Iraqi Bulletin of Geology and Mining *Vol.14, No.2, 2018* *p 1 – 15*

MICROFACIES ANALYSIS AND DEPOSITIONAL ENVIRONMENT OF KHURMALA FORMATION (PALEOCENE – LOWER EOCENE), IN THE ZENTA VILLAGE, AQRA DISTRICT, KURDISTAN REGION, IRAQ

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Received: 06/ 01/ 2018, Accepted: 22/ 02/ 2018
Key words: Khurmala, Paleocene, Zenta, Microfacies analysis, lagoon

ABSTRACT

Microfacies and environmental analysis of Khurmala Formation (Paleocene – Lower Eocene) was studied in the Zenta area, near Zenta village, Aqra district – Kurdistan region Northern Iraq. The formation is composed of 71 m thick bedded grey dolomitic limestone, partially bituminous with chert nodules and rare chert lenses and medium to thick bedded yellow limestone, interbedded with thin beds of marl and mudstone. The petrographic study showed the majority of the limestones are carbonate mud (micrite). The skeletal grains consist principally of benthonic foraminifera, calcareous green algae, ostracods, gastropods, pelycepods, and rare larvae echinoids. Non skeletal grains include peloids only. Three main microfacies were distinguished in the limestones of the studied section and two different lithological units were recognized, based on field evidence and petrographic study. They are in ascending order: thick bedded dolomitic limestone unit and bedded limestone with marl unit. Evidence derived from petrographic study, facies and textural analyses suggest that the Khurmala Formation was deposited in a shallow marine environment of shelf lagoon with circulation, under quiet and semi restricted conditions.

تحليل السحنات الدقيقة والبيئة الترسيبية لتكوين خرمالة (باليوسين – ايوسين الاسفل) في قرية زنطة، قضاء عقرة، اقليم كردستان، العراق

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المستخلص

تمت دراسة السحنات الدقيقة والبيئة الترسيبية لتكوين خرمالة (باليوسين – ايوسين الاسفل) في قرية زنطة الواقعة في قضاء عقرة في اقليم كردستان – شمال العراق. تتألف صخارية تكوين خرمالة في مقطع المختار من 71 متر من طبقات سميكة من حجر الجيري المدلمت الرصاصي الحاوي جزئيا على القير ودرنات وعدسات الصوان في جزئه السفلي وطبقات متوسطة السمك الى السميكة من حجر الجيري الاصفر المتداخل مع المارل وحجر الطيني في جزئه العلوي. أظهرت الدراسة البتروغرافية لـ 32 شريحة رقيقة ان معظم صخور الحجر الجيري تتكون من الوحل الجيري. تضمنت الحبيبات الهيكلية كل من الفورامينفيرا القاعية وطحالب خضراء وصدفيات وبطنيات القدم وفأسيات القدم فضلا عن

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شوكيات الجلد الصغيرة. اما الحبيبات غير الهيكلية فهي الدمالق فقط. تم تشخيص ثلاث سحنات رئيسية في مقطع الدراسة لتكوين خرمالة وتم تقسيم صخور التكوين اعتمادا على المشاهدات الحقلية والدراسات المجهرية الى وحدتين صخريتين هما من الاسفل الى الاعلى: الحجر الجيري المدملت الرصاصي السميك والحجر الجيري الاصفر ذو طبقات الرقيقة الى المتوسطة المتداخلة مع المارل. اعتمادا على الدراسة البتروغرافية والسحنية والنسيجية تبين ان صخور التكوين ترسبت في بيئة بحرية ضحلة (لاغونية) هادئة وشبه محصورة.

INTRODUCTION

The Khurmala Formation represents the middle part of the tectonostratigraphic AP 10 megasequences of Sharland *et al*. (2001), that comprises six lithostratigraphic units of Middle Paleocene – Eocene age in the northern part of Iraq, namely Kolosh, Sinjar, Khurmala, Avanah, Gercus and Pila Spi formations. Although there are several studies on the Khurmala Formation, concerning stratigraphy, sedimentology and paleontology, the formation needs more studies, particularly in the non-studied areas, in order to clarify it is distribution and correlation with other Paleocene – Lower Eocene units.

The Khurmala Formation was first described by Bellen (1953 in Bellen *et al*., 1959) from well Kirkuk-114, comprising dolomite (pseudoolitic in parts) and finely recrystallized limestone. The carbonates of the Khurmala Formation interfinger with clastics of the Kolosh Formation and are locally anhydritic. The formation is restricted in its distribution to a belt between Bashiqa – Jabal Maqlub in the northwest and Chemchemal – Qizil Dagh area in the southeast. Jassim and Goff (2006) believed that the Khurmala Formation was most probably deposited in a relict basin corresponding to the southeast part of the Kolosh trough. This basin was separated from the off-shore Aaliji basin by a partly disconnected submarine ridge on which shoals of Sinjar Formation were deposited. A brief description of the formation is reported in the Iraq Geologic Lexicon (Bellen, 1953 in Bellen *et al*. 1959). Later, Buday (1980), in a general review of the formation, agreed with the description given by Bellen (1953 in Bellen *et al*., 1959).

Since that time, several works were conducted on the Khurmala Formation. These included the works of Al-Eisa (1983), Al-Hashimi and Amer (1985), Al-Berzanji (1989), Al-Qayim (1995), Al-Sakry (1999 and 2006), Bashir, (2001), Lawa (2004), Abdul-Azeez (2009), Karim (2009), Salih (2010), Mohammed Salih (2013) and Omer *et al*. (2014). The main topics of the present study are stratigraphy, sedimentology and paleontology and the main aim is to use a combination of field, petrographic observations and microfacies analysis to understand the depositional environment of the Khurmala Formation in Zenta area, northern Iraq, Kurdistan region

The Khurmala Formation is well exposed in the High Folded Zone of North Iraq. For this reason, the Zenta section was chosen for the purpose of this study which is not covered by previous works. The studied section is located near Zenta Village, at the inlet of Gali Zenta in the Aqra area, 3 Km west of Bjeel town in Duhok Governorate (Fig.2), approximately at Lat. 36° 44' 01'' N and Long. 43° 58' 19'' E (Fig.1).

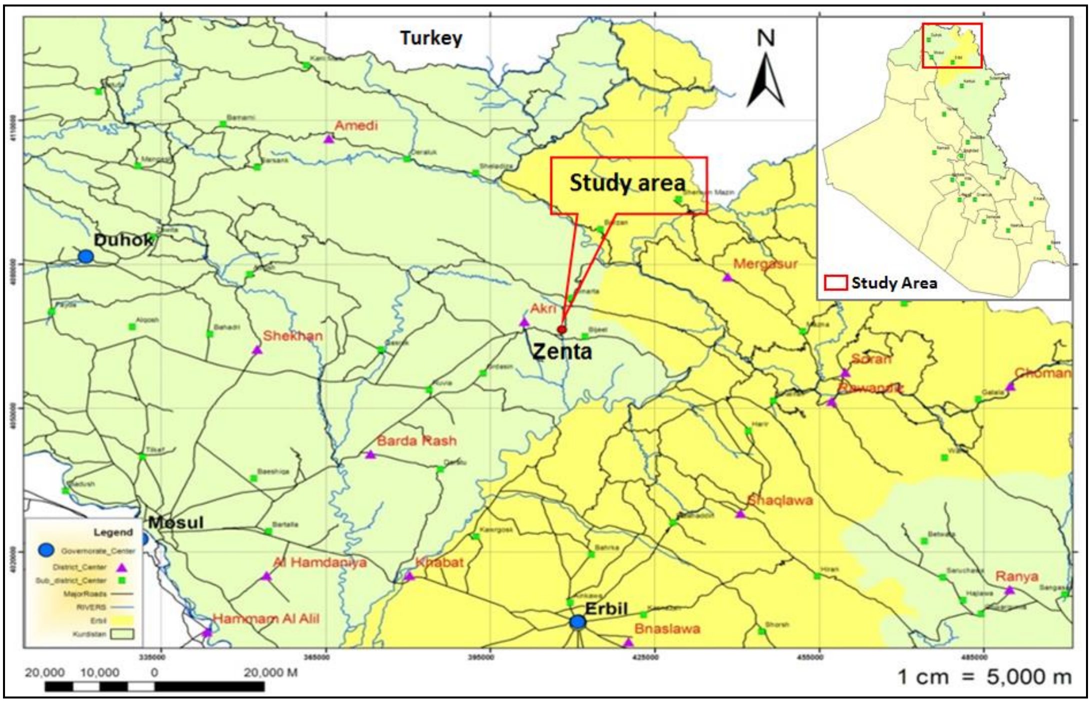

Fig.1: Location of the studied area

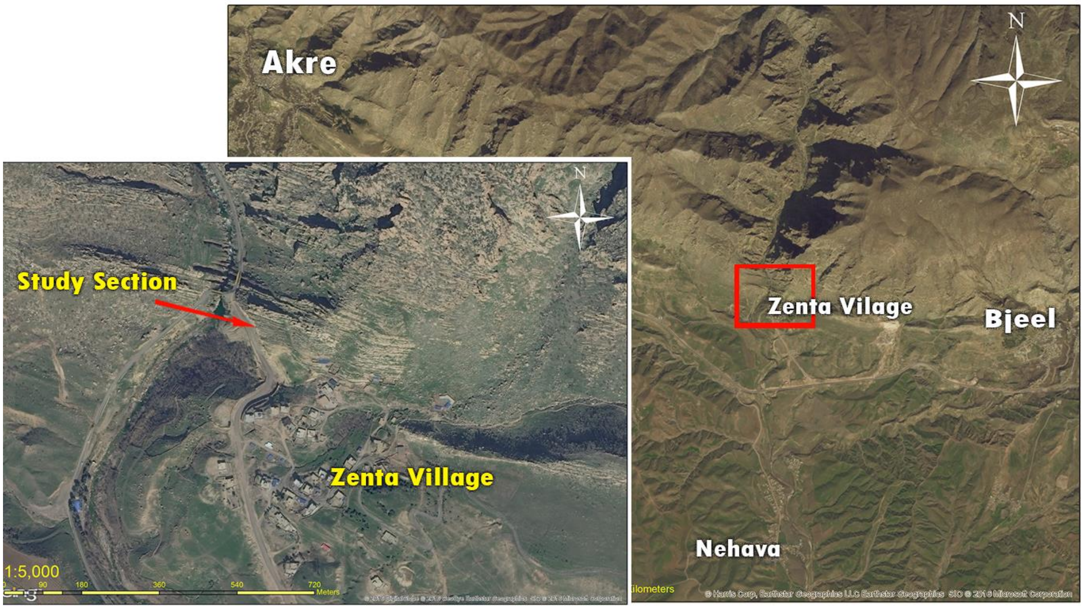

Fig.2: Satellite images of the area around Zenta Village.

METHODOLOGY

The fieldwork involved the study of general geology and structural relationships of the Cretaceous – Tertiary succession in the surroundings of studied area, in order to select the appropriate section for the purpose of this study. The Zenta section was selected for the present study and the outcrop was described and measured in detail, logging the lithology and mineralogy. The main lithology of the studied outcrop is limestone, interbedded with mudstone, marl and marly limestone in the upper part with rare nodules of cherts in some beds within the lower part of the Formation.

The total of 32 samples was collected from the carbonate beds, across the underlying and overlying contacts with the Aqra and Gercus Formations respectively, in order to check the position of these boundaries in the studied section. The samples were collected at every change in lithology, and/ 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 hand lens, and dilute HCl acid was performed. The sum of 32 thin sections was prepared in the workshop of the Geology department, College of Science, University of Salahaddin. At least one thin section for each sample was prepared. The thin sections were oriented and stained with the Alizarin Red S Solution (ARS) following the procedure of Friedman (1959) for the identification of calcite and dolomite.

GEOLOGICAL SETTING

The Paleocene – Eocene cycle is characterized by the development of the Inner Foredeep on the shelf and by the full development of the sedimentary basin (Buday, 1980). The Middle Paleocene – Eocene Megasequence was deposited during a period of renewed subduction and volcanic arc activities associated with final closure of the Neo-Tethys (Sharland *et al*., 2001). This led to uplift along the margins of the Arabian Plate with the formation of ridges and basins, generally of NW – SE trend, in north and central Iraq. Significant lateral facies change occurred across these tectonic features. Uplift of the east margin of the Arabian Plate during the Early Paleocene explains the absence of the Danian from most of the High Folded Zone and the Foothill Zone (Jassim and Goff, 2006). The Paleocene – Lower Eocene succession records the foreland basin in Iraq, between the Arabian Craton and the Alpine Orogen proper and is commonly known as the Folded Zone in Iraq. It is comprised of Mesozoic and Tertiary successions and show well exposed anticlinal and synclinal structures (Numan and Al-Azzawi, 1993). Zenta village is located in the High Folded Zone at the southern limb of the Aqra anticline (Fig.3).

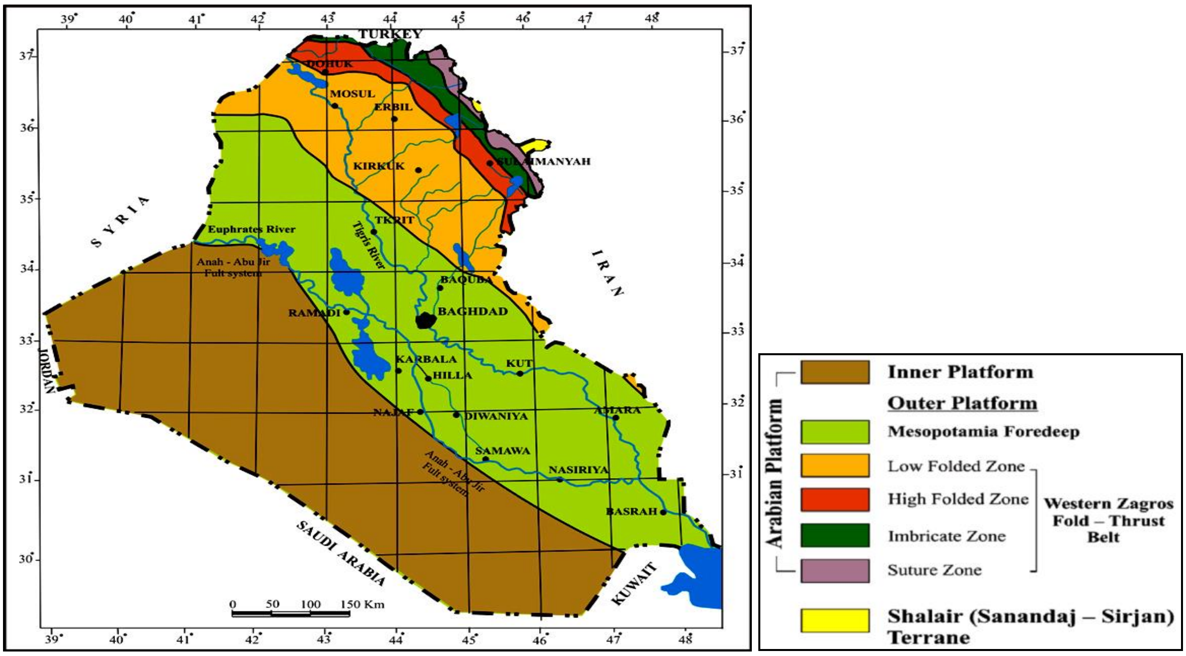

Fig.3: Tectonic map of Iraq (after Fouad, 2012)

The Zenta section includes a stratigraphic succession starting, in ascending order, from Sarmord, Qamchuqa and Aqra Formations (Cretaceous) and overlain by the Khurmala Formation as the first Tertiary unit encountered in the section. The Khurmala Formation is overlain, from older to younger; by the Gercus, Pilaspi, Fatha, Injana, Muqdadiya and Bai Hasan formations of Tertiary age (Fig.4). The nature of the boundary of the Khurmala Formation with the underlying Aqra Formation is abrupt and unconformable, but it is conformable with the overlying Gercus Formation.

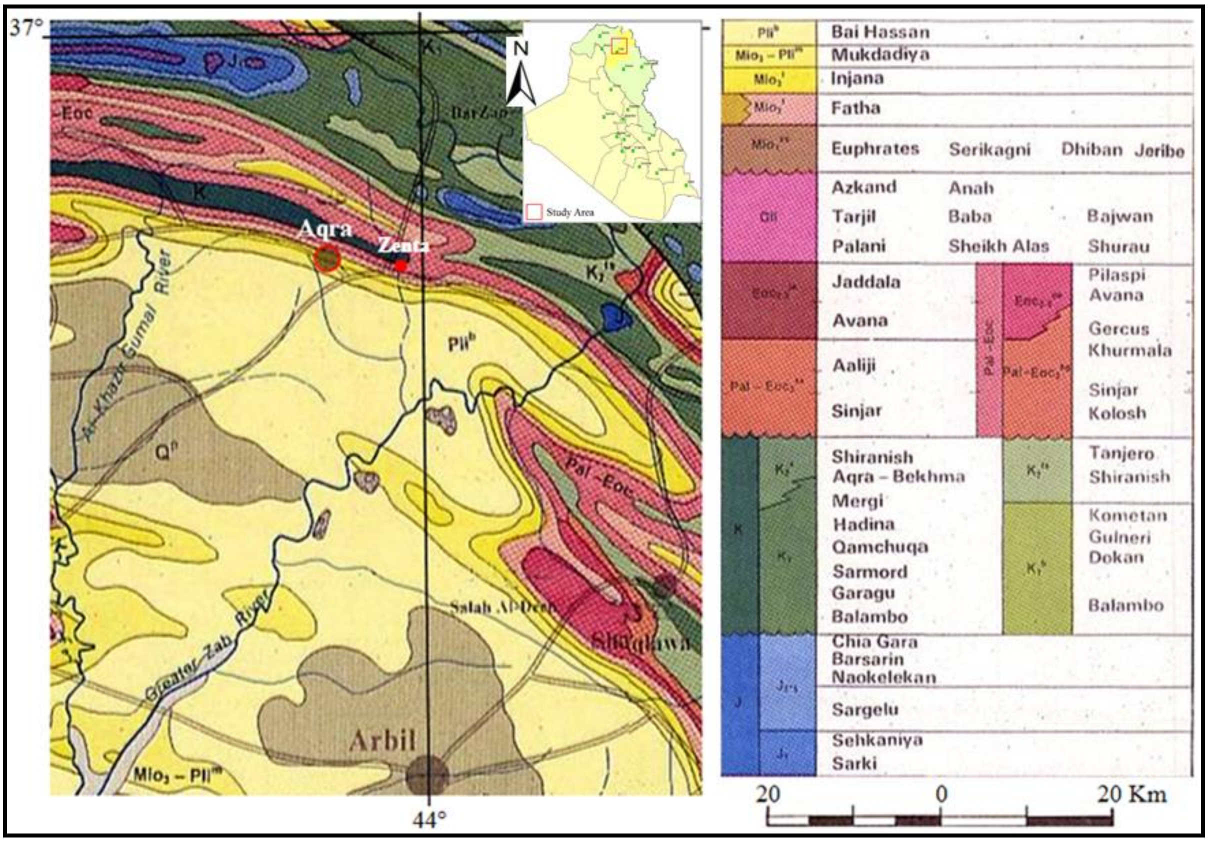

Fig.4: Geological map of the studied area (from Sissakian, 2000)

PALEOGEOGRAPHY

During the period of renewed subduction and volcanic arc activities in the Paleocene – Eocene time, associated with the final closure of the Neo-Tethys, the Middle Paleocene – Eocene Megasequence was developed into two subsequences: The Paleocene – Early Eocene sequence and Middle to Late Eocene sequence (Jassim and Goff, 2006). The Khurmala Formation is part of the Paleogene stratigraphic units of the Paleocene – Lower Eocene Cycle and was said to have a somewhat obscure stratigraphic position (Buday, 1980). The Early Paleocene time in the Arabian Platform was characterized by ending of ophiolite obduction and erosion along the NE margin of the Platform (Haq and Al-Qahtani, 2005). The cycle, as a whole, is marked by the origin and full development of the "geosynclinal area" in the Iraqi territory and the start of a widespread transgression, most probably throughout the whole area of Iraq (Buday, 1980).

The Paleocene – Lower Eocene succession records foreland sedimentation developed during the Alpine orogeny. The foreland basin in Iraq was located between the Arabian Craton and the Alpine Orogen proper and now is commonly called the Folded Zone in Iraq, where Mesozoic and Tertiary successions are exposed in folded structures (Numan and Al-Azzawi, 1993).

Haq *et al*. (1988) suggested a generally high eustatic sea level with high frequency regressive events during this period. On the other hand, Ziegler (2001) presented paleofacies of the Paleocene – Early Eocene time interval which covers the deposition of the Sinjar and Khurmala formations in northern Iraq (Fig.5). The NE part of the former Late Cretaceous foreland basin was strongly uplifted, and a new depocenter formed 50 Km to the SW according to Goff *et al*. (1995). This is referred to as the Paleogene Mesopotamian Basin (Aqrawi *et al*., 2010).

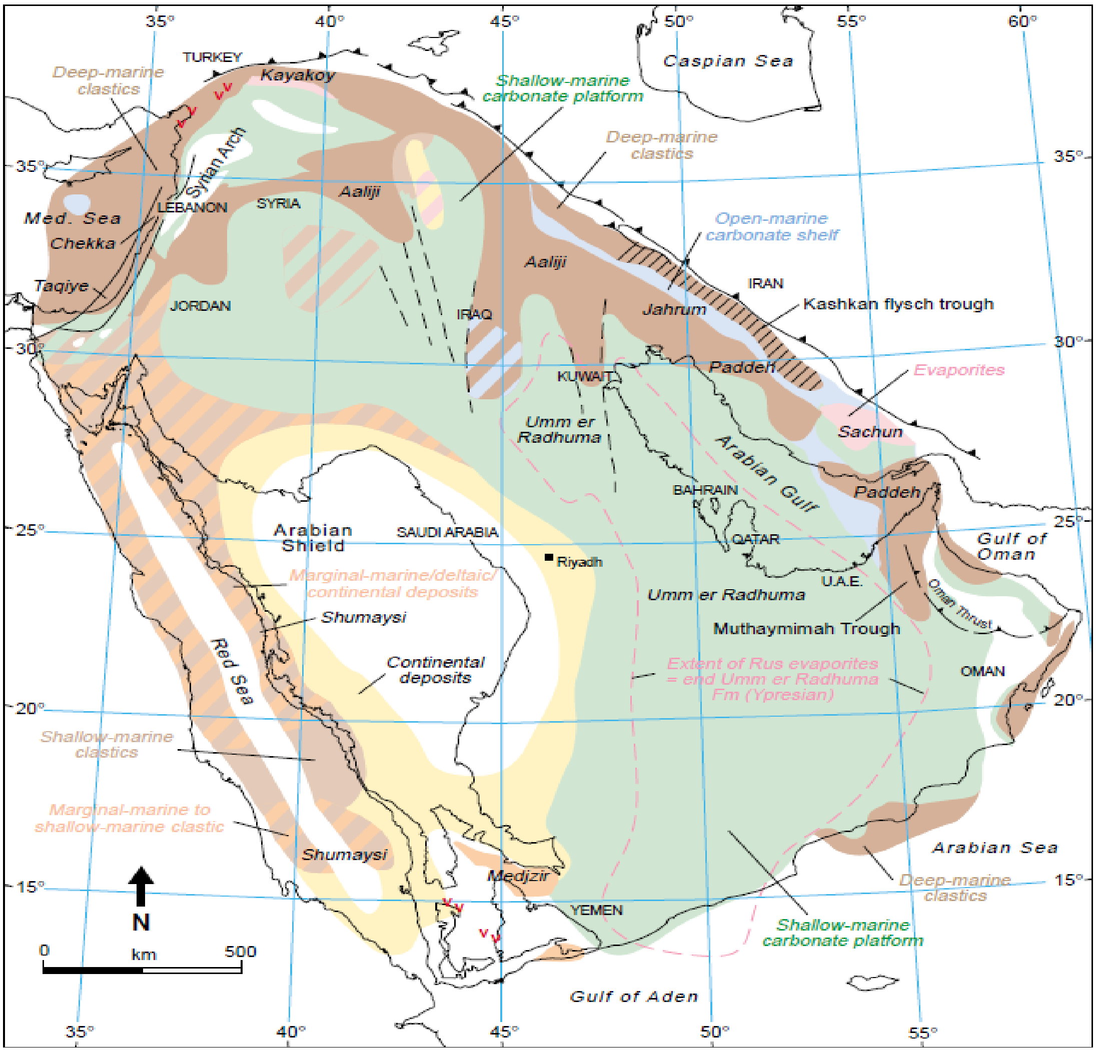

Fig.5: Paleofacies of the Late Paleocene to Early Eocene
(after Ziegler, 2001)

LITHOSTRATIGRAPHY

The total thickness of the Khurmala Formation in the studied section is about 71 meters (Fig.6). Based on field observations and petrographic study, the Khurmala Formation in the Zenta area can be divided into two units, which are in ascending order (Fig.7):

Fig.6: Field photograph showing Khurmala Formation, the underlying Aqra Formation and the overlying Gercus Formation in Zenta section

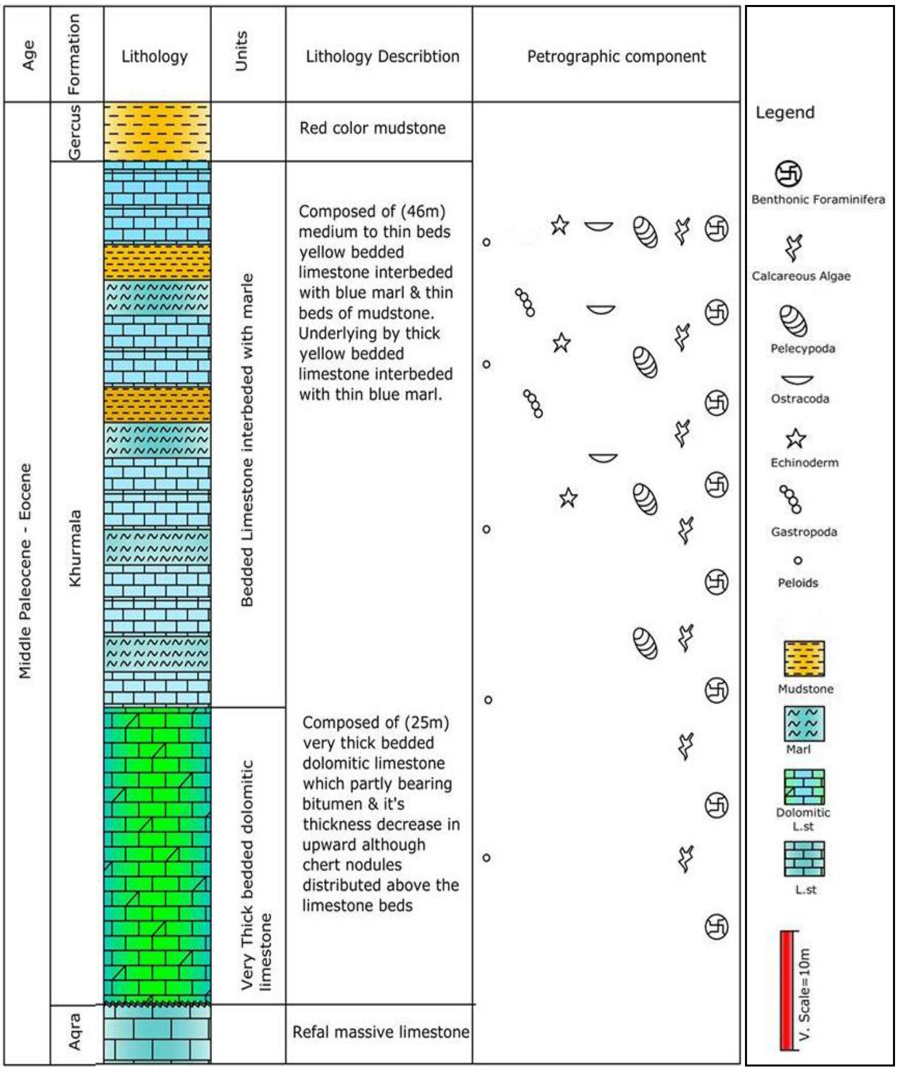

Fig.7: Stratigraphic column of the Khurmala Formation, Zenta section

- **Thick-Bedded Dolomitic Limestone Unit**

This unit forms the base of the Khurmala Formation, overlying reefal massive limestone of the Aqra Formation and is overlain by bedded limestone, interbedded with marl. The thickness of this unit is 25 m and consists of thick (50 – 100 cm) to very thick (more than 1 m), grey, dolomitic, partly bituminous limestone beds, thinning upward (Fig.8a). Chert nodules are distributed above the limestone beds (Fig.8c). Fossil molds are common in the limestone beds, which seem to be of bivalves and gastropods (Fig.8b). Physical sedimentary structures of this unit are thin horizontal (planar) millimeter-thick laminations.

The petrographic components of this unit include benthonic forminifera, calcareous algae, ostracods, and pelycepods. Non skeletal grains include peloids only. Authigenic minerals include pyrite.

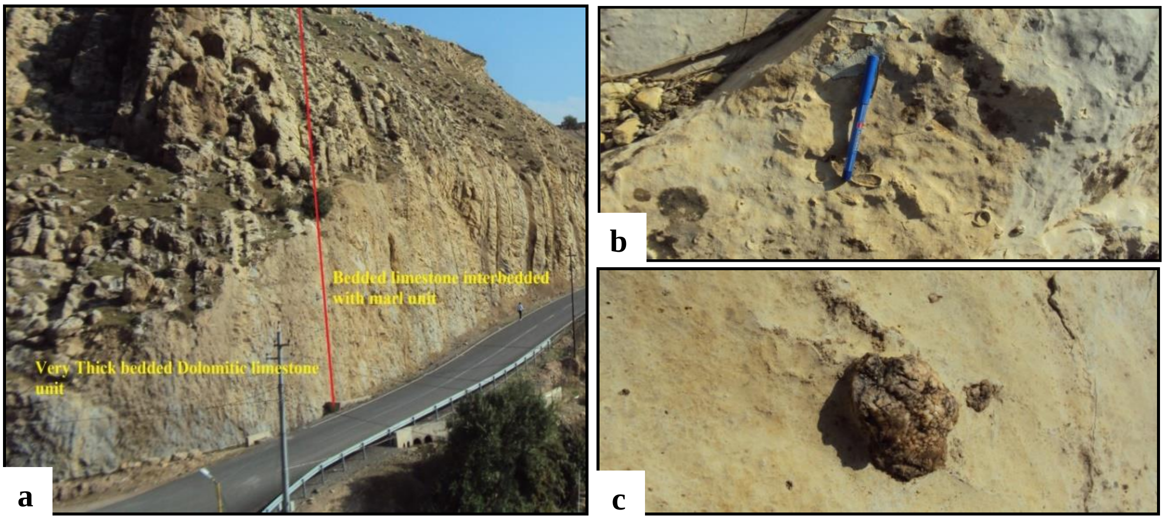

Fig.8: **a)** Photograph showing thick bedded dolomitic limestone in the left side. **b)** Photograph showing molds of macrofossils (Ostracods) in limestone beds of the Khurmala Formation. **c)** Photograph showing chert nodules observed at the bedding planes of the Thick-Bedded Dolomitic Limestone Unit

- **Interbedded Limestone – Marl Unit**

This unit overlies dolomitic limestone (Fig.9a) and underlies red colored mudstone of the Gercus Formation. The total thickness of the unit is about 46 m. The lower 13 m consist of thick (50 – 100 cm) yellow bedded limestone interbedded with thin (10 – 30 cm) of blue marl and shale, overlain by 33 m of medium (30 – 50 cm) to thick (50 – 100 cm) yellow bedded limestone interbedded with thin (10 – 30) beds of blue marl . The limestone of this unit is partly fractured and impregnated by bituminous matter.

Physical sedimentary structures of this unit include: thin horizontal (planar) millimeter-size laminations. Minor folding occurs in limestone beds in the middle part of the unit (Fig.9b), largely affected by bioturbation (Fig.9c). Petrographic components of this unit include benthonic forminifera, calcareous algae, ostracods, pelycepods, gastropods and rare larvae of echinoderms. Non skeletal grains include peloids. Authigenic minerals include pyrite.

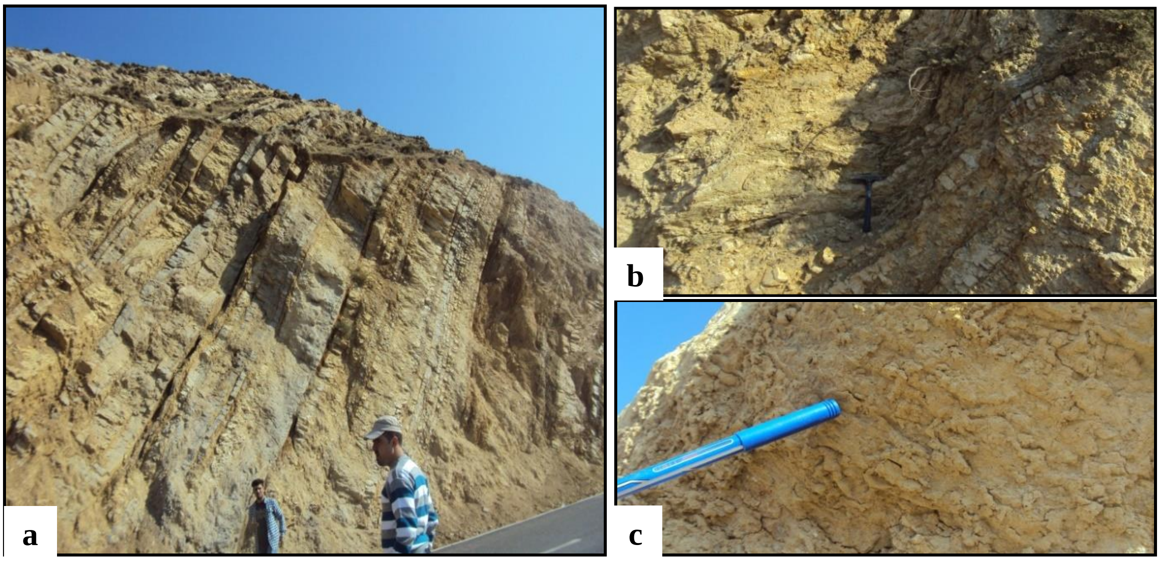

Fig.9: **a)** Photograph showing Bedded limestone interbedded with marl unit in Zenta section. **b)** Photograph showing minor folding in the Bedded limestone interbedded with marl unit. **c)** Photograph showing high bioturbation in the marls of the Bedded limestone interbedded with marl unit of Khurmala formation

MICROFACIES ANALYSIS

Three main microfacies types were recognized in the studied limestone samples of the Khurmala Formation. Each was later subdivided into several submicrofacies, based on significant fossil type and diagenetic processes. Table (1) shows the main and submicrofacies recognized in the petrographic study.

Table 1: Microfacies of the Khurmala Formation

Main Microfacies Dunham (1962)	**Subdivision of Dunham (1962) terms**	**Diagnostic features (main skeletal grain + common diagenetic process)**	**Equivalence to Wilson's (1975) SMF**
Lime Mudstone	Pure Lime Mudstone	- Neomorphism - Dissolution	**SMF 8**
	Small Benthonic Forminifera Lime Mudstone	- *Textularia* , Rotalids. - Neomorphim + Micratization	
	Dasycladaceaen Lime Mudstone	- Green Algae - Neomorphism	
Lime Wackestone	Peloidal Lime Wackestone	- Peloids - neomorphism + dolomitization + micritization	
	Dasycladaceaen-Rotalid Lime Wackestone	- Dasycladaceae + Rotalid - Dolomitization + neomorphism	
Lime Packstone	Dasycladaceaen-Rotalid Lime Packstone	- Dasycladaceaen + Rotalid - Micratization + dolomtization	

- **Lime Mudstone Microfacies**

This microfacies consists of micrite only with rare (generally less than 10%) fossil content (Dunham, 1962). This microfacies is common in the studied samples and can be divided into three submicrofacies.

– **Pure Lime Mudstone Submicrofacies (Fig.10a):** This microfacies is common in the upper part of the studied section. Severe neomorphism of micrite to microspar and pseudospar is recognized, although highly affected by dissolution. Skeletal grains are rare, except for a few rotalids and ostracods.

– **Small benthonic Forminiferal Lime Mudstone (Fig.10b):** This microfacies was noticed in both units of the Khurmala Formation. Rotalids and textularia are the dominant skeletal grains. The facies was highly affected by neomorphism and micratization.

– **Dasycladaceaen Lime Mudstone (Fig.10c):** This submicrofacies was observed in the upper part of the studied section. Calcareous algae (Dasycladaceae) are dominant skeletal grains with rare pelycepods and ostraocds. The main diagenetic processes affected the facies were neomorphism and dolomitization.

- **Lime Wackestone Microfacies**

This represents the common facies in the lower part of studied section. Grains of wackestone range between 10 – 50% in micrite matrix (Dunham, 1962). The wackestone of the Khurmala Formation was subjected to variable diagenetic processes. Depending on the grain ratio, the wackestone are subdivided into the following subdivisions:

– **Peloidal Lime Wackestone Submicrofacies (Fig.10d):** This is found in the lower part of studied formation within the dolomitic limestone lithofacies and sometimes in the upper parts, within the thin to medium bedded limestone lithofacies. The common grains are peloids. This facies is subjected to different diagenetic processes such as neomorphism, dolomitization, and micratization. Authigenic minerals include pyrite.

– **Dasycladaceaen-Rotalid Lime Wackstone Submicrofacies (Fig.10e):** This submicrofacies is dominated by calcareous algae (Dascladacayae) and benthic foraminifera (rotalids) standing as the main skeletal grains and minor amount of articulated pelycepods. Some ostracods and ammonites are frequently observed. Non-skeletal grains include peloids. This facies is found in the lower part of the Dolomitic – Limestone Lithofacies in the Zenta section, highly affected by dolomitization and neomorphism. Pyrite is a common authigenic mineral seen in this facies.

- **Lime Packstone Microfacies**

This facies is less common in the studied samples. The skeletal grains increase up to 60% in the packstone leaving minor micrite between grains-supported limestones (Dunham, 1962). Only one submicrofacies in the studied section was observed.

– **Dasycladaceaen-Rotalid Lime Packstone Submicrofacies (Fig.10f):** This submicrofacies is observed in the lower part of the studied section. It is rich in microfauna of Dascldacya and rotalids. In addition the pelycepods and ostracods are also observed. Micratization and dolomtization are the main digenetic processes in this facies.

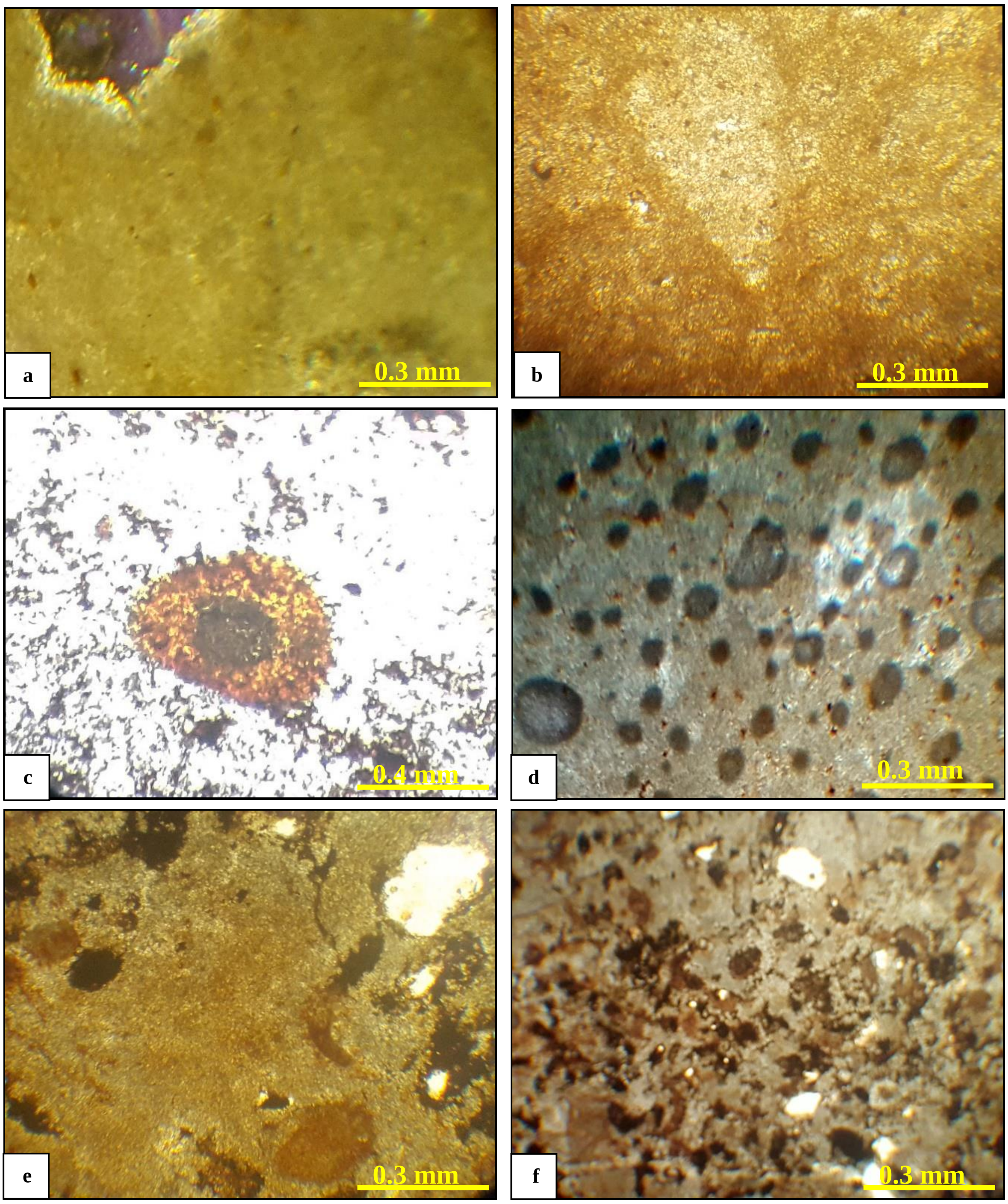

Fig.10: Microfacies types
a) Pure Lime Mudstone Submicrofacies Kh-24. **b)** Small benthonic Forminifera Lime Mudstone Kh-18. **c)** Dascladacean Lime Mudstone Kh-20. **d)** Peloidal Lime Wackestone Submicrofacies Kh-11. **e)** Dascladacaen-Rotalid Lime Wackstone Submicrofacies Kh-6. **f)** Dasycladaceaen-Rotalid Lime Packstone Submicrofacies Kh-5.
(Kh = Khurmala)

FACIES ASSOCIATION

- **Lagoonal facies association**

This association is equivalent to facies zone 7 of Wilson (1975) and standard microfacies 8 of Flugel (1982). It consists mainly of light grey to yellow bedded limestones within lime-mudstone – wackestone and packstone microfacies. The upper part of the Khurmala Formation consists of limestones intercalated with thin to medium beds of marl and mudstone; both of which refer to the quite sea bottom at the time of deposition. In addition, chert nodules and bioturbations are noticed on the bedding planes of the limestones in the upper and lower parts of the studied section. Limestones of the Khurmala Formation consist of macro and microfaunas, which include, small benthonic foraminifera, calcareous algae, ostracods, pelycepods in addition to rare larvae echinoderms. The microscopic study of thin sections revealed different facies types of which similarity in litho and biocontent was obvious. This would indicate homogeneity of both facies and environment in this section. Following the terminology of Dunham (1962), it was found that mudstone is the most abundant facies followed by wackestone and packstone. All these microfacies were dominated by micrite matrix. The dominance of micrite within these facies indicates that the sea bottom was stagnant and calm enough for lime mud to accumulate (Dunham, 1962).

The bituminous material present in the limestones of the Khurmala Formation, provides evidence of prolific production of plants and burrowing organisms that feed on the decaying organic matters. According to the Standard Microfacies (SMF) and Facies Zone (FZ) of Wilson (1975) and Flugel (1982), it is found that facies of the Khurmala Formation correspond to SMF-8 which belongs to FZ-7 (shelf lagoon with semi restricted circulation). From the environmental point of view, the dominance of micrite is a general indicator for the quite nature of the environment. The absence of planktonic foraminifera suggests shallow environment and the lack of corals and rudists suggest remoteness from reefal environment. The microfossils found in the studied section indicate that the Khurmala Formation was deposited in a shallow marine environment and precisely lagoonal environment, which was separated from the deep sea by reefal development of the Sinjar Formation.

The common presence of rotalids and *Textularia* in the studied section indicates a shallow marine environment (Hallock and Glenn, 1986). Calcareous green algae (Dasycladaceaen) are distributed in all parts of studied section and indicates shallow water environment of less than 10 m deep (Aguirre *et al*., 2000). Ostracods are highly obliterated inhabitants of several aquatic environments; marine, transitional and fresh, found at various depths from shoreline to bathyal and wide distribution from the equator to polar seas (Haq and Boersma, 1998). Pelycepods have a wide environmental range; from near- shore to off-shore environments (Clarkson, 1998). The larvae echinoderms, rarely found in the limestones of the Khurmala Formation, inhabit depths ranging from shallow waters at tide lines to the deep seas (Brusca and Brusca, 2003). The association of ostracods, pelecypods and echinoderms with other benthic foraminifera and calcareous algae in the Khurmala Formation indicate lagoonal shallow marine environment. Gastropods are also observed in the Khurmala Formation. Clarkson (1998) mentioned that the association of gastropods with ostracods and bivalves indicate a brakish-lagoonal faceis in Tertiary limestones. The study has shown that the rocks of the Khurmala Formation are highly affected by bioturbation and borrowing particularly in the upper parts. As Nichols (2009) mentioned that in lagoons, the fine, organic-rich sediment provides a favorable feeding area for organisms that are able to tolerate the reduced/ enhanced salinity, and bioturbation may be common. Burrowing is common in shelf lagoon with circulation and shallow lagoon with open circulation too (Flugel, 2004).

All the biological criteria, fossils and trace fossils discussed above, indicate a lagoonal environment for the Khurmala Formation. The presence of chert nodules in the limestones of the lower part of the Khurmala Formation indicates shallow marine environment with land input source (river-water with high silica content). As Laschet (1984) confirmed that in shallow-marine areas, the input of silica from land is an important source. On the other hand, the common presence of authigenic pyrite in the Khurmala Formation limestones, offer evidence of restricted-lagoonal environment (Kauffman and Sageman, 1990). From the sum of all petrographic, facies and textural analyses, it is concluded that the Khurmala Formation at Zenta Village was deposited in a shallow marine environment (shelf lagoon) partly quiet with semi restricted conditions. To imply all these interpretation a proposed model is compiled (Fig.11). This model illustrates the inferred paleoenvironmental conditions of the Khurmala Formation in Northern Iraq (Kurdistan Region).

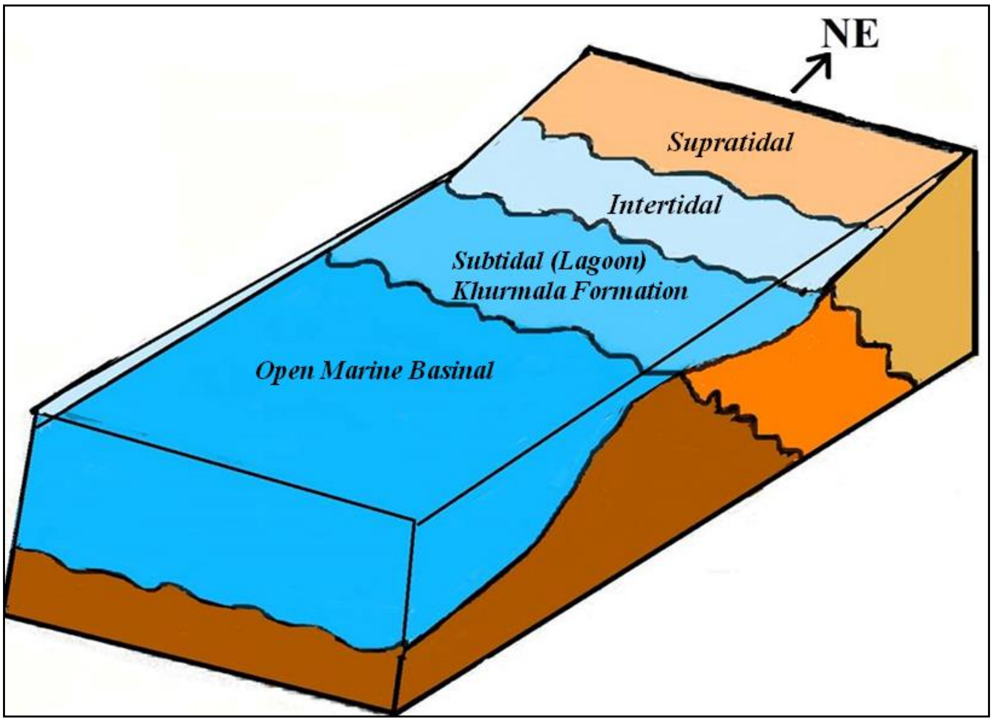

Fig.11: The Depositional model of the Khurmala Formation in Zenta section, High Folded Zone, Northern Iraq

CONCLUSIONS

- Field observations and petrographic analysis show two different lithological units in the Khurmala Formation at Zenta Section. They are, in ascending order: Thick-Bedded Dolomitic Limestone Unit and Interbedded Limestone-Marl Unit.
- Petrographic study revealed six micro facies which are grouped into one basic type of facies association (Lagoonal facies association).
- Petrographic, facies and textural analyses indicate that the Khurmala Formation in the Zenta Village was deposited in a shallow marine environment (shelf lagoon) partly quiet with semi restricted conditions.

AKNOWLEDGMENTS

The authors would like to express their appreciation to Mr. Chawshin Ch. Fryaand. Mr. Muhmad A. in Geology Department, Salahaddin University for their helps during field works. Mr. Wria Jabbar in Geology Department, Salahaddin University and Kawa Salih in Petroleum Geosciences, Soran University are also thanked for computer facilities of the manscriput.

REFERENCES

Abdul-Azeez A., 2009. Petrography of surface section of Paleocene – Eocene in Erbil area. State Company of Geological survey and Mining, GEOSURV, int. rep. no. 3182, 40pp.

Aguirre, J., Riding, R. and Braga, J.C., 2000. Late Cretaceous incident light reduction: evidence from benthic algae. *Lethaia*, Vol.33, p. 213 – 213.

Al-Barzanji, Sh.J., 1989. Microfacies study of the Khurmala Formation from selected sections in north and north east Iraq. Unpublished M.Sc. thesis, Salahaddin University, 113pp.

Al-Eisa, M.E., 1983. Study of the foraminifera and depositional environment of fossil in the Khurmala Formation, Shaqlawa area. Unpublished M.Sc. thesis, Mosul University, 94pp.

Al-Hashimi, H.A. and Amer, R.M., 1985. Tertiary microfacies of Iraq. S.O.M., Baghdad, 56pp, 159 plates.

Al-Qayim, B., 1995. Sedimentary Facies Anatomy of Khurmala Formation, Northern Iraq. Iraqi Geol. Jour., Vol.28, No.1, p. 36 – 46.

Al-Sakry, S.I., 1999. Stratigraphy and facies of Paleogene carbonate formations of selected sections, Northeastern Iraq. Unpublished M.Sc. thesis, Baghdad University, 113pp

Al-Sakry, S.I., 2006. Sequence Stratigraphy of the Paleocene – Lower Eocene Succession, Northeastern Iraq, Unpublished Ph.D. thesis, Baghdad University, 240pp.

Aqrawi, A.A.M., Goff, J.C., Horbury, A.D., Sadooni, F.N., 2010. The Petrolum Geology of Iraq.Statoil Scientific Press.424 p.

Bashir, W.P., 2001. Petrogrphy of subsurface section of Paleocene – Eocene rocks in Bashiqa Area. State Company of Geological survey and Mining, GEOSURV, int. rep. no. 2626, 25pp.

Bellen, R.C., Van Dunnington, H.V., Wetzel, R. and Morton, D., 1959. Lexique Stratigraphic International. Asie, Fasc. 10a, Iraq, Paris, 333pp.

Brusca, R. and Brusca G., 2003. Invertebrates, Sunderland, Massachusetts, Sinauer. Associates, Inc., 895pp.

Buday, T., 1980. The Regional Geology of Iraq. Vol.1, Stratigraphy and Paleogeography. Dar Al-Kutub Pub. Univ. of Mosul, Iraq, 445pp.

Clarkson E.N.K., 1998. Invertebrate Palaeontology and Evolution (London, England: Allen and Unwin), 468pp.

Dunham, R.H., 1962. Classification of carbonate rocks according to depositional texture. In: Ham, W.E., ed., Classification of carbonate rocks. AAPG. Memoir 1, p.108 – 121.

Flugel, E., 1982. Microfacies Analysis of Limestones, Springer – Verlag, Berlin, 633pp.

Flugel, E., 2004. Microfacies of Carbonate Rocks: Analysis, Interpretation and Application. Springer, Berlin, 976pp.

Fouad, S.F., 2012. Tectonic Map of Iraq, Scale 1: 1000 000. 3rd edit, GEOSURV, Baghdad.

Friedman, G.M., 1959. Identification of carbonate minerals by staining methods. Jour. Sed. Pet., Vol.29, No.2, p. 87 – 97.

Goff, J.C., Jones R.W. and Horbury A.D., 1995. Cenozoic basin evolution of the northern part of the Arabian Plate and its control on hydrocarbon habitat. In: M.I. Al-Husseini (ed.), Middle East Petroleum Geosciences Conference, GEO' 94. Gulf Petro Link, Bahrain, Vol.1, p. 402 – 412.

Hallock, P. and Glenn, E.C., 1986. Larger foraminfera: Atoll for Paleoenvironmental analysis of Cenozoic Carbonate Depositional Facies, The society of Economic palaeontologists. Minerologists. U.S., Vol.1, p. 55 – 64.

Haq, B.U. and Al-Qahtani, A., 2005. Phanerozoic cycles of sea-level change on the Arabian platform: GeoArabia, Gulf Petro Link, Bahrain, Vol.10, No.2, p. 127 – 160.

Haq, B.U. and Boersma, A., 1998. Introduction to Marine Micropaleontology. Elsevier New York, 376pp.

Haq, B.U., Hardenbol, J. and Vail, P.R., 1988. Mesozoic and Cenozoic chronostratigraphy and eustatic cycles. In: Wilgus, C.K., Hasting, B.S., Kendall, C.G., Posamentier, H.W., Ross, C.A., and van Wagoner, J.C., eds., Sea Level Changes, SEPM Spec. Pub. No.42, p. 71 – 80.

Jassim, S.Z. and Goff, J.C., 2006. Geology of Iraq. Dolin, Prague and Moravian Museum, Brno. 341pp.

Karim, Ch.A., 2009. Stratigraphical and Paleontological Study of Khurmala Formation (Paleocene – Lower Eocene) in Shaqlawa Area – Northern Iraq, Unpublished M.Sc. thesis, Mousl University, 103pp.

Kauffman, E.G. and Sageman, B.B., 1990. Biological sensing of benthic environments in dark shales and related oxygen – restricted facies. In: Ginsburg, R.N. and Beaudoin, B., eds., Cretaceous resources, events and rhythms background and plans for research. Kluwer Academic publishers. London. 352pp.
Laschet, C. ,1984. On the origin of cherts. Facies, Vol.10, p. 257 – 289.
Lawa, F.A., 2004. Sequence stratigraphic analysis of the Middle Paleocene – Middle Eocene in the Sulaimani district (Kurdstan region). Unpublished Ph.D. thesis, Sulaimaniya University, 258pp.
Mohammed Salih A.L., 2013. Sedimentology of Sinjar and Khurmala Formations (Paleocene – Lower Eocene) in Northern Iraq. Unpublished Ph.D. thesis, Baghdad University, 215pp.
Nichols, G., 2009. Sedimentology and Stratigraphy. Wiley – Blackwell, UK, 419pp.
Numan, N. and Al-Azzawi, N., 1993. Structural and Geotectonic Interpretation of Vergence Directions of Anticlines in the Foreland Fold in Iraq, Yarmouk University, Vol.2, p. 557 – 730.
Omer, M.F, Omer, D. and Zebari, B.Gh., 2014. High resolution cathodoluminescence spectroscopy of carbonate cementation in Khurmala Formation (Paleocene – L. Eocene) from Iraqi Kurdistan Region, Northern Iraq. Journal of African Earth Sciences, Vol.100, p. 243 – 258.
Salih N.M., 2010. Stratigraphy and paleoenvironment of the Khurmala and Sinjar Formations at Shira Swar, Shinawa and Bekhme in Kurdistan Region, Northeastern Iraq. M.sc. Thesis, Salahaddin University. Unpublished.
Sharland, P.R., Archer, R., Casey, D.M., Davies, R.B., Hall, S.H., Heward, A.P., Horbury, A.D. and Simmons, M.D., 2001. Arabian Plate Sequence Stratigraphy, Geo Arabia, Special publication 2, Gulf Petro Link, Bahrain, 372p.m Pet., Vol.52, No.4, p. 1087 – 1100.
Sissakian, V.K., 2000. Geological Map of Iraq. Sheet No.1, scale 1: 1000 000, 3rd edit. GEOSURV, Baghdad, Iraq.
Wilson, J.L., 1975. Carbonate Facies In Geologic History. Springer-Verlag, Berlin, 471pp.
Ziegler, M.A., 2001. Late Permian to Holocene paleofacies evolution of the Arabian Plate and its hydrocarbon occurrences. GeoArabia, Vol.6, No.3, p. 445 – 504.

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