomitic limestone unit (Unit C). The petrographic study of the 81 thin sections of the Khurmala carbonates revealed that the majority of skeletal grains are shallow marine derivative faunas and non-skeletal grains include peloids, cortoids and intraclasts. Depending on detailed field observations and petrographic study of the carbonate rocks, five main microfacies were recorded, these are; lime mudstone, lime wackestone, lime packstone, grainstone and boundstone in addition to one lithofacies which is an intraformational conglomerate. Based on the integration of the recognized microfacies and the field criteria of the Khurmala Formation, two facies associations were identified which elucidate deposition in a lagoonal environment including reef patches. Accompanying facies indicate that the formation's sedimentary model is a ramp carbonate platform.

Keywords: Paleocene-Early Eocene; Khurmala; Depositional model; Nerwa; Northern Iraq

1. Introduction

The Paleogene rocks in northern Iraq are comprised of marine carbonates and clastics (Sissakian and Al-Jibouri, 2012). One of the carbonate units which developed on the shoaling Zagros foreland basin during the Late Paleocene to Early Eocene time is the Khurmala Formation (Al-Qayim et al., 2012). The formation was first reported by Bellen (1953) in Bellen et al. (1959) from KirkukWell-114, consisting of dolomite (partly pseudoolitic) and recrystallized limestone. The Khurmala Formation is distributed in a limited belt between Chemchemal-Qizil Dagh in the southeast to Bashiqja-Jabal Maqlub area in the northwest of the Zagros Thrust Belt trend (Bellen et al., 1959; Asaad and Balaky, 2018). The Khurmala Formation was deposited in a lagoonal-tidal setting separated from basinal marly limestone of the Aaliji Formation by a discontinuous belt of reefal-shoal limestone Sinjar Formation (Bellen et al., 1959; Al-Qayim, 1995). Whereas, in the northeast direction, Kolosh Formation was deposited in the foreland basin (Jassim and Goff, 2006).
The Khurmala Formation was studied from stratigraphic, palaeontologic and sedimentation points of view both at outcrops and subsurface sections in the high folded and low folded zones (Al-Eisa (1983), Al-Barzanji (1989), Al-Quaym (1995), Al-Sakry (2006), Lawa (2004), Karim (2009), Al-Dabagh (2010), Salih (2010), Tamar-Agha et al. (2015), Asaad and Balaky (2018), Karim et al. (2018), Barzani and Al-Quaym (2019), Barzani (2020) and Al-Quaym and Barzani (2021). The aim of this study is to clarify the depositional setting of the Khurmala Formation in the Nerwa section indicating the integration of microfacies analysis and field observation.

2. Geologic Setting

The Paleocene-Lower Eocene succession including the Khurmala Formation located in the foreland basin in Iraq, between the Arabian Craton and the Alpine Orogen proper which is well-known by the Folded Zone of Iraq (Al-Quaym et al., 2012). The latter is mainly formed by Mesozoic and Tertiary formations and display well-exposed anticlinal and synclinal structures (Numan and Al-Azzawi, 1993). The Nerwa section is situated in the high folded zone (Fig. 1). It is located about 800m northwest of Nerwa Village, in the Nerwa Valley, 19 km east of Bjeel town and 6 km west of Qandil bridge in the Akre area, Duhok Governorate, approximately at Lat 36° 41’ 51” N and Long. 44° 10’ 47” E (Fig.1).

The studied area is situated in the western part of the southern limb of Berat anticline which exhibits E-W trending of anticline axis in the area whereas its trend is NW-SE in the S and SE parts. This changing of the axis trends is associated with convergence and collision along with the Taurus–Zagros orogenic belts (Al-Ma’amar and Obaidi, 2016). The core of the Berat anticline is formed by high-resistant thick Cretaceous carbonate rocks, while the stiff carbonate beds of the Paleogene (Pila Spi and Khurmala formations) are creating an outstanding homoclinic ridge at both limbs of the anticline (Balaki and Omer, 2019) (Fig.2).

![Fig.1. Location and tectonic map of the study area (After Jassim and Goff 2006).](image-url)
Stratigraphically, Qamchuqa and Bekhme formations (Cretaceous) formed the core of the Berat anticline in the Nerwa area. The Shiranish Formation is exposed in the southern limb of the anticline comprising an eroded patch. The Latter is overlain by the Kolosh, Khurmala, Gercus, Avanah, Pila Spi, Fatha (Lower Fars), Injana (Upper Fars), and in remote Mukdadiya (Lower Bakhtiari) and Bai Hasan (Upper Bakhtiari) formations of Tertiary age (Asaad, 2022) (Fig.2). The nature of the boundaries of the studied formation is unclear with the underlaying lower grey shale of the Kolosh Formation because it covered by recent sediments. At the same time, it is conformable with the overlaying Gercus Formation and marked over grey beds of intraformational conglomerates.

3. Materials and Methods

The fieldwork was done in the area of Berat anticline to choose a suitable section for this study. This includes the description of general geology and stratigraphic relationships of the Upper Cretaceous-Tertiary rocks of the studied area and its surroundings. The Nerwa section was not studied previously and is characterized by the large thickness and easy logging of the Khurmala Formation. The studied section was described and measured in detail, including the lithology and mineralogy. The main lithology of the formation in Nerwa outcrop is limestone, dolomitic limestone, marly limestone and marl. Sixty-nine fresh samples were collected from carbonate rocks for macroscopic study and petrographic analysis (Fig.3). Eighty-one thin sections were made at the workshops of the Department of Earth Sciences and Petroleum at Salahaddin University –Erbil. All thin sections were stained by the Alizarin Red Solution (ARS) followed the Friedman (1959) procedure to differentiate between calcite and dolomite minerals. The petrographic and microfacies studies were done using a polarized microscope, depending on Dunham classification (1962) and its modification by Embry and Klovan (1971).
Fig. 3. Columnar section of the Khurmala Formation (Paleocene-Early Eocene) in Nerwa section, Berat anticline, High Folded Zone
4. Results

4.1. Lithostratigraphy

The total thickness of the Khurmala Formation in the Nerwa section is about 113 m (Figs. 3 and 4a). Based on field observation and petrographic examination, the rock succession is divided into three units, which are in ascending order:

4.1.1. Fossiliferous bedded limestone unit (Unit A)

This unit is underlain by 80 m of sedimentary covers, set above the grey shale of the Kolosh Formation (Figs. 4b and b1). It is overlain by a massive dolomitic limestone unit about 13 m thick (Fig. 4c), starting with 1 m of thickly bedded (50-100cm) milky limestone followed by 4 m of medium bedded (30-50cm) grey to yellow fossiliferous limestone including pelecypods and gastropods (Fig. 4d). Subsequently, the latter is overlain by 8 m of yellow to grey medium bedded limestone, which is laterally changed to massive limestone, forming a patch reef (Fig. 4e). This, in turn, is overlain by 5 cm of yellow calcareous marl (Fig. 5a). The sedimentary structures of the unit involved thin horizontal (planar) millimeter-thick laminations, burrowing (Fig. 5b) and macrostylolitization (Fig. 5c).

4.1.2. Massive dolomitic limestone unit (Unit B)

The massive dolomitic limestone unit overlies the fossiliferous bedded limestone unit (Unit A) and underlain the bedded marly dolomitic limestone unit (Unit C). It is thickness is about 74 m and comprises massive reefal beds (> 2m) of brown to yellow dolomitic limestone (Fig. 5d) in addition to coralline limestone (Fig. 5e). The unit includes 3 m intervals of brecciated limestone (Fig. 5f) and the thickness of beds reduces laterally from 2 to 1 m. It is characterized by solution caves which is formed by the dissolution of large spherical nodules of coralline algae (Fig. 6a). The sedimentary structures of the unit include honeycomb sedimentary structure (Fig. 6b) and bioturbation (Fig. 6c).

4.1.3. Bedded marly dolomitic limestone unit (Unit C)

This unit overlies the massive dolomitic limestone unit and underlies the red mudstone beds of the Gercus Formation (Fig. 6d). The entire thickness of the unit is 26 m. The lower 9.5 m comprises thickly (50-100cm) bedded grey dolomitic limestone overlain by 16 m of medium to thickly bedded(30-50cm) yellow to grey marly limestone (Fig. 6e). The last 0.5 m of this unit comprises of dark grey intraformational conglomerate, which forms the contact of the Khurmala Formation with the overlying Gercus Formation (Fig. 6f). Joints and grooves were observed on the beds of this unit (Fig. 6f).

4.2. Facies Analysis

Detailed field observation and petrographic analysis of carbonate rocks of the Khurmala Formation revealed that these rocks could be organized into five microfacies (MF) and one lithofacies types (Table 1).

4.2.1. Dolomitic lime mudstone microfacies

This microfacies (MF) occurs at the middle and upper part of the formation. It is about of 28 m thick and displaying milky, massive, hard dolomitic limestone. It composed of less than 10% of undifferentiated grains. The intense dolomitization of the micritic groundmass had led to the suture mosaic texture vugs and fenestral porosity (Fig. 7a). The large dolomite rhombs are formed in different parts of this microfacies (Fig. 7b). This microfacies could be compared with the standard microfacies (SMF) 21 of Flügel (1982) within facies zone (FZ) 8 Wilson (1975). This type of microfacies was deposited in the subtidal (lagoon) environment.
Fig. 4. Field photographs showing: a) Stratigraphic succession in the Nerwa section southern limb of the Berat anticline; b) The Lower contact of the Khurmala Formation, which is separated from the grey shale of the Kolosh Formation by recent covers. b1) Enlarged photograph of Kolosh Formation from the photo (b); c) Fossiliferous bedded limestone unit is underlain massive dolomitic limestone unit; d) Macrofossils are mainly pelecypods (yellow arrows) and gastropods (red arrow) on the thick grey beds of limestone. Scale: High of Hummer head 2cm; e) Bedded limestone unit had a patch of massive limestone and was affected by bending due to tectonic effect.
Fig. 5. Field photographs showing: a) Thin beds of yellow calcareous marl (Red arrow) overlies unit A; b) Burrowing on the limestone beds of the Khurmala Formation; c) Chemical compaction (stylolites) (red arrows) on bedded limestone unit of the Khurmala Formation; d) Massive dolomitic limestone unit. e) Yellow to grey coralline limestone beds; f) Brecciated limestone bed
4.2.2. Lime wackestone microfacies

It is a dominant and widespread MF that has been recognized throughout the rock succession of the studied section. The grains of this MF do not exceed 50% of the total components. It is about 31m thick, which can be subdivided into three submicrofacies, as follows:
Bioclastic lime wackestone submicrofacies

This MF consists mainly of bioclasts. The bioclasts include pieces of the shells such as pelecypods, echinoderms, ostracods and bryozoans (Fig. 7c). A small percentage of some benthic foraminifers such as the rotaliid (Fig. 7d) and miliolids in addition to rare planktonic foraminifers (Fig. 7e), are locally present at the lower part of the formation. It is groundmass affected by dolomitization, and it is subjected to neomorphism, dissolution and cementation diagenetic processes. The characteristics of this microfacies is close to the SMF 8 and FZ 7 of Flügel (1982) and Wilson (1975), respectively and represent low-energy shallow lagoon environment with open marine water circulation.

Dasycladacean lime wackestone submicrofacies

This MF occurs in the middle part of the formation and is characterized by the abundance of dasycladacea and bryozoans (Fig. 7f). In addition, the pelecypod, ostracod and miliolid bioclasts are also present. Micritization, dolomitization and neomorphism are the main digenetic processes. This MF is equivalent to the SMF 18 of Flügel (1982) and FZ 7 of Wilson (1975), representing shelf lagoons with open circulation.

Table 1. Microfacies types of Khurmala Formation in Nerwa section according to Dunham (1962), Embry and Klovan (1971)

<table>
<thead>
<tr>
<th>Main microfacies</th>
<th>Subdivision of Dunham (1962)</th>
<th>Diagnostic features (prominent skeletal grain + common diagenetic process)</th>
<th>SMF Flügel (1982)</th>
<th>Environment of deposition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lime Mudstone</td>
<td>Dolomitic lime mudstone</td>
<td>-Dolomitization+ fenestral porosity</td>
<td>21</td>
<td>Subtidal (lagoon)</td>
</tr>
<tr>
<td></td>
<td>Bioclastic lime wackestone</td>
<td>-Bioclasts + Benthonic foraminifera+ Rare planktonic foraminifera+</td>
<td></td>
<td>Shallow lagoon with open circulation</td>
</tr>
<tr>
<td>Lime Wackestone</td>
<td>Dasycladacean lime wackestone</td>
<td>-Dasycladacean algae+ Bioclast</td>
<td>18</td>
<td>Shelf lagoon with open circulation</td>
</tr>
<tr>
<td></td>
<td>Intraclasts lime wackestone</td>
<td>-Intraclasts+ microgastropods</td>
<td></td>
<td>Shelf lagoon with circulation</td>
</tr>
<tr>
<td></td>
<td>Miliolidal lime packstone</td>
<td>-Miliolids + Micritization+ Dolomitization+ Neomorphism</td>
<td>18</td>
<td>Restricted lagoon</td>
</tr>
<tr>
<td>Lime Packstone</td>
<td>Bioclastic lime packstone</td>
<td>-Bioclasts+ Rare miliolids +Dolomitization+ Silification</td>
<td>8</td>
<td>Shelf lagoon with circulation</td>
</tr>
<tr>
<td></td>
<td>Fossiliferous lime packstone</td>
<td>-Benthonic foraminifera+ dasycladacea algae+ bryozoa.</td>
<td>18</td>
<td>Restricted platform</td>
</tr>
<tr>
<td></td>
<td>Miliolidal-peloidal-Bioclastic Lime grainstone</td>
<td>-Fraturing + Dissolution+ Neomorphism</td>
<td></td>
<td>Restricted platform lagoon</td>
</tr>
<tr>
<td>Grainstone</td>
<td>Cortoid lime grainstone</td>
<td>-Cortoid non-skeletal grains +Dolomitization+ Neomorphism</td>
<td>11</td>
<td>Back reef /lagoon</td>
</tr>
<tr>
<td></td>
<td>Brachiopod-dasycladacea-peloidal grainstone</td>
<td>-Peloids + Valvulina +Peloids + Micritization+ Dissolution</td>
<td></td>
<td>Back reef/ lagoon</td>
</tr>
<tr>
<td></td>
<td>Lime bindstone</td>
<td>-Neomorphism</td>
<td>18</td>
<td>Patch reef</td>
</tr>
<tr>
<td></td>
<td>-Red algae</td>
<td>-Dissolution+ Dolomitization</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Boundstone</td>
<td>Lime floatstone</td>
<td>-Neomorphism+silicification+ Dissolution</td>
<td>12</td>
<td>Patch reef</td>
</tr>
<tr>
<td></td>
<td>Lime framestone</td>
<td>-Sclerectinal coral+ Midiolids+ peloids +Neomorphism</td>
<td>7</td>
<td></td>
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</tbody>
</table>
Fig. 7. Photomicrographs of Khurmala Formation showing microfacies types: a, b) Dolomitic lime mudstone submicrofacies: a) Fenestral porosity, K62, X.N; b) Large dolomite rhombs, K39, P.P; c and d) Bioclastic lime wackestone submicrofacies includes: c) Bryozoa (Br) and ostracods (O) affected by micritization, K68, P.P. d) Rotaliid (R) and bioclasts. K6, P.P. e) Bioclastic lime wackestone submicrofacies includes planktonic foraminifera (PF), K21, P.P. f) Dasycladacean (Da) lime wackestone submicrofacies, K36, P.P., A.S. Key: K: Khurmala, P.P.: Plane polarized light, X.R: Crossed Nicols, A.S.: Alizarin Stained.
• **Intraclastic lime wackestone submicrofacies**

It is mainly composed of intraclasts (> 40%) with rare gastropods (Fig. 8a and b). The intraclasts size range between 0.2 and 2 mm with semi-rounded grains. It has corresponded with SMF 8 and FZ 7 of Flügel (1982) and Wilson (1975) respectively.

4.2.3. **Lime packstone microfacies**

This MF has grain-supported fabric with some micritic matrix forming hard bed and shows partial dolomitization. It can be divided into three secondary microfacies as follows:

• **Miliolidal lime packstone submicrofacies**

This MF mainly consists of various types of miliolids (*Quinqueloculina, Pyrgo, and Triloculina*) constituting more than 60% of the total components (Fig. 8c). Bioclasts of pelecypods, gastropods, and echinoderms are also present. It occurs at the lower part of the formation. This submicrofacies is equivalent to the standard microfacies (SMF 18) within the facies zone (FZ 7) (Wilson 1975; Flügel 1982) and represents a restricted lagoon.

• **Bioclastic lime packstone submicrofacies**

This MF occurs predominantly at the lower part of the formation. It consists mainly of bioclasts with more than 60% of the total components. The bioclasts mainly consist of pelecypods, ostracods and echinoderms (Fig.8d). Small percentage of some benthic foraminifers (miliolids), such as *Quinqueloculina, Triloculina*. are locally present. The characteristics features of this microfacies are similar to the standard microfacies (SMF: 8) deposited within the facies zone (FZ: 7) (Wilson 1975; Flügel 1982) and corresponds to the shelf lagoon with circulation environment.

• **Fossiliferous lime packstone submicrofacies**

This submicrofacies is mainly confined to the upper part of the studied section. It contains a high percentage of allochems (about 65%) consisting mainly of different fossils such as benthonic foraminifers, dasycladacean green algae, bryozoa and other unidentified extensively dolomitized fossils (Figs. 8e and f). The dissolution process affected the micritic matrix mainly, resulted in the widespread development of vuggy and moldic porosity. These pores were filled by the druzy and granular calcite cement in some cases. The charters of this MF is identical to the SMF 18 of Flügel (1982) and FZ 8 of Wilson (1975) and correspond well with a restricted marine platform environment.

4.2.4. **Grainstone Microfacies**

• **Miliolidal-peloidal-bioclastic grainstone submicrofacies**

This MF occurs in the lower part of the studied section. It consists of 55% bioclastic grains of the total component. The bioclasts consist of different types of shell fragments such as gastropods, pelecypods, echinoderms and a moderate percentage of benthic foraminifers (miliolids), such as *Quinqueloculina, Triloculina* (Fig. 9a). The peloids are also locally abundant and are supported by microspars and sparites to denote the high-water energy depositional environment. Moreover, the effect of high agitation water can be indicated by the roundness shape of its allochems. It is equivalent to standard microfacies 18 Flügel (1982) and facies zone 7 of Wilson (1975) respectively, representing the restricted lagoonal platform environment.
**Fig. 8.** Photomicrographs of Khurmala Formation showing microfacies types: a and b) Intraclastic lime wackestone submicrofacies displays: a) Intraclasts in sparry calcite groundmass, K69, P.P; b) intraclasts with gastropod (Mg), K64, P.P; c) Miliolidal lime packstone submicrofacies, K8, P.P; d) Bioclastic lime packstone submicrofacies include ostracods (O) and debris of pelecypod (Pl) and echinoderm (Ech), K13, P.P., A.S; e and f) Fossiliferous lime packstone submicrofacies displays: e) Pelecypod (Pl), miliolids (M) and Locharita (Lo), K11., P.P. f) Dasycladacean green algae (Da), bryozoa (Br) and miliolids (M). K3, P.P

- **Cortoid grainstone submicrofacies**

  This MF contains fossils and intraclasts surrounded by a thin envelope of dark micrite, whose percentage reaches more than (60%) of the total components in the microfacies. The shapes of the grains are semi-circular to sub-angular within the micropar matrix (Fig. 9b). The matrix was subjected to dolomitization. The characteristics of this microfacies resembles the standard microfacies (11) within the facies zone (8) according to the models (Wilson 1975; Flügel 1982) in high energy backreef environment.
• **Brachiopod-dasycladacean-biolcasts grainstone submicrofacies**

It mainly occurs at the middle part of the Khurmala Formation in the studied section. It is characterized by abundant bioclasts of mollusca and skeletal grains including dasycladacean green algae and brachiopods (Fig. 9c). Neomorphism is the main diagenetic process of this submicrofacies. This submicrofacies is match to SMF 18 of Flügel (1982) and FZ (7) of Wilson (1975).

4.2.5. **Boundstone microfacies**

It is dominant in the middle part of the studied section of the Khurmala succession. It is mainly formed by corals and red algae that form the reefal limestone. It can be divided into three submicrofacies (Emery and Klovan 1971), as follows:

• **Bindstone submicrofacies**

It occurs in the upper part of unit A, and is commonly repeated at various intervals in unit B of the studied section. It ranges from 1 to 7.5m thick. In the field, this facies appears in the form of well-bedded limestone with white to cream colors. It mainly consists of red algae forming about 80 percent of the rock component. Moreover, few benthonic foraminifers, ostracods, pelecypods, and rare bioclasts are enclosed by algal lamination (Fig. 9d). The facies were affected by dissolution, cementation (blocky cement), and dolomitization. This facies is identical to the standard microfacies (SMF: 7) of Flügel (1982).

• **Floatstone submicrofacies**

It normally occurs at the lower part of the unit B composed predominantly of red algae and intraclasts which have a size more than 2 mm, and composed of about 30% of the total components (Figs. 9e and f). It has commonly matrix-supported fabric. The micritic matrix suffered recrystallization, as well as cementation. The character of this microfacies is identical to the standard microfacies (SMF: 12) of Flügel (2010), deposited in patch reef environments.

• **Framestone submicrofacies**

It occurs typically at the lower part of unit B. It is mainly composed of corals which constitute 90-80% of the total component (Fig. 10a); Moreover, the skeletal grains such as foraminifers, ostracods and bioclasts are confined within the coral structure. It is associated with miliolid peloidal grainstone (Fig. 10b). This MF mainly suffered dissolution forming small vugs, as well as recrystallization. This facies is analogous to the standard microfacies (SMF: 7); according to Flügel (1982) was deposited within the facies zone (FZ: 8) which represents the organic buildup environment.

4.2.6. **Intraformational conglomerate lithofacies**

This lithofacies occurs as sandwiched between Khurmala and Gercus formations (Fig. 6f). It is 0.5m thick and consists of conglomerate embracing carbonate pebbles ranging in diameter between 5-10 mm and cemented by a matrix made of sparite. It is mostly comprised of intraclasts packstone which may indicate an intraformational accumulation in the shallowest part of the basin. It is equivalent to standard microfacies (SMF: 24) of Flügel (1982) within the facies zone (FZ: 8) of Wilson (1975).

4.3. **Facies Association**

Based on the integration of the microfacies and the field criteria of the Khurmala Formation in the Nerwa section, two basic types of facies associations (FA) were identified relating to their environmental interpretation (Fig. 11).
4.3.1. Lagoonal facies association

This FA is equivalent to standard microfacies 8,11,18,19, 21 and 24 of Flügel (1984) and facies zone 7 and 8 of Wilson (1975). It occupies the lower 10m of the lower unit and the whole upper unit of the Formation, in addition to several intervals in the middle unit of the Khurmala Formation. It comprises 10m of thick-bedded milky limestone with common grainstone and medium bedded grey to yellow fossiliferous limestone with dominant wackestone, packstone and grainstone associated with thin beds of yellow calcareous marl at the lower part. The repeated intervals at the middle part consist of a total of 49 m of massive brown to yellow dolomitic limestone rich in lime mudstone and wackestone. Rare lime packstone and grainstone, and yellow brecciated limestone rich in lime wackestone are locally present. Whilst in the upper part, it commonly consists of 26m of thick-bedded grey dolomitic limestone rich in lime wackestone and grainstone with rare lime mudstone and medium to thick bedded of yellow to grey marly limestone rich in lime mudstone, wackestone and packstone with rare lime grainstone at the upper part and is finally overlain by 0.5m of dark grey of intraformational conglomerate.

Fig.9. Photomicrographs of Khurmala Formation showing: a) Miliolid-peloidal-bioclastic grainstone submicrofacies include Quinqueloculina (Q), Spiriloculina (S) and Valvulina (V) lime grainstone submicrofacies, K1, P.P; b) Cortoid grainstone submicrofacies, K51, P.P; c) Brachiopods (Bp)-dasycladacean (Da) – bioclastic (B) grainstone submicrofacies, K23, P.P; d) Algal bindstone submicrofacies, K32, P.P; e) Red algae (Ra)- Mollusca (Mo) Wackstone-floatstone submicrofacies, K 18, X.N; f) Coral - intraclasts floatstone submicrofacies, K45, P.P
The sedimentary structures of this association include: planar laminations, bending of beds, burrowing, macrostylolitization at the lower part and honeycomb and bioturbation at the middle part. While at the upper part, joints and grooves on the limestone beds are commonly present.

Fig.10. Photomicrographs of Khurmala Formation showing microfacies types: a) Miliolid-peloidal coral grainstone- boundstone (framestone) submicrofacies, K16, P.P. b) Coral framestone submicrofacies, K30, P.P.

Petrographically, the dominant skeletal grains are benthonic foraminifers (miliolids (*Triloculina, Quinqueloculina* and *Spirloculina*), rotaliids (*Nodosaria* and *Locharita* and *Valvulina*), dacycladacean green algae, pelecypods, ostracods, brachiopods, gastropods, bryozoa, mollusca, echinoids, rare planktonic foraminifera in addition to fragmented bioclasts. Whereas, non-skeletal grains are peloids, cortoids and intraclasts. The groundmass of this association comprises of micrite with less microspar and sparry calcite. The main diagenetic process is dolomitization.

4.3.2. *Patch reef Facies Association*

It occupies the upper 3m of unit A and 25m of repeated intervals at the unit B. It is equivalent to standard microfacies 7 and 12 of Flügel (1984) and facies zone 8 of Wilson (1975). Lithologically, it comprised medium bedded grey to yellow limestone rich in lime wackestone-floatstone and grainstone-boundstone in the lower unit. While in the middle part it consist of massive reefal beds of brown to yellow dolomitic limestone and coralline limestone with dominant lime bindstone-boundstone and floatstone. This FA is characterized by massive beds and solution caves that were formed by large spherical nodules of coralline algae. It mainly composed of skeletal grains including solitary and colony of sclerectinal corals, coralline red algae, mollusks and miliolids, whilst, non-skeletal grains comprising peloids and intraclasts. The groundmass of this association is composed of micrite and sparry calcite.
Fig. 11. Columnar sections and depositional environments of the Khurmala Formation in Nerwa section, Berat anticline.

4. Discussion

Facies association of the Khurmala Formation shows that the Formation in Nerwa locality was deposited in a lagoonal environment including reef patches. The lagoonal setting of the formation was characterized by variability in microfacies including lime mudstone, wackestone, packstone and grainstone which reflect the variation in the calmness of the depositional basin. Dolomitized lime mudstone is common in the restricted platform (Wilson, 1975; Flügel, 2010). Miliolids dominate in shallow restricted low turbulence water (Safari et al., 2020), whereas, the occurrence of miliolids within peloids- bioclastic grainstone, which are mainly debris of molluscs that are characterized by semi - rounded shapes in sparry calcite groundmass suggest a relatively high energy water in back reef/ lagoonal environment (restricted platform) (Al-Đabbas et al., 2014; Tamar-Agha et al., 2015). Rare bryozoan, echinoderms, brachiopods and planktonic foraminifers within benthonic foraminiferal wackestone microfacies can be found in shallow lagoon with open circulation (Flügel, 2010). The dasycladacean green algae which is common in the middle part of the studied section indicates shallow
water environment with less than 10m depth (Aguirre et al., 2000). The coexistence of gastropods and ostracods with benthonic foraminifera indicate lagoonal shallow marine environment (Asaad et al., 2021). Intracast lime wackestone-packstone is occur in the backshoal/lagoonal setting (Asaad and Omer, 2020). The cortoid lime grainstone which form skeletal and non-skeletal grains with dark thin micritic envelope are formed in the high-energy area of backreef setting (Flügel, 2010). Intraformational conglomerate bearing intraclasts lime packstone supposed to be accumulated in the shallowest part of the basin below storm wave-base (Enos, 1983) and may be created from reworking of subtidal sediments by storms (Dravis, 1979). The extensive bioturbation of the beds at the middle and lower part of the studied section may interpret as the fine, organic-rich sediment in lagoons furnishes an excellent feeding places for organisms that can tolerate the reduced/enhanced salinity conditions and producing bioturbation (Nichols, 2009). Brecciated limestone within the beds of this association indicated to the restricted condition of lagoonal environment and supposed to be form by collapse of beds resulted from to the removal of soluble material e.g., evaporites within them (Flügel, 2010). It supported by occurring a considerable ratio of anhydrites within the subsurface sections of the Khurmala Formation particularly in their type locality (Bellen et al., 1959).

The presence of patch reefs in various repeated intervals at the middle part of the Khurmala Formation is considerably indicated by the massive and coralline limestone beds and red algae. The boundstone subdivisions include bindstone, framestone and floatstone reflect in-situ organic growth of potential reef builders (Flügel, 2010). The depositional setting of coral reefs could be a small patch reefs within the open inner platform when the coral dominate interval sandwiched between the restricted facies of miliolids (Scheibner and Speijer, 2007). Red algal encrustation regarded as principal binding organisms in most Cenozoic to modern reefs (Scholle and Scholle, 2003). Thus, the above interpretation indicates that the Khurmala Formation was deposited in lagoonal environment with open marine water circulation include the patch reefs at the middle part (Fig.12). The Khurmala Formation regarded as foreland carbonate rocks progressed during Alpine orogeny. The foreland basin of Iraq was situated between Arabian Craton and Alpine Orogen proper which is renowned by Zagros–Taurus Folded Zones (Tamar-Agha et al., 2015). It is suggested that it transited from leftover of oceanic basin and it happen due to the tectonic interruption of the basin and its shallowing and migration southwestward of the oceanic belt. The Paleocene-Lower Eocene shelf carbonate which equipped the upper part of Kolosh Formation in many areas indicate to the final shoaling of the basin and characterized by calming tectonism period (Al-Qayim,1995). Khurmala Formation in Nerwa section suggested to be deposited in the lagoonal setting with repeated patches of reef. Accompanying facies indicates that the sedimentary model of the formation is a ramp carbonate platform. It is indicated by having low compositional maturity in packstone and grainstone microfacies expressed by a mixture of different skeletal grains, peloids, cortoids and intraclasts (Flügel, 2010). Also, it supported by absence of rimmed carbonate platform (complete reef parts) and connecting with the deeper facies of Kolosh Formation in the studied section (Fig.12).

In correlation with its type section, which studied by bellen et al. (1959), generally it has a same lithological characteristic which comprised of dolomitic limestone but differ by occurring reefal limestone and absence of suboolitic limestone and secondary anhydrite. The stratigraphic correlation with the its type section shows the absence of clastic rocks of the Gercus Formation in its upper contact and replaced by Avanah Formation in type section. Microfacies interpretation and faunal content of the formation in type sections shows it deposited in lagoonal environment and absence of patch reef facies comparing to Nerwa section. The present finding of the formation in the studied section concise with other studies relating to the depositional setting of the formation in the nearby localities. The depositional environment of Paleocene- Eocene carbonates in Bekhma locality 6 km east of Nerwa section was lagoonal according to Al-Qayim (1995) and reef-back reef setting according to Tamar-Agha et al. (2015). Asaad and Balaky (2018) concluded that the formation was deposited in shallow marine
environment (semi restricted shelf lagoon) in Zenta section in Aqra anticline 19 km northwest studied section. While, Al-Qayim and Barzani (2021) suggested that in Spindar section in Gara anticline and Birkyat section in Khairi anticline 81 km and 62 km northwest far from Nerwa section respectively was deposited in tidal and lagoonal environments. The carbonates of the Khurmala Formation in the Nerwa section are characterized by their large thickness (113 m) compared to the formation's thickness in other surface sections in northern Iraq and set above Kolosh Formation. Whereas, some of them exhibit as interfingers within the upper part of the Kolosh Formation (Al-Sakry, 2006; Karim, 2009). This is indicated that the Paleocene-Lower Eocene ramp setting in the Nerwa section developed to be shallower than other areas and been a carbonate factory for depositing Khurmala Formation, which had a lagoonal environment including patches of reef.

Fig. 12. The depositional model of the Khurmala Formation at Nerwa section, Berat anticline, High Folded Zone (The information northeastward of the model after Jassim and Goff (2006)

5. Conclusions

- The Khurmala Formation in the Nerwa section has about 113 m and can be divided into three units; fossiliferous bedded limestone unit (Unit A), massive dolomitic limestone unit (Unit B) and bedded marly dolomitic limestone unit (Unit C). The formation’s boundaries are unclear and covered with the underlying Kolosh Formation. At the same time, it is conformable with the overlying Gercus Formation and marked over grey beds of an intraformational conglomerate.
- Based on the classifications of Dunham (1962) and Embrey and Klovan (1971) integrated with the field observations five main microfacies were recorded in carbonate rocks of Khurmala Formation, these are; lime mudstone, lime wackestone, lime packstone, grainstone and boundstone and one lithofacies association is recognized which is intraformational conglomerate. Microfacies and
lithofacies are grouped in relative to their environmental interpretation, and vertical variations into two basic types of facies associations which are lagoonal and patches of reef.

- From the field inspection, petrographic study, and facies analysis, the Khurmala Formation in the Nerwa section was deposited in the lagoonal environment including reef patches. Accompanying facies indicates that the sedimentary model of the formation is a ramp carbonate platform.

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