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THE SEDIMENTOLOGY OF THE SERIKAGNI FORMATION (LOWER MIOCENE) AT SINJAR MOUNTAIN AREA, NW IRAQ

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ABSTRACT

This study deals with establishing the depositional environments, mineralogy and diagenesis of the Serikagni Formation (lower Miocene) in northwest Iraq. Four sections are described and sampled from Sinjar Mountain region, the only exposure area.

Mineralogical studies revealed that the major mineral is calcite with variable admixture of insoluble residues, which are mostly clay minerals and quartz. Subordinate dolomite and infrequent glauconite and pyrite are also recorded. The main clay minerals are kaolinite, palygorskite and illite with occasional smectite. Petrographic analyses reveal that the Serikagni Formation comprises mostly micrite and skeletal grains, represented by dominantly planktic foraminifera and subordinate benthic foraminifera and bioclasts. The main diagenetic processes that affected the studied rocks are bioturbation, dissolution, neomorphism, cementation (granular), replacement and mechanical compaction.

Field description and laboratory confirmation reveal the existence of three lithogies namely, limestone, marly limestone and limey marl arranged as orbital cycles. Petrographic analysis revealed three microfacies namely, Planktic Foraminiferal Lime Mudstone, Planktic Foraminiferal Wackestone/ Packstone and Biolithoclastic Packstone. Facies analysis indicates that deposition has taken place in a basinal environment with hemipelagic character (deep shelf, toe-of-slope and slope). Turbidites of slumping origin is identified at Sinjar section.

رسوبية تكوين سريكاكني (المايوسين الاسفل)، منطقة جبل سنجار شمال غرب العراق

مازن يوسف تمراغا و اسماء عبد العزيز ابراهيم

المستخلص

تعرض هذه الدراسة معدنية تكوين سريكاكني (المايوسين الأسفل في شمال العراق) والعمليات التحويرية التي عانى منها التكوين واستنباط بيئة الترسيب. تم وصف وجمع عينات لأربعة مقاطع من منطقة جبل سنجار وكشفت الدراسة المعدنية ان المعدن الرئيسي هو الكالسيات مع اختلاف في الفضالة غير ذائبة والتي تتكون غالبا من معادن طينية وكوارتز فضلا عن كميات قليلة جدا من الدولومايت والكلوكونايت والبايرايت.

أما المعادن الطينية الرئيسة فهي الكاؤلينايت والباليغورسكايت والالايت والمونتمورلونايت. كما كشفت التحليلات البتروغرافية ان تكوين سريكاكني يتكون في الغالب من المكرايت مع حبيبات هيكلية متمثلة بالفورامنيفرا الطافية وهي السائدة والفورامنيفرا القاعية الثانوية مع الأحياء المتكسرة. أما العمليات التحويرية الرئيسة التي أثرت في صخور الدراسة فهي التعكرات الحياتية، الذوبان، التشكل الجديد، السمنتة (حبيبي)، استبدال وإحكام ميكانيكي. كما كشف الوصف الحقلي والتحليل المختبري عن وجود ثلاث وحدات صخارية هي الحجر الجيري، الحجر الجيري المارلي والمارل الجيري على هيئة دورات مدارية منتظمة وثلاث سحنات هي المنخربات الطافية المارلية والمنخربات الطافية الواكية/ المرصوصة والأحياء المتكسرة المرصوصة. يشيرالتحليل السحني الى ان الترسيب حصل في بيئة الحوض.

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INTRODUCTION

The Serikagni Formation is part of the Early Miocene Sequence which includes the Ghar (dominantly clastics), Serikagni (dominantly globigerinal carbonates) and Dhiban (dominantly evaporites) Formations. This formation is exposed in the Sinjar mountain area only, where the present study focuses. The Sinjar Mountain is a geomorphic expression of a salient doubly plunging anticline dominating the area and extending E – W (Figs.1 and 2).

Amer (1977) studied the biostratigraphy of Serikagni Formation in Sinjar area and found that the age of this formation, according tothe assemblages of planktic foraminifera is lower Miocene. Ma'ala (1977) reported the geological mapping of Sinjar area and described the formations exposed there, including the Serikagni Formation. Karim (1978) studied the micropaleontology, biostratigraphy and paleoecology of Serikagni Formation in the Jebel Goulat area and defined the age of this formation as lower Miocene (Aquitanian – Burdigalian) depending on planktic and benthic foraminifera. She assumed the depositional environment as open marine environment in tropical and semitropical conditions. Al-Banna (2004) studied the lithostratigraphy and microfacies of the Serikagni Formation at its type section and recognized three microfacies which belong to Wilson’s (1975) standard microfacies 3 and 8 and Facies Zones 1 and 2. In addition he recognized an intraformational conglomerate lithofacies which is attributed to accumulation in the shallowest part of the basin and probably later exposed.

Al-Dabbas and Hassan (2013) studied the geochemistry and palynology of the Serikagni Formation in the same area using the samples of current research and recognized two palynofacies. Palynofacies PF-1is characterized by high percentage (> 80%) of amorphous organic matter indicating deep marine depositional environment. Palynofacies PF-2 is characterized by low quantities of amorphous organic matter (< 40%) with increase of translucent type phytoclasts (> 30%) and miospores (> 20%) indicating near shore and shallow marine depositional environment.

The aim of this study is to establish the depositional environment, nature of cyclicity and paleogeography of the Serikagni Formation in the Sinjar area. This would be accomplished through facies analysis as well as investigating the mineralogy and digenetical changes of the sequence.

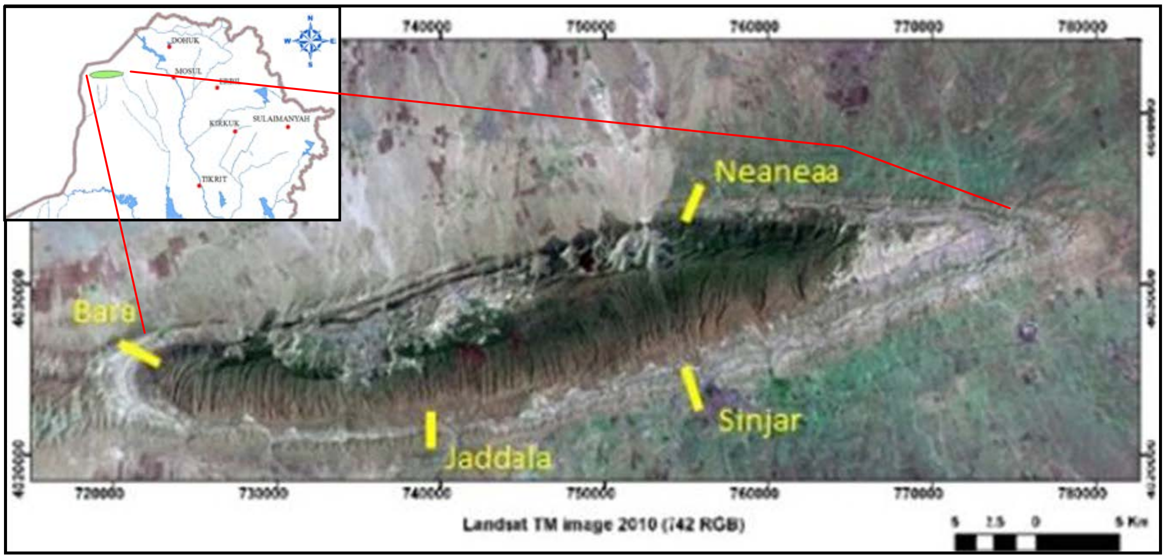


Fig.1: Location map of the study area and the studied sections

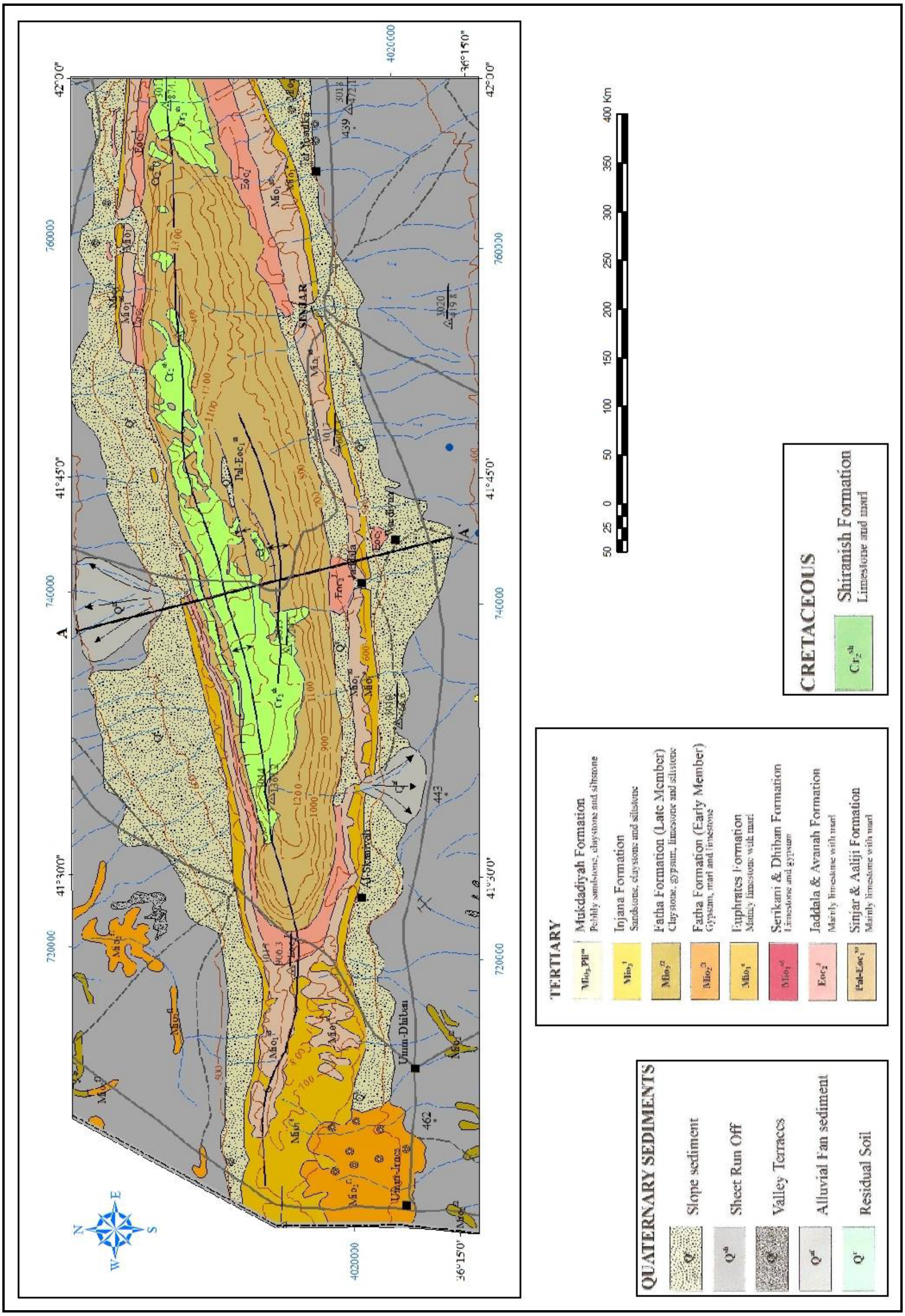


Fig.2: Geological map of Sinjar anticline (Sissakian and Fouad, 2012)

GEOLOGICAL SETTING

The Serikagni Formation is first introduced by Bellen (1955, in Bellen *et al*., 1959) for about 150 meters of rhythmic globigerinal chalky limestone. It is well exposed in a narrow strip around Sinjar Mountain in northwest Iraq and the type section near the village of Bara (Fig.1). Structurally, the Sinjar Mountain is a conspicuous trilobed feature consisting of a doubly plunging asymmetrical anticline (Fig.2).

The lower contact of the studied formation is unconformable either with the middle-upper Eocene Jaddala Formation (Bellen *et al*., 1959) or the Oligocene Ibrahim Formation (Ma'ala, 1977; Al-Mutwali and Al-Banna, 2002). The Serikagni Formation underlies the Dhiban Anhydrite (lower Miocene) conformably or the Jeribe Formation (lower Miocene) unconformably (Ma'ala, 1977).

The Serikagni Formation belongs to the Arabian Plate Tectonostratigraphic Megasequence AP11 (latest Eocene to the present) of Sharland *et al*. (2001). This megasequence is subdivided by Jassim and Goff (2006) into three sequences and the Serikagni Formation belongs to the middle sequence (early – middle Miocene Sequence) together with Asmari, Euphrates, Dhiban, Ghar, Jeribe and Fatha (formerly named Lower Fars) Formations, and Kalhur Gypsum. The Serkagni Formation has a fairly limited distribution and exposures (Fig.3). The extension of this lithostratigraphic unit in Syria is marl interfingering with evaporites (Jassim and Goff, 2006).

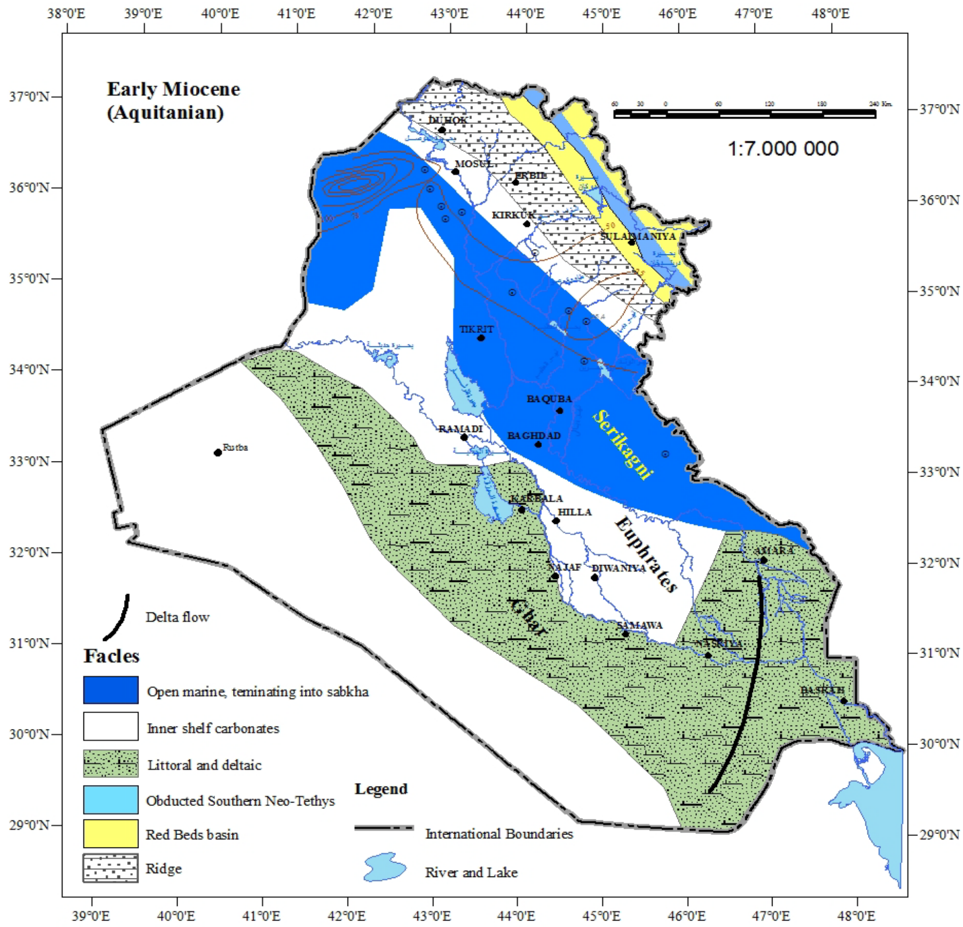


Fig.3: Isopach map of the Serikagni Formation overlaid on the facies map given by Jassim and Goff (2006)

The collision between Arabia and Eurasia during Eocene time (Beydoun, 1991 and Numan, 2001) marks the consumption of the oceanic floor and henceforth end of the Neotethys in the area. Later on, epicontinental sea was developed, after the closure of the Neotethys. The depositional environment was dominantly shallow marine, except in some areas such as in the Sinjar Graben where deep marine facies has developed. The Serikagni Formation is deep marine facies deposited in the Sinjar Graben. Compressional conditions prevailed before, during and after the late Miocene (Fouad, 2007).

MATERIAL AND METHODS

Four outcrops are described and sampled from the Sinjar mountain area: Bara, Jaddala, Sinjar and Neaneaa (Fig.1) representing the Serikagni Formation. These outcrops are located at Longitudes 41° 25' 00" and 42° 05' 00", and Latitudes 36° 3' 00" and 36° 15' 00". The sequence in each section is described considering the lithology, colour, sedimentary structures, fossil content, bioturbation and contacts. A total of 83 samples are collected (Jaddala section – 24 samples, Sinjar section – 32 samples, Neaneaa section – 14 samples, Bara section – 13 samples). All samples are thin sectioned and stained with Alizarin red S and potassium ferricyanide following Dickson's method (1965) for the standard petrographic analysis. Weak-acid insoluble residues for all collected samples are determined using 10% HCl (Ireland, 1958). Mineralogy of 18 samples representing the four sections are investigated with X-ray diffractometry. These samples are digested with diluted acetic acid (0.018%). Four oriented smear mounts are prepared for the < 2 µm size fraction of each sample, using the technique of Ostram (1961) and Gipson (1966). One smear mount is glycolated (in an Ethylene Glycol bath for 24 hours at 60 °C); the second and third are heated to 350 and 550 °C respectively, whereas the fourth remained in an air-dried state. The four smear mounts are run in a Philips X-ray Diffractometer PW 1965/60 (20 mA, 40 kV, Cu-Ni Kα, at 1 centimeter/minute, 1°2θ/minute speed). Identification of the reflections is carried out according to Grim (1968), Carroll (1970) and Thorez (1976).

LITHOLOGY

The lithology of the Serikagni Formation relies on field description which is later verified by laboratory confirmation, basically by determining the weak-acid insoluble residues of 83 samples. Three main lithologies are identified forming couplets of limestone, marly limestone and/ or marl (Fig.4), which are arranged repeatedly in rhythmic pattern though are not necessarily complete rhythms.

Fig.4: The rhythmic pattern in the Serikagni Formation at Sinjar section showing lithological couplets of limestone (dark) marly limestone and/ or marl (light)

The rhythms are clearly reflected in the exposures owing to the differential weathering of the different lithologies (Fig.4). Each package of rhythm usually has lower sharp, flat or irregular and sharp contact and passes gradually and slowly upwards into the next lithology (Fig.5). The thickness of each lithology is variable (Fig.6). The beds contain sporadic pyrite (occasionally oxidized) and less frequent green and brownish green glauconite. Small lenses and patches of iron and manganese oxides, occasionally associated with calcite veins, are common on joint planes. The lithofacies are described below:

Fig.5: Nature of contacts between lithological couplets. The lower contact is sharp and the upper contact is gradational

Fig.6: The rhythmic nature (↑) of the Serikagni Formation with variable thickness. The delineation of the rhythms is enhanced by differential weathering

- **Limestone**

Two major kinds of lithologies are described. The first is common in all studied sections. It is fine dense, occasionally chalky consisting of about one to four meters of thin to medium bedded, pale grey and pale greenish grey, bioturbated (Figs.7a and b) and medium tough. The second is described from the Sinjar section only. It is yellowish grey, tough, bioclastic calacarenite and calcirudite with lower wavy and sharp contact grading gradually upwards to finer-grained limestone and marly limestone. Its thickness ranges from 0.8 to 2.7 meters. These limestones are graded bedded, laminated and cross laminated with syndepositional slumping and faulting (Fig.17a, b, c and d).

- **Marly Limestone**

This lithology consists of about 0.5 to five meters of thin to medium bedded, greenish grey and medium tough to friable. It is laminated or massive (Fig.9).

- **Limey Marl**

Limey marl is the least common in the studied succession. It consists of about 0.5 to 8 meters of thin to medium tough to friable (Fig.10).

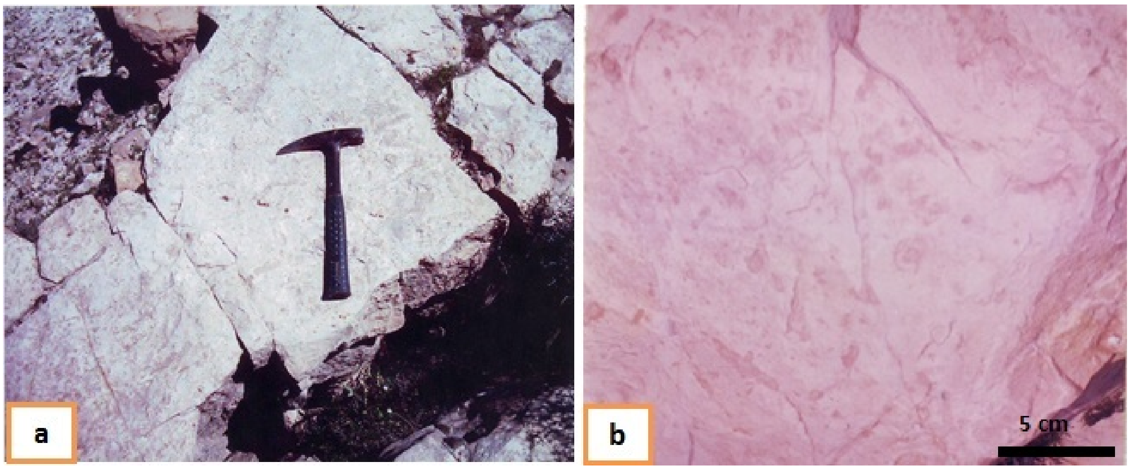


Fig.7: Bioturbation in the limestones of the Serikagni Formation at Jaddala section

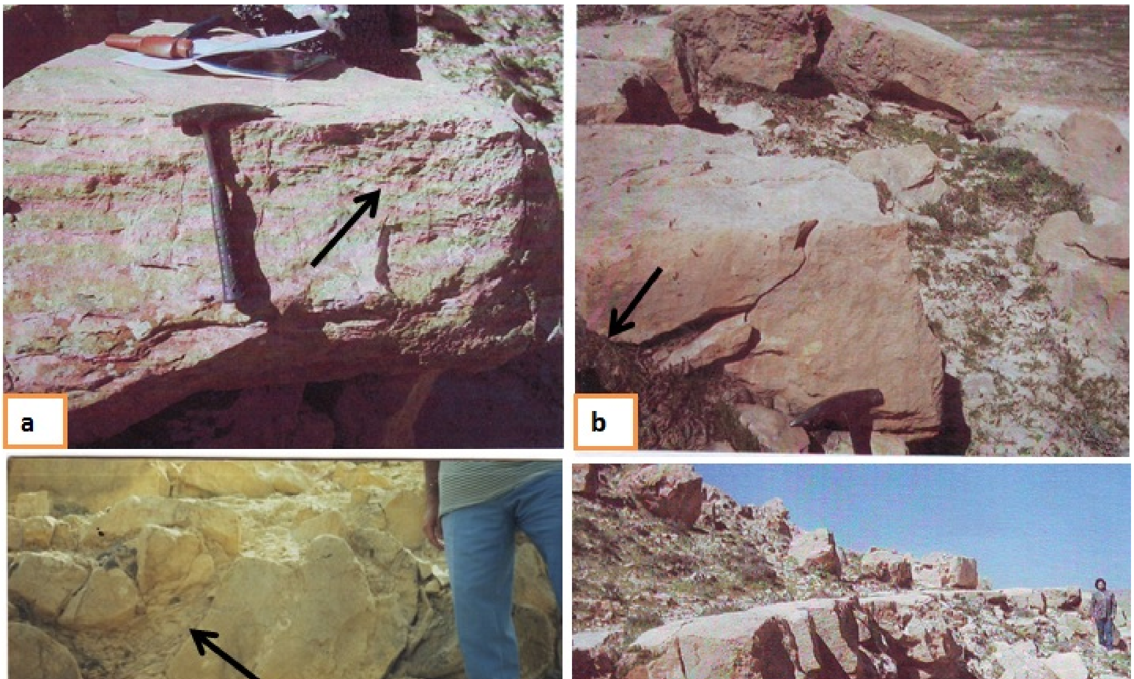


Fig.8: Some features in the limestones of the Serikagni Formation at Sinjar section. **a)** Cross stratified, **b)** Synsedimentary slumping (↑) on some in situ and dislocated blocks, **c)** Synsedimentary slumping (↑) and **d)** Synsedimentary slumping (↑) within the bed whereas the top is undisturbed

Fig.9: Thickly-laminated marly limestone in the Serikagni Formation at Jaddala section

Fig.10: Limey marl in the Serikagni Formation at Jaddala section. Note the effect of the differential weathering showing the recession of the limey marl

PETROLOGY

Petrographic analysis, X-ray diffractometry and weak-acid insoluble residues of the studied samples of the Serikagni Formation revealed that carbonates (69.0 – 99.0 with mean 86.2%), especially calcites, are the major constituents. Calcite is identified from petrographic studies and in X-ray diffractograms by its reflection at 3.03 Å (Figs.12a and b). The insoluble materials (1.0 – 31.0% with mean 13.8% shown in Table 1) are dominantly clay minerals (including glauconite), subordinate quartz and traces of pyrite. Petrographic studies reveal that the quartz grains are silt size (0.01 – 0.03 mm) and subrounded to rounded. The content of the insoluble residues show irregular pattern upwards as they vary erratically. The collected samples of the Serikagni Formation can therefore be classified according to Barth *et al*. (1939, in Pettijohn, 1975) as shown in Figure 11: pure limestone (17.3%), marly limestone (48.1%), marl-limestone (29.6%) and limy-marl (5%). They are therefore, mostly marly limestone and limestone with subordinate limey marls which comply with the field observations (i.e. marly limestone and limestone couplets).

Table 1: Average and range of the insoluble residues in the studied samples of the Serkagni Formation

Average (%)	Range (%)		Section
	Maximum	Minimum	
11.0	20.5	1.5	Jaddala
16.0	31.0	1.0	Sinjar
20.0	30.0	10.0	Neaneaa
11.1	20.6	1.5	Bara

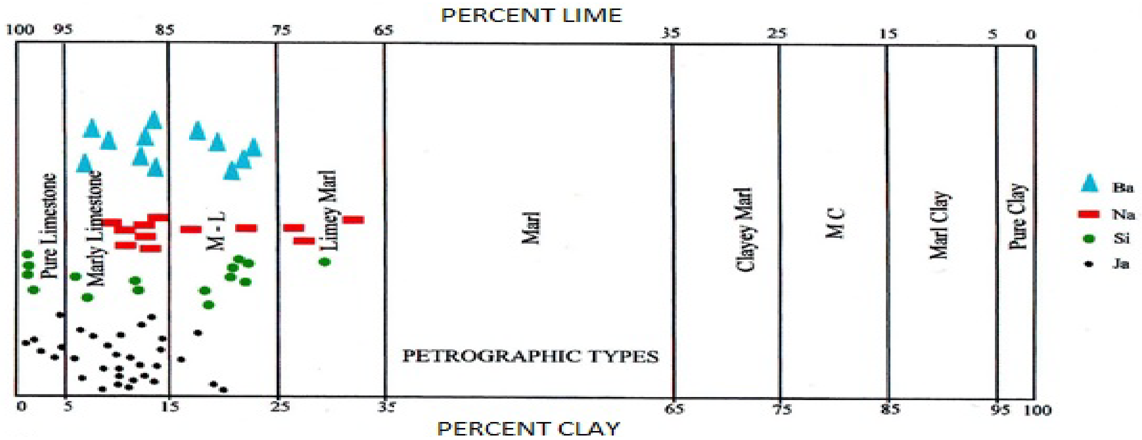


Fig.11: Classification of the collected samples (83 samples) according to Barth (1939)

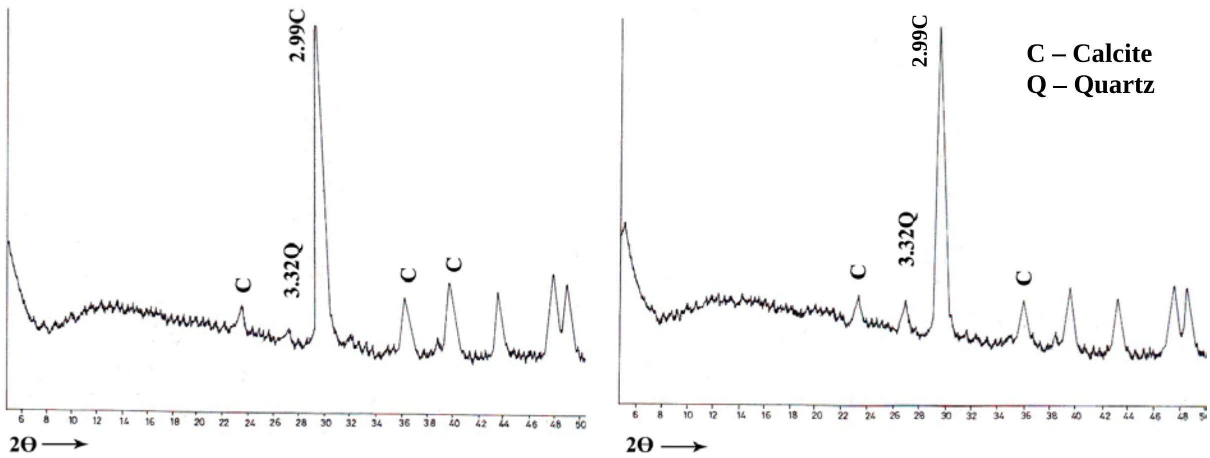


Fig.12: X-ray diffractograms of the bulk samples of: **a)** Jaddala section (Ja 9) and **b)** Bara section (Ba 1). C – calcite and Q – quartz

XRD reveals that the studied samples consist of clay minerals with variable admixtures. Palygorskite and kaolinite are the main clay minerals present with occasional illite and/ or smectite (Table 2 and Figs.13a and b). The dominant clay mineral is palygorskite and/ or kaolinite. The overriding of the first basal reflection of palygorskite and illite has prevented accurate estimation of their proportions. The dominance of a certain mineral is irrespective of lithology (Table 2).

The clay minerals are possibly a mixture of eolian source and from reworking induced by slumping from the shelf. Some of the illite could have transformed from smectiteduring diagenesis.

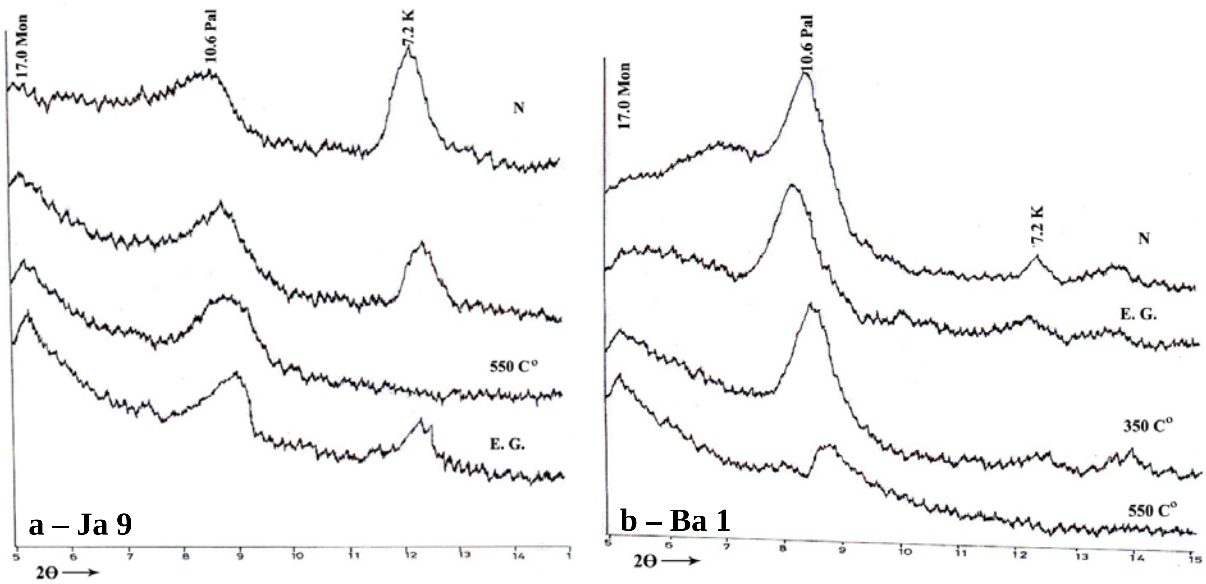


Fig.13: X-ray diffractograms of separated clay fraction from two representative samples (Ja 9 and Ba 1) from the Serikagni Formation

Table 2: Percentage of insoluble residues, lithology and relative clay mineral content of the studied samples of the Serikagni Formation

Sample no.	IR[1] (%)	Lithology[2]	Relative mineral content			
			Palygorskite	Kaolinite	Illite	Smectite
Ja/A	4.7	Pure limestone	***	***	–	–
Ja/1	20.5	Marl – Limestone	**	**	*	–
Ja/4D	14.0	Marly limestone	**	***	–	–
Ja/5	16.5	Marl – Limestone	**	***	–	–
Ja/9	14.0	Marly limestone	**	***	–	–
Si/1	17.0	Marl – Limestone	***	**	*	–
Si/5	16.5	Marl – Limestone	***	*	–	**
Si/7	21.5	Marl – Limestone	***	*	**	–
Si/9	19.0	Marl – Limestone	***	*	**	–
Si/12	5.0	Marly limestone	***	–	–	**
Si/13	19.5	Marl – Limestone	***	–	–	–
Ne/2	27.5	Limey marl	**	***	*	–
Ne/3	12.5	Marly limestone	**	***	*	–
Ne/4	26.5	Limey marl	**	***	–	–
Ne/6	21.5	Marl – Limestone	**	***	–	–
Ne/8	30.0	Limey marl	***	**	*	–
Ba/1	18.0	Marl – Limestone	***	***	–	–
Ba/4	11.0	Marly limestone	***	**	–	–

[1] IR is insoluble residues, [2] Lithology according to Barth *et al*. (1939 – in Pettijohn, 1975), *** Major, ** Minor, * Trace, – Not detected.

▪ **Diagenesis**

Six major diagenetic processes have affected the sediments of the Serikagni Formation since their deposition. These processes are bioturbation, dissolution, neomorphism, cementation, replacement and mechanical compaction. The majority of these processes are early diagenetic, using Schmidt (1965) terminology. They belong to eogenesis (shallow burial) and mesogenesis (deep burial) of Worden and Burley's (2003) scheme. These changes are discussed below in the expected paragenetic order:

– **Bioturbation:** is a process of destructive diagenesis. In the Serikagni Formation chondrite are the most common bioturbation (Fig.7) in addition to some unidentified burrow mottling. Seilacher (2007) described chondrite as a plant-like kind of branching along bedding plane and considered them as feeding burrows (fodinichia).

– **Dissolution:** is an isochemical constructive diagenesis. Dissolution of the skeletal grains is common in the studied samples, forming biomolds and fractures (Fig.14) but it is selective as not all fossils are affected.

– **Neomorphism:** is an isochemical constructive diagenesis. Inversion is variable depending on the nature of the minerals forming the shells and tests of the skeletal grains (Fig.15a, b and c).

– **Cementation:** is an isochemical constructive diagenesis. It is represented by filling of the biomolds and small calcite veins with granular type cement B. The crystals are mostly anhedral, clear and ranging in size from 10 to 60 µm (Fig.16).

– **Replacement:** is an allochemical constructive diagenesis. Replacement in the studied samples involves two paths. The first is the dissolution of the original mineral forming voids which are later filled by different minerals such as glauconite and/or pyrite (Figs.17a, b and c).

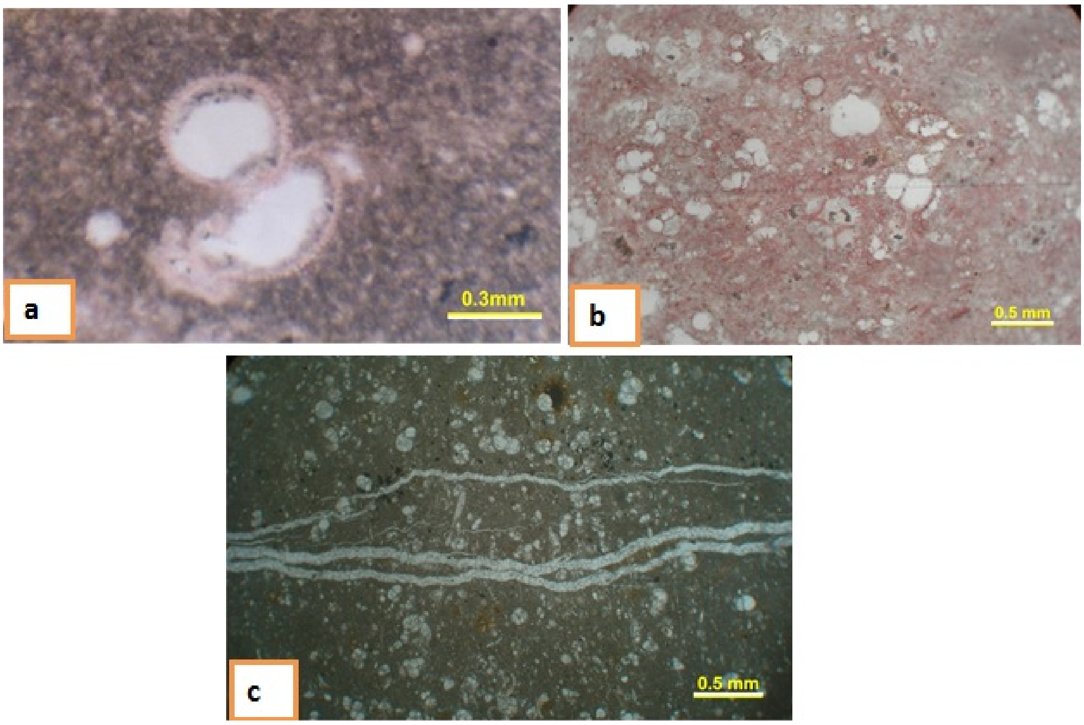


Fig.14: Photomicrographs showing **a** and **b)** biomolds (Sample Ja10, PPL.); **c)** Veins due to fractures (Sample Ja10, PPL.)

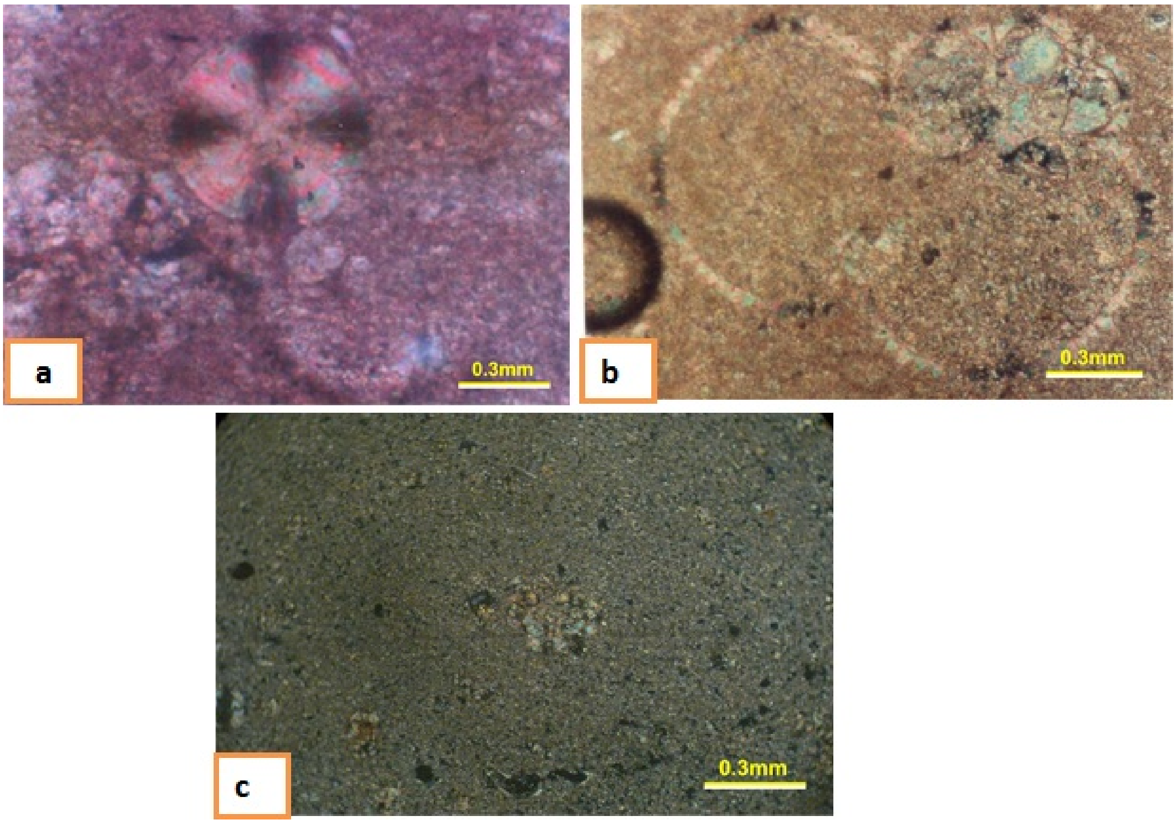


Fig.15: Photomicrographs showing **a)** inversion (Sample Ba7, XPL.), **b)** recrystallization of fossils (Sample Ja9, XPL.) and **c)** recrystallization of groundmass (Sample Ja6, XPL.)

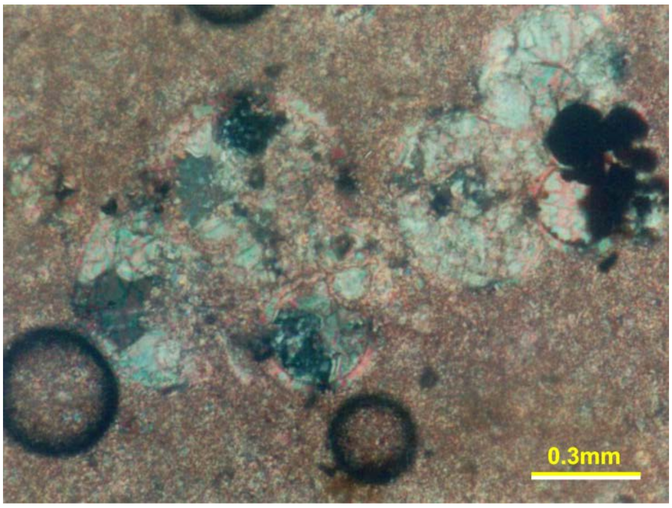


Fig.16: Photomicrograph showing cementation (Sample Si9, XPL.)

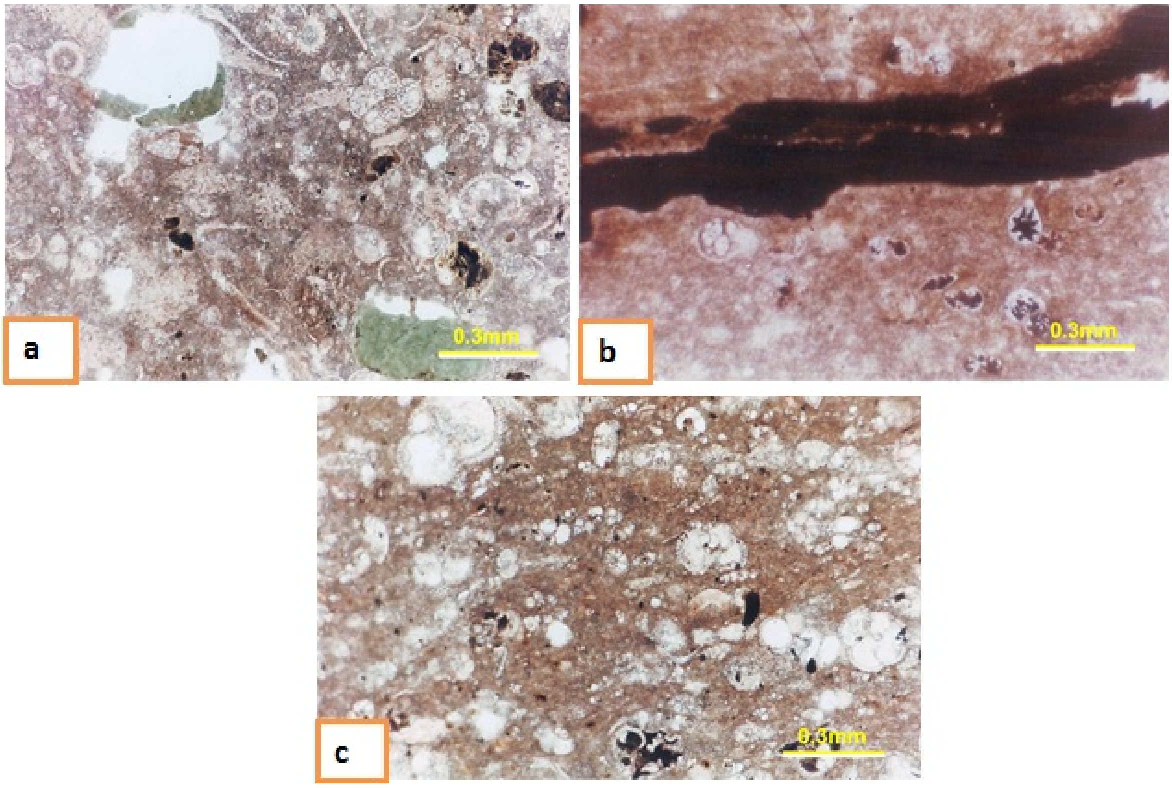


Fig.17: Photomicrographs showing **a)** replacement by glauconite (Jaddala section, PPL.), **b** and **c)** replacement by pyrite at Jaddala section also (PPL.)

The second involves the dissolution of the original mineral and the precipitation of another mineral of different composition in its place almost simultaneously. Replacement is rare in the studied rocks of the Serikagni Formation. Dolomitization is present as rare incipient dolomite crystals in the matrix. Silicification and phosphatization are even less common than dolomitization in the studied sequence. They are observed as microcrystalline silica or carbonate-fluorapatite replacing some of the calcite tests (Figs.18a and b).

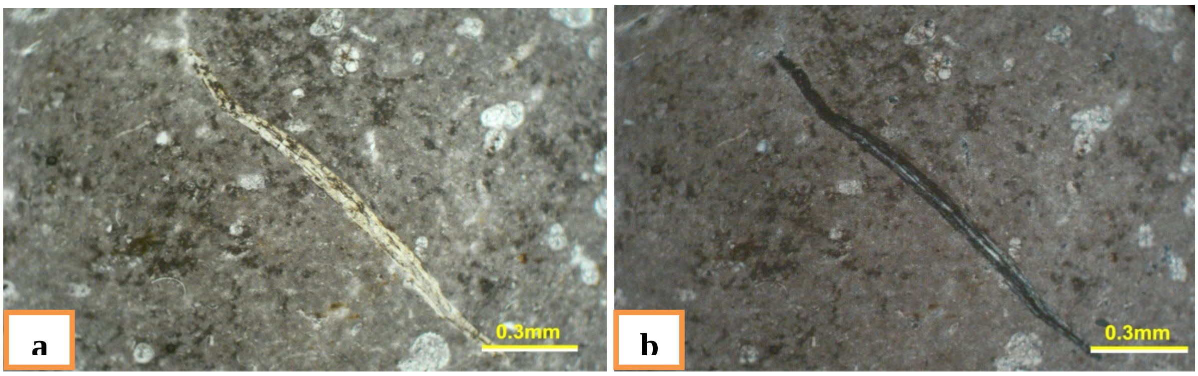


Fig.18: Photomicrographs showing phosphatization from sample at Sinjar section
a) PPL. **b)** XPL.

– **Mechanical compaction:** This is a process of destructive diagenesis. It represents grain reorientation and tighter packing owing to shallow burial (Fig.19), which results into loss of porosity and thinning of beds. It has partially distorted the depositional textures and structures.

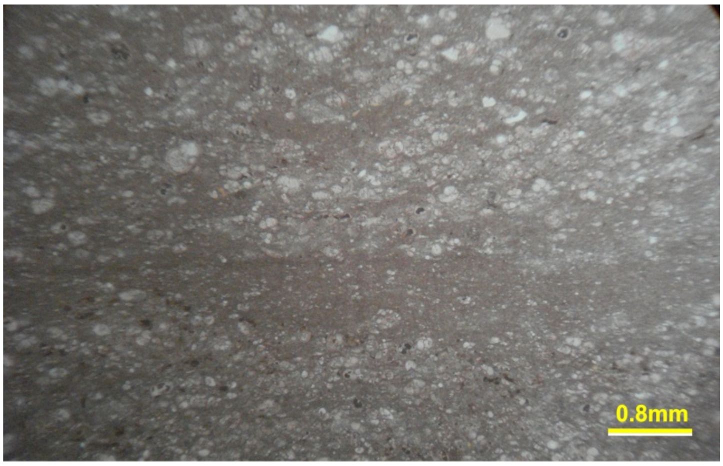
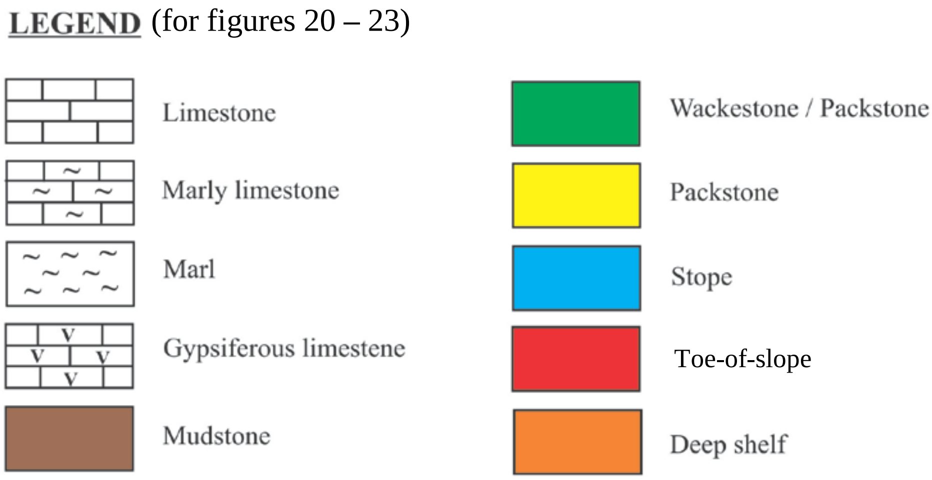


Fig.19: Photomicrographs showing mechanical compaction/ orientation to fossils Jaddala section (Ja 5, PPL.)

MICROFACIES

Three microfacies are identified in the Serikagni Formation using Dunham's (1962) classification of carbonate rocks according to the depositional textures. The various features and textures are recognized with the help of many references such as Scholle and Ulmer-Scholle (2003) and Flugel (2010). Despite that they are affected by digenetic processes but the original textural features are well preserved. These microfacies are described below and are plotted on the columnar sections as in Figures 20, 21, 22 and 23:



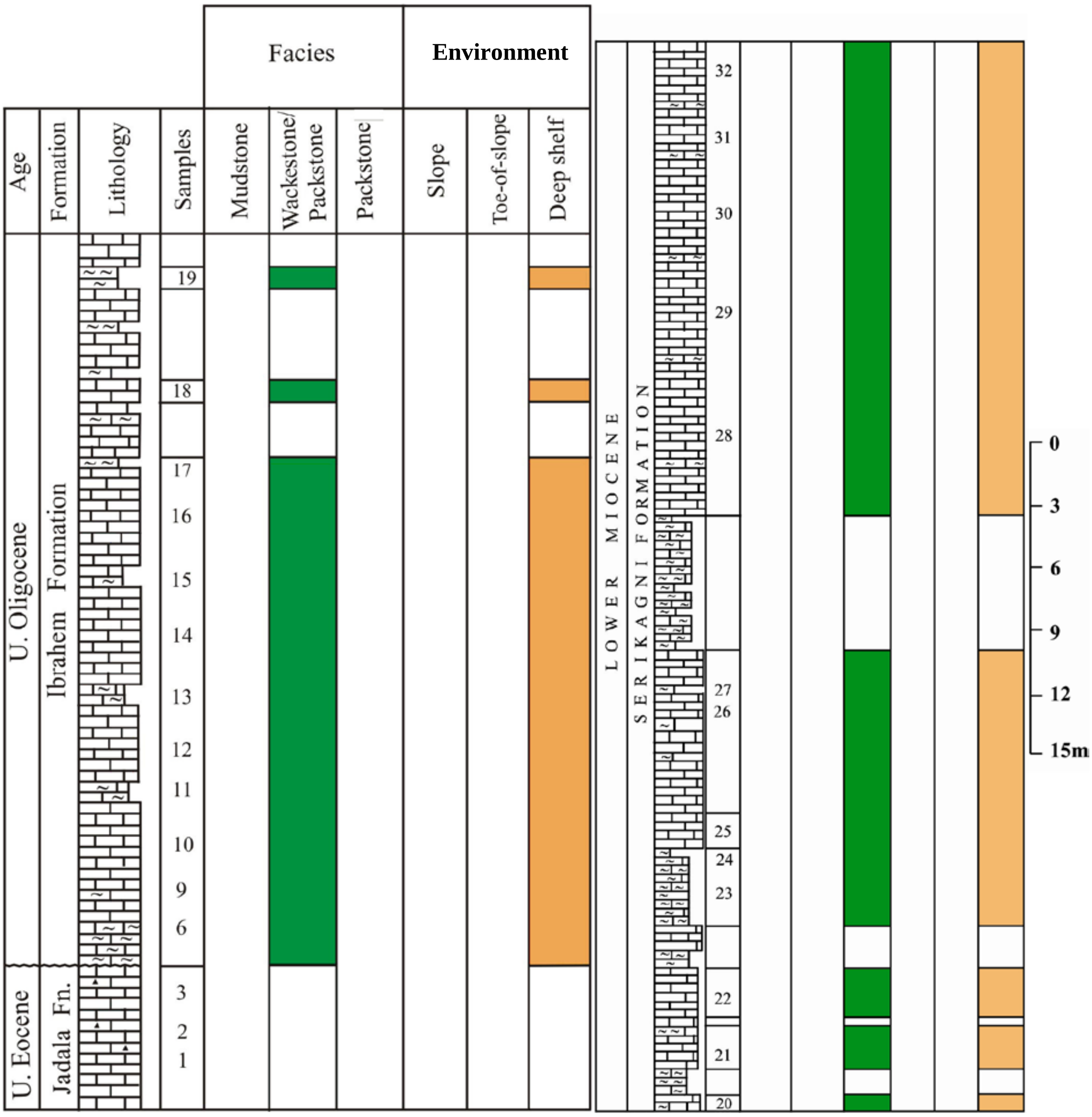


Fig.20: Columnar section of the Jaddala section showing facies and depositional environment

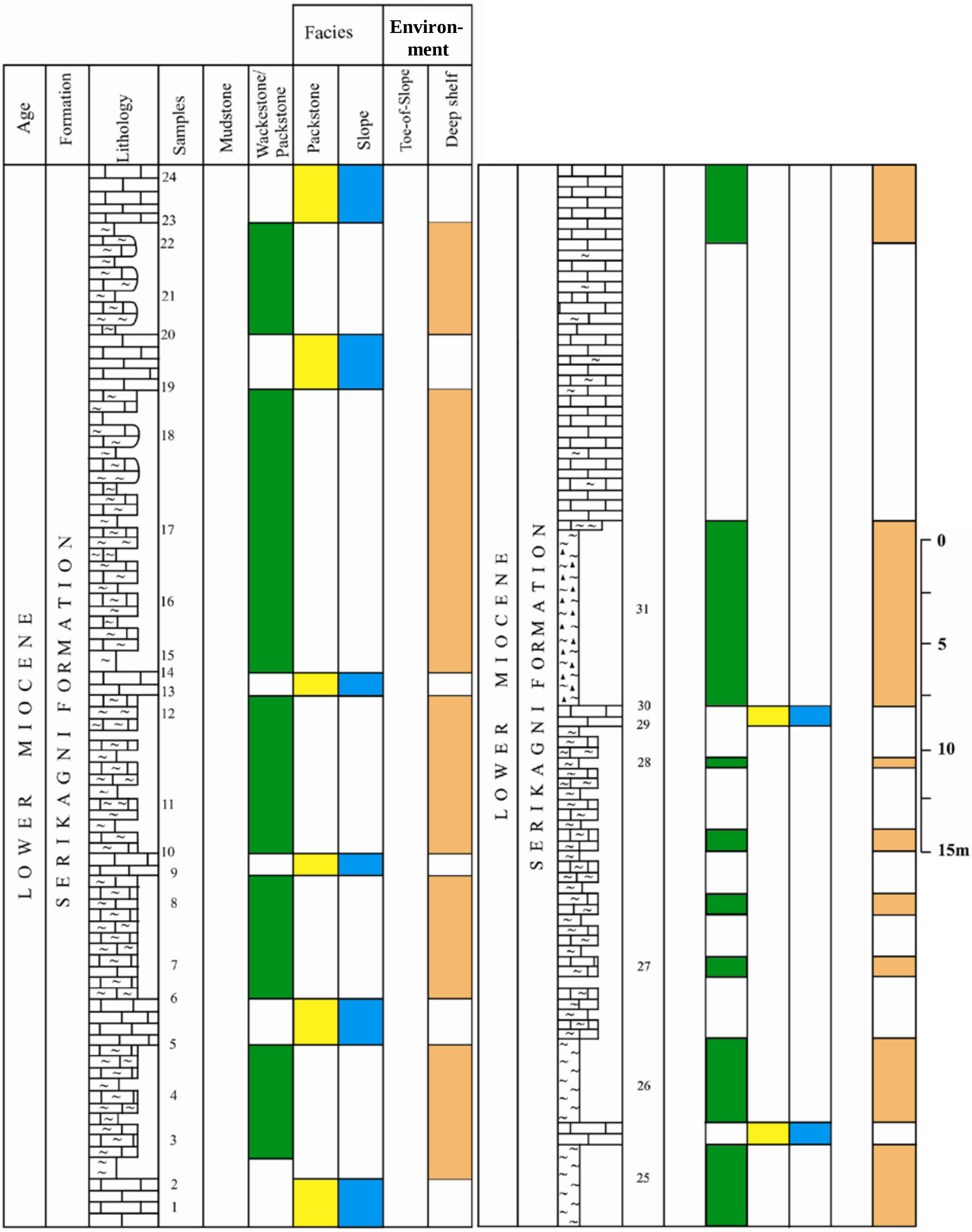


Fig.21: Columnar section of the Sinjar section showing facies and depositional environment

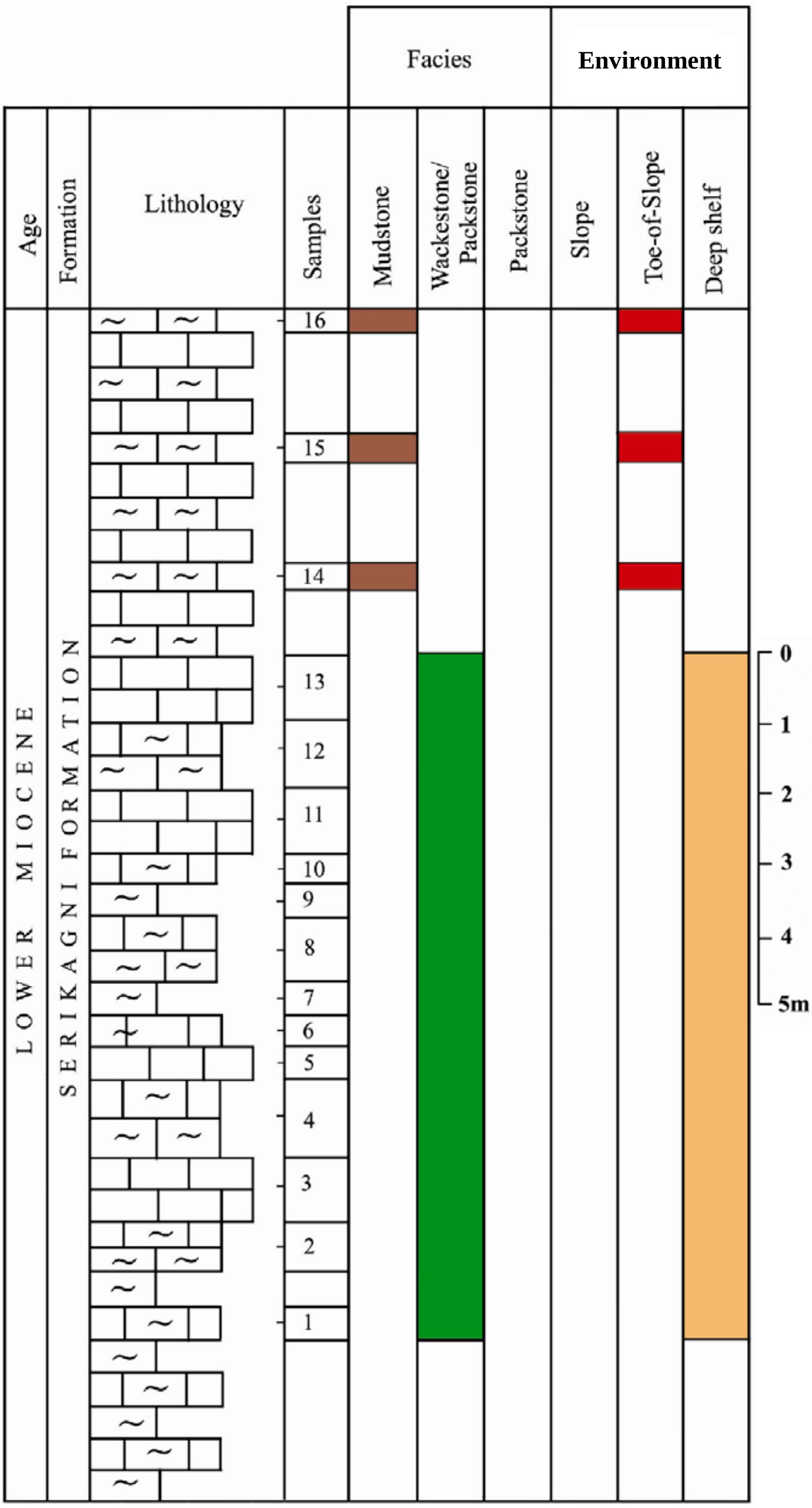


Fig.22: Columnar section of the Bara section showing facies and depositional environment

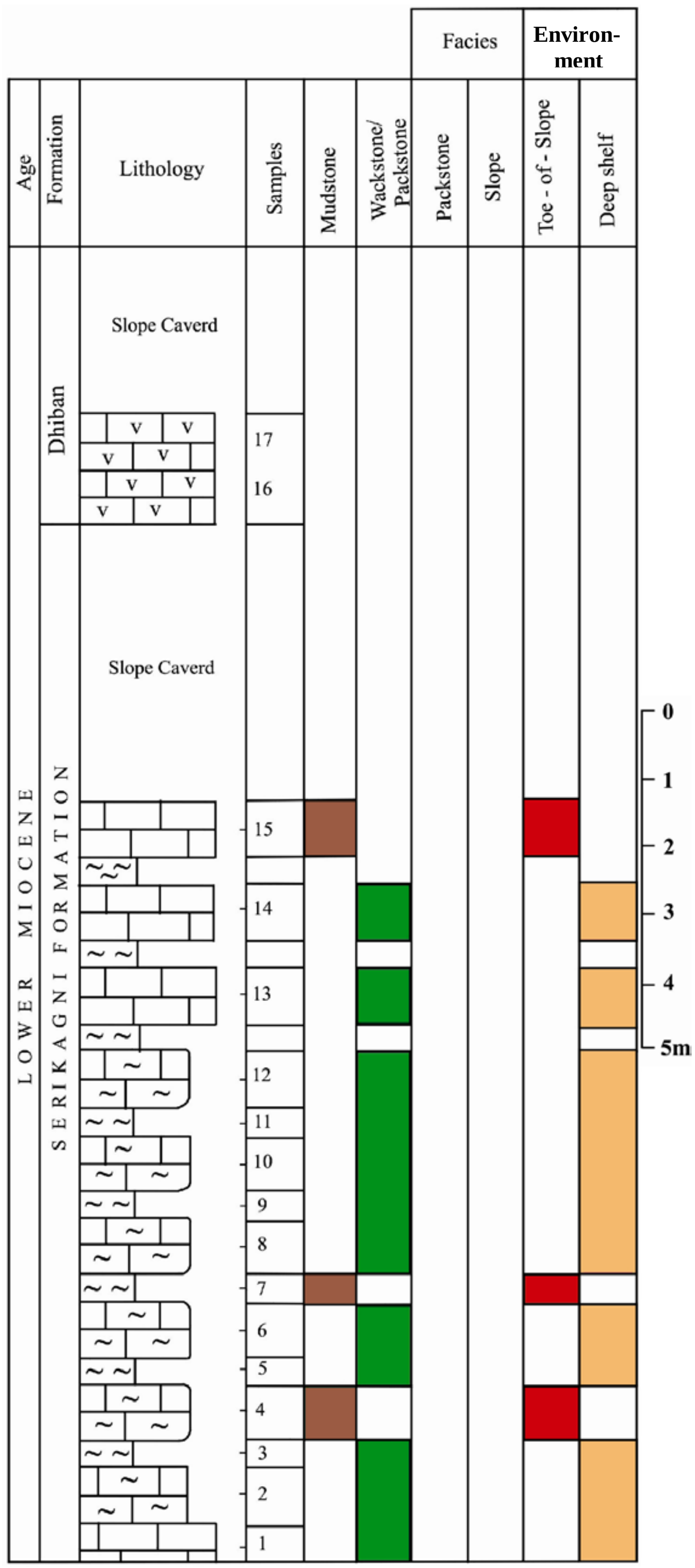


Fig.23: Columnar section of the Neaneaa section showing facies and depositional environment

- **Facies S1: Planktic Foraminiferal Lime Mudstone**

This facies consists of less than 10% skeletal grains floating in lime mud (Fig.24a). Planktic foraminifera are the main skeletal grains such as *Globigerina* (Fig.24b), *Globigerinoids* (Fig.24c), *Globorotalia* (Fig.24d) and *Catapsydrax* (Fig.24e). Occasionally few benthic forams such as *Textularia* and *Rotalia* as well as shell fragments, ostracods and echinoderm plates are found mixed with the planktic forams. Clay admixtures, fine quartz and phosphatic grains as well as iron oxides patches are found in the matrix. Pyrite occasionally fills the fossil chambers. Facies S1 is recognized at Bara and Neaneaa sections only.

Planktic Foraminiferal Lime Mudstone Facies is equivalent to Wilson's (1975) and Flugel's (2010) Standard Microfacies 3 (SMF 3). It represents deposition at Facies Zone 3 (FZ 3) that is toe-of-slope.

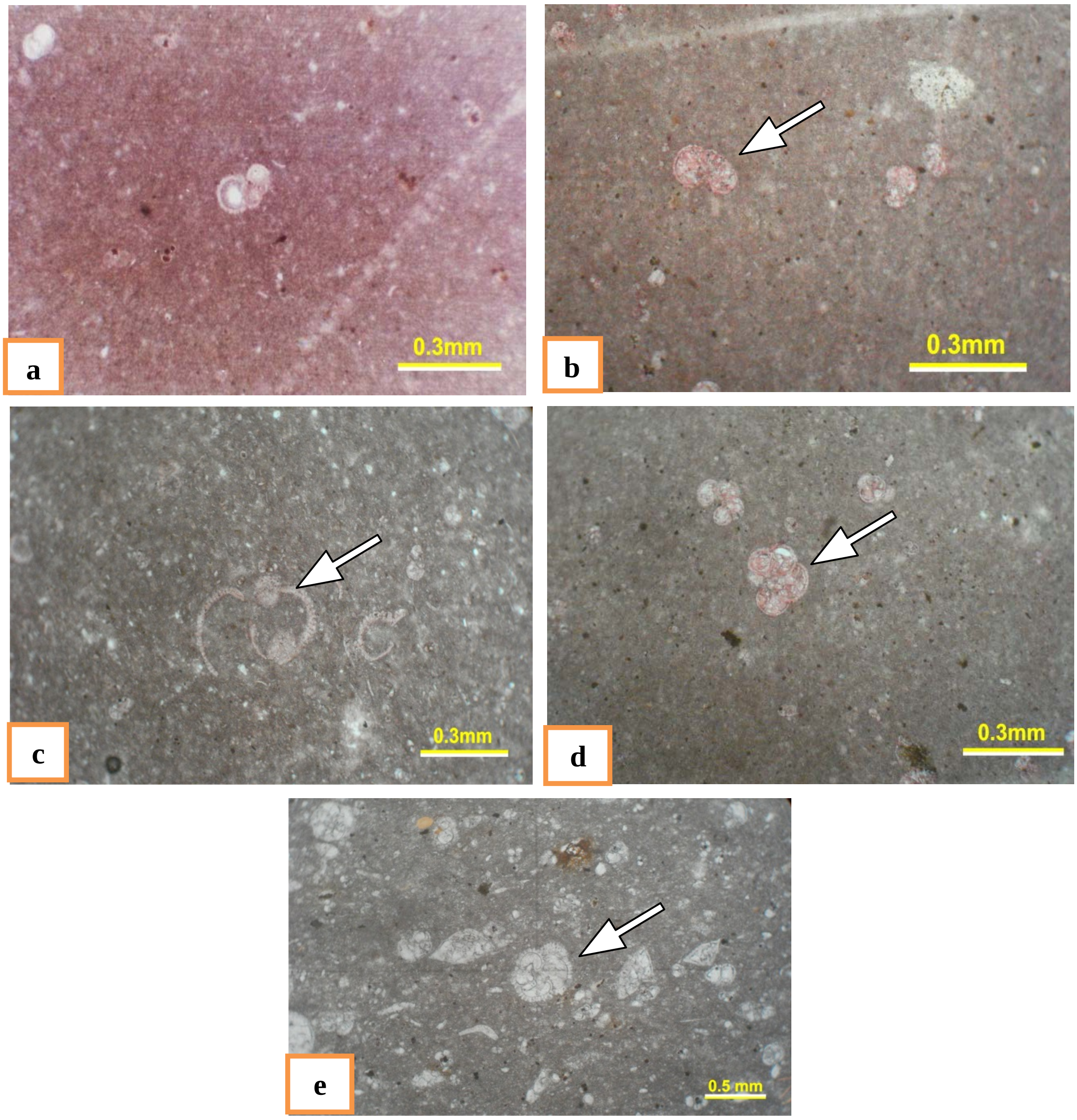


Fig.24: Photomicrographs showing facies S1: **a)** Lime mudstone, **b)** *Globrotalia*, **c)** *Globigerinoides*, **d)** *Globigerina*, **e)** *Catapsydrax* (sample Ja6)

- **Facies S2: Planktic Foraminiferal Wackestone/ Packstone**

This is the most common facies in the Serikagni Formation. It is highly fossiliferous and interbedded limestone and marly limestone. The grains are solely skeletal making about 50% (Fig.25a) although it may reach 70% becoming packstone. The components are mostly planktic foraminifera such as *Globigerina*, *Globigerinoids* and *Globorotalia* (Fig.25b) with few benthic forams (such as *Textularia* and *Rotalia*), shell fragments, (Fig.25c) ostracods and echinoderm plates (Fig.25d). The groundmass is micrite and clayey micrite (Fig.25e) with scattered fine and rhombic dolomite crystals. In addition, some non-carbonate components are frequent such as clay admixture, quartz, pyrite, glauconite and phosphate.

Planktic Foraminiferal Lime Wackestone Facies is equivalent to Wilson's (1975) and Flugel's (2010) Standard Microfacies 3 (SMF 3). It represents deposition at Facies Zone 2 (FZ 2) that is deep shelf.

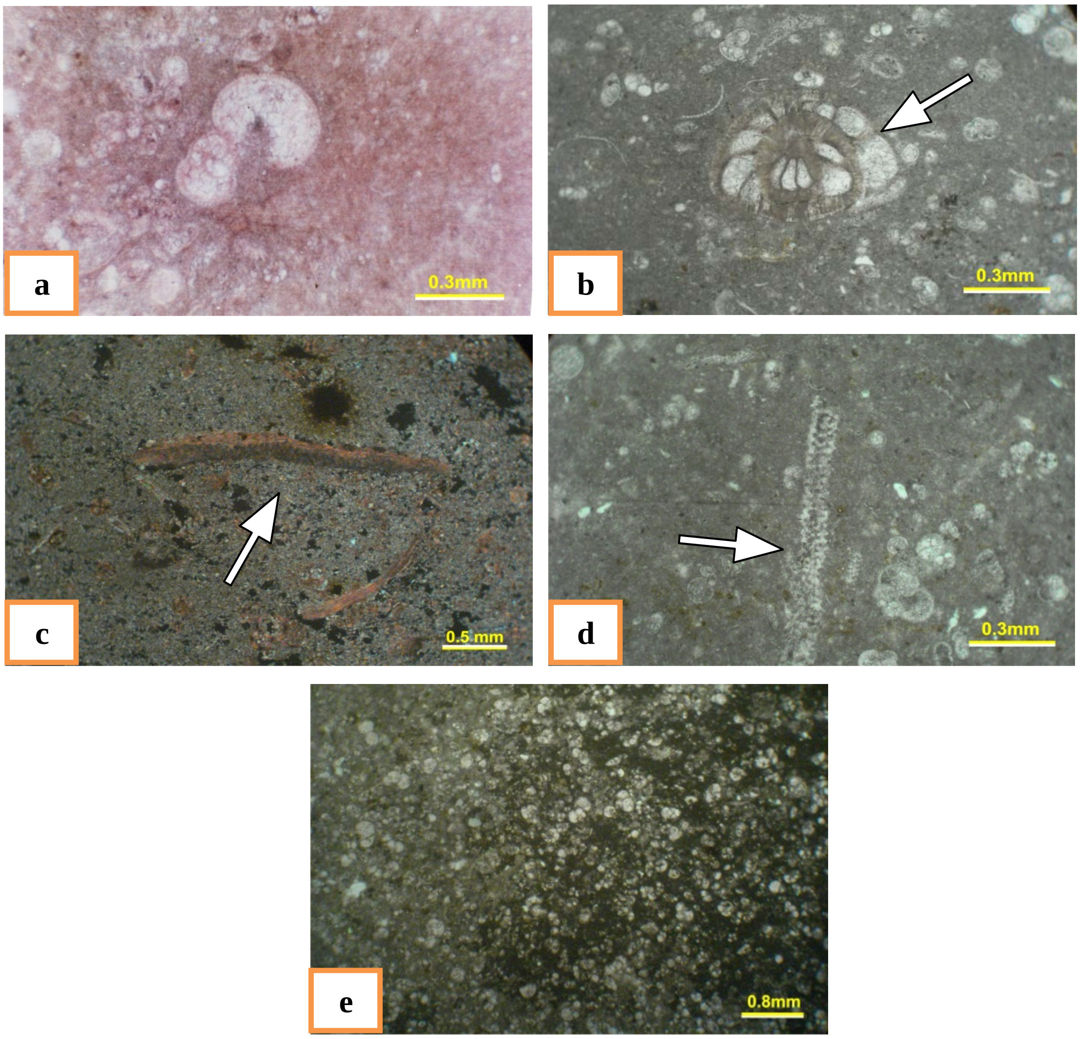


Fig.25: Photomicrographs showing facies S2: **a)** Lime Mudstone/ Wackestone (sample Ja10), **b)** Benthic forams, **c)** Shell fragments, **d)** Echinoderms, **e)** Clayey micrite packstone (sample Si1)

- **Facies S3: Biolithoclastic Packstone**

BiolithoclasticPackstone is described from the Sinjar section only. It occurs eight times in the whole section (Fig.21) ranging in thickness from 0.8 to 2.7. Its lower contact is wavy or irregular and sharp whereas its upper contact is flat and gradational passing to other facies. Graded bedding and convolute and current laminations are common as well as occasional syndepositional faulting and folding. The grains are both litho- and bioclastic ranging from 75 – 85% and the matrix is both micrite and microsparite (Fig.26a). The skeletal grains are *Miogypsina*, miliolids, *Textularia*, *Rotalia*, algae, planktic forams (such as *Globigerina*, *Globigerinoids* and *Globorotalia*). Some of the grains such as the *Miogypsina* and lithoclasts are broken, worn and rounded (Fig.26b). The Biolithoclastic Packstone Facies apparently contains a mixture of faunal assemblages of the Serikagni Formation and the lower Miocene shelf limestone the Euphrates Formation.

Biolithoclastic Packstone Facies is equivalent to Wilson's (1975) and Flugel's (2010) Standard Microfacies 4 (SMF4). It represents deposition of turbidites (both proximal and distal) at Facies Zone 3 (FZ3) that is toe-of-slope and Facies Zone 4 (FZ 4) slope.

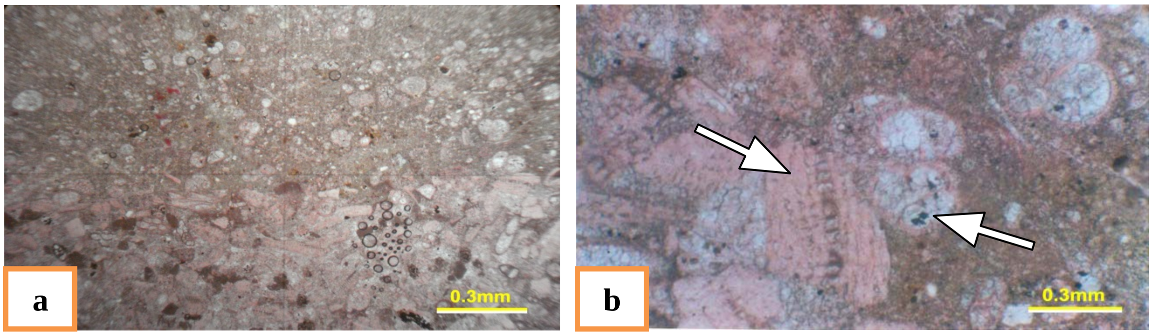


Fig.26: Photomicrographs showing facies S3: **a)** BiolithoclasticPackstone, **b)** Broken *Miogysina* (sample Si12)

DEPOSITIONAL ENVIRONMENT

The paleogeographic map constructed by Jassim and Goff (2006) and the isopach map constructed here (Fig.3) show that deposition took place in a narrow and fairly deep sea extending from northwest to southeast Iraq. It is divided into two sub-basins, the Sinjar sub-basin opening towards Syria and the Badra sub-basin opening towards Iran. The study area is part of the Sinjar sub-basin (Jassim and Goff, 2006). The Sinjar sub-basin represents a graben which existed since the Early Cretaceous (Al-Sharhan and Nairn, 1997) and received deep marine sediments during the Late Cretaceous to the Late Miocene.

Faunal assemblages and microfacies show that the Serikagni Formation is deposited in a deep marine environment characterized by hemipelagic sediments (Fig.27). The fauna are marked by abundant and diversified planktic forams such as *Globigerina*, *Globigerinoids* and *Globorotalia* and rare benthic forams. Such an association is indicative of deep marine environment (Scholle *et al*., 1983; Burchette and Britton, 1985).

Facies analysis reveals that the Serkagni Formation represents deposition in deep marine environment at deep shelf (FZ2), toe-of-slope (FZ3) and slope (FZ4). Al-Dabbas and Hassan (2013) believe that the palynofacies in the upper and lower part of the Serikagni Formation (same studied samples) reflect distal suboxic – anoxic basin whereas the middle part of the studied sections show transition from basinal to shelf environments. The present authors believe that the transition from basinal to shelf environments is attributed to the sweeping down of shelf sediment to the deeper parts of the basin by turbidity currents, as will be discussed later. In the Sinjar section, turbidite due to slumping is evident as indicated by bioclastic calacarenite and calcirudite with lower wavy and sharp contact grading gradually upwards to finer-grained limestone and marly limestone. These limestones are graded bedded, laminated and cross laminated with syndepositional slumping and faulting (Fig.17). The skeletal grains are mixture of faunal assemblages of the Serikagni Formation and the lower Miocene shelf limestone the Euphrates Formation. The faunal assemblage comprises *Miogypsina*, miliolids, *Textularia*, *Rotalia*, algae and planktic forams (such as *Globigerina*, *Globigerinoids* and *Globorotalia*). Some of the grains such as the *Miogypsina* and lithoclasts are broken, worn and rounded (Fig.26b).

The presence of chondrites indicates that it is not very deep marine environment. Chondrites are feeding burrows (fodinichia) common through the Ordovician to modern deep sea mud. They are of heterogenous origin found in turbidites, shallow marine shale and even in storm sands with a preference for relatively quiet and low-oxygen environments (Seilacher, 2007). Authigenic minerals as pyrite and glauconite, dominance of lime mud and hemipelagic rain of clay particles and planktic forams indicate quiet and low reducing environment. In general it shallows upwards to restricted platform interior evaporites (Dhiban Formation) and shelf carbonates with physical and organic buildups (Euphrates Formation).

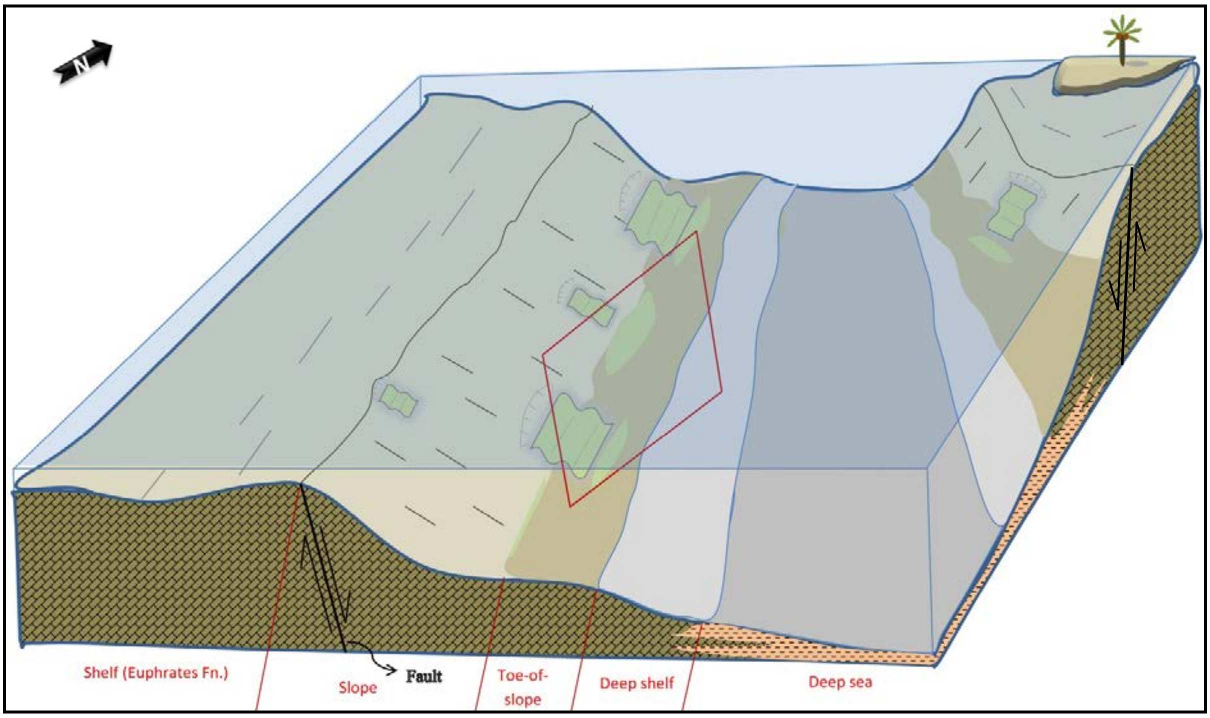


Fig.27: The sedimentary depositional model of the Serikagni Formation showing slumps and turbidites in green and the study area is outlined in red

The rhythmic nature which characterizes the Serikagni Formation represented by the repetitions of limestone and marly limestone (or limey marl) may be attributed to orbital cycles that are Milankovitch rhythms and bundles. They appear to be Fourth-order and fifth-order cycles, related to changes in Earth's orbital parameters. However, this suggestion requires further investigations to be verified. The change in shallow marine environment is more prominent in comparison to deep marine environment because the change in depth is comparatively less effective.

CONCLUSIONS

Field and petrographic studies show that the Serikagni Formation at the Sinjar mountain area, northwest Iraq consists of repeated rhythmic alternations of marly limestone and pure limestone with subordinate marl. These may be related to Milankovitch rhythms. Detrital admixtures are mostly kaolinite, palygorskite and illite with subordinate silt-size quartz and occasional smectite. These admixtures are mostly driven from the adjacent land by wind.

Facies, facies map and paleogeography reveal deposition in narrow and deep marine (hemipelagic) environment with influence of turbidite at the Sinjar section. The environment, using Wilson's (1975) and Flügel's (2010) terminology, ranges from deep shelf (FZ2) throughtoe-of-slope (FZ3) to slope (FZ4).

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