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FACIES ANALYSIS AND DEPOSITIONAL ENVIRONMENT OF THE UPPER JURASSIC NAOKELEKAN FORMATION IN TWO SELECTED OUTCROP SECTIONS FROM KURDISTAN REGION, NE IRAQ

Arkan O.H. Sharezwri[1*], Mohammad S. Nourmohammadi[1] and Rzger A. Abdula[1, 2]**

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ABSTRACT

The Upper Jurassic Naokelekan Formation is mainly composed of organic calcareous shale with some limestone and dolomite. According to the lithology of the formation in two selected sections, three units can be identified as follow, from bottom to top: **a)** soft, black, fissile, and highly bituminous, calcareous shale and thin-medium bedded, dark brown, bituminous limestone and dolomitic limestone, **b)** hard, fine-grained, highly mottled and stylolitic, fossiliferous, dark grey, medium-thick bedded limestone and dolomitic limestone, **c)** fissile, soft black, calcareous, medium-grained, fetid shale and dark grey, hard, dolomitic and argillaceous medium grained limestone. The microfacies include Lime-Mudstone, Lime-Wackestone and Lime-Wackestone/ Packstone. The Benthic (Miliolid) and pelagic (Globigerina) foraminifera, ammonites, ostracods, pelecypods, gastropods and calcispheres of various sizes are the most common skeletal grains, while peloids are the main non-skeletal grains. Based on lithology and microfacies analysis, the formation was deposited in two different sedimentary environments including lagoon (subtidal) environment for the lower and upper units and shallow marine environment for the middle unit. The upper contact with the Barsarin Formation and lower contact with the Sargelu Formation are gradational and conformable.

التحليل السحني والبيئة الترسيبية لتكوين ناوكيليكان (الجوراسي الاعلى) في مقطعين مختارين من إقليم كردستان، شمال شرقي العراق

أركان الشهرزوري، محمد سعدي نور محمدي و رزگار عبد الكريم عبد الله

المستخلص

يتكون تكوين ناوكيليكان (الجوراسي الاعلى) من صخور السجيل الجيرية العضوية مع بعض الحجر الجيري والدولومايت. يشير للتركيب الصخري لتكوين ناوكيليكان في المقطعين المختارين الى وجود ثلاث وحدات صخريه هي من الاسفل إلى الأعلى: **أ)** سجيل جبيري صفائحي أسود، ناعم وصخر جيري بني غامق وطبقات نحيفة الى متوسطة السمك من الحجر الجيري القيري و الدولومايتي، **ب)** حجر جيري وحجر جيري دولومايتي رمادي داكن، صلب، دقيق الحبيبات، يحتوي على أحافير، مرقش بكثافة وستايلولايتى, متوسط الى عالى السمك **ج)** سجيل أسود، صفائحي, لين، ذو

[1] Department of Petroleum Geosciences, Soran University, Soran, Kurdistan Region, Iraq
[2] Department of Petroleum Engineering and Mining, Tishik University, Erbil, Kurdistan Region, Iraq, e-mail: rzger.abdulkarim@ishik.edu.iq
*e-mail: arkan.osman@hotmail.com ; **e-mail: nourmohammadi.ms94@gmail.com

رائحة كريهة، رمادي داكن، ذو حبيبات متوسطة وحجر دولومياتي وجيري طيني. تشمل السحنات الدقيقه الطين الكلسي والواكي والواكي المرصوص. معظم الحبيبات الهيكلية هي الفورامنيفيرا القاعية (المليوليد) والطافية (كلوبوجرينا) والأمونايت والأوستراكودا ورأسية القدم وبطنية القدم والكالسيسفيرات بأحجام مختلفة. أما أهم الحبيبات اللاهيكلية هي البيلويدات. اعتمادا على تحليل السحنات الدقيقة والصخرية، تم ترسيب التكوين في بيئتين رسوبيتين مختلفتين هما بيئة البحيرة (شبه المدارية) لكل من الجزئين السفلي والعلوي والبيئة البحرية الضحلة للجزء الاوسط. ان سطح التماس العلوي للتكوين مع تكوين البارسرين وسطح التماس السفلي مع تكوين سارگلو تدريجيه ومتوافقه.

INTRODUCTION

The Naokelekan Formation was first described in outcrop section from the Imbricate Zone (Balambo – Tanjero Zone) in the High Folded Zone near the Rowanduz Town in the NE of Iraq by Wetzel and Morton (1950 in Bellen *et al*., 1959). The type locality of the Naokelekan Formation is located near the Naokelekan Village, about 25 Km southeast of Soran Town, Erbil Governorate, NE Iraq. A supplementary type section was established in the Chia Gara fold of the High Folded Zone (Bellen *et al*., 1959). The formation was reported in Jassim and Buday (2006a) as one of the Unstable Shelf units and was assigned to Megasequence AP7 (Jassim and Buday, 2006b). It is 10 – 30 meters thick and consists of three parts; the Upper part is obscured in the type section (Bellen *et al*., 1959). They are comprised from top to bottom of: **a)** Alternation of laminated shaly bituminous limestone and bituminous shale; **b)** Thin bedded fine grained fossiliferous dolomitic limestone and **c)** Thin bedded highly bituminous dolostone and limestone intercalated with black bituminous shale (Buday, 1980).

The age of the Naokelekan Formation was reported as Upper Oxfordian – Lower Kimmeridgian (Upper Jurassic) (Bellen *et al*., 1959), Callovian – Lower Kimmedgian (Middle – Upper Jurassic) (Jassim and Buday, 2006b). According to (Abdula, 2016) it can be placed between Callovian and Upper Oxfordian (Middle – Upper Jurassic), based on the occurrence of *Cyclagelosphaera deflandrei* sp. and *lotharingius* sp. According to Buday (1980) and Jassim and Buday (2006a), the Naokelekan Formation is considered as the age equivalent of the Najmah Formation, in the middle and southern parts of Iraq. The Naokelekan Formation was deposited in the Late Jurassic within the Gotnia euxinic intra-platform basin of the Arabian Plate margin (Alsharhan and Nairn, 2003) (Fig.1). Euxinic marine source rocks and evaporites were deposited in the Gotnia and other intra shelf basins due to continued but subtle subsidence of extensional origin (Goff, 2005). The Middle Jurassic rocks are considered very significant source rocks over all southern, northeastern, and northern Iraq due to the high Total Organic Carbon (TOC) content of the Sargelu and Naokelekan formations that were deposited throughout the Jurassic basin (Jassim and Al-Gailani, 2006). The Naokelekan Formation, according to its age, is comparable to some stratigraphic units in surrounding countries. These units are the Hanifa Formation in Bahrain and Saudi Arabia, the Diyab Formation in Qatar, the Najmah Formation in Kuwait, the Qamchuqa Formation in Syria, the Tuwaiq Mountain Limestone and the Hanifa Formation in Oman, and the lower part of the Surmeh Formation of southwestern Iran (James and Wynd, 1965; Buday, 1980; Enay and Mangold, 1994; Jassim and Buday, 2006b) (Fig.2).

MATERIALS AND METHODS

Two sections have been selected for this study, located near the Ranya Town, Sulaymania Governorate within the High Folded Zone, NE Iraq (Fig.3). Both sections are located in the western limb of the Makook asymmetrical anticline. The main rock units in the studied area are carbonate-sedimentary rocks of the Cretaceous and Jurassic ages. They are commonly exposed within some of the eroded cores and limbs of anticlines in the area (Fig.4). Section-I is located to the west of the Zewa Village about 15 Km north of the Betwata Town, with the latitude and longitude 36° 23' 33.13" N and 44° 38' 15" E, respectively. Section-II is located to the southeast of the Dwawa Village about 2 Km northeast of the Shkarta Town, with the latitude and longitude 36° 19' 40.08" N and 44° 42' 33.28" E, respectively. Twenty two thin sections (8 for section-I, and 14 for section-II) were made at the Department of Petroleum Geosciences, Soran University. The thin sections are studied under polarized microscope for petrographic description, facies analysis and diagenetic processes. The classification of Dunham (1962) and its modified version by Embry and Klovan (1971) are utilized to characterize the microfacies.

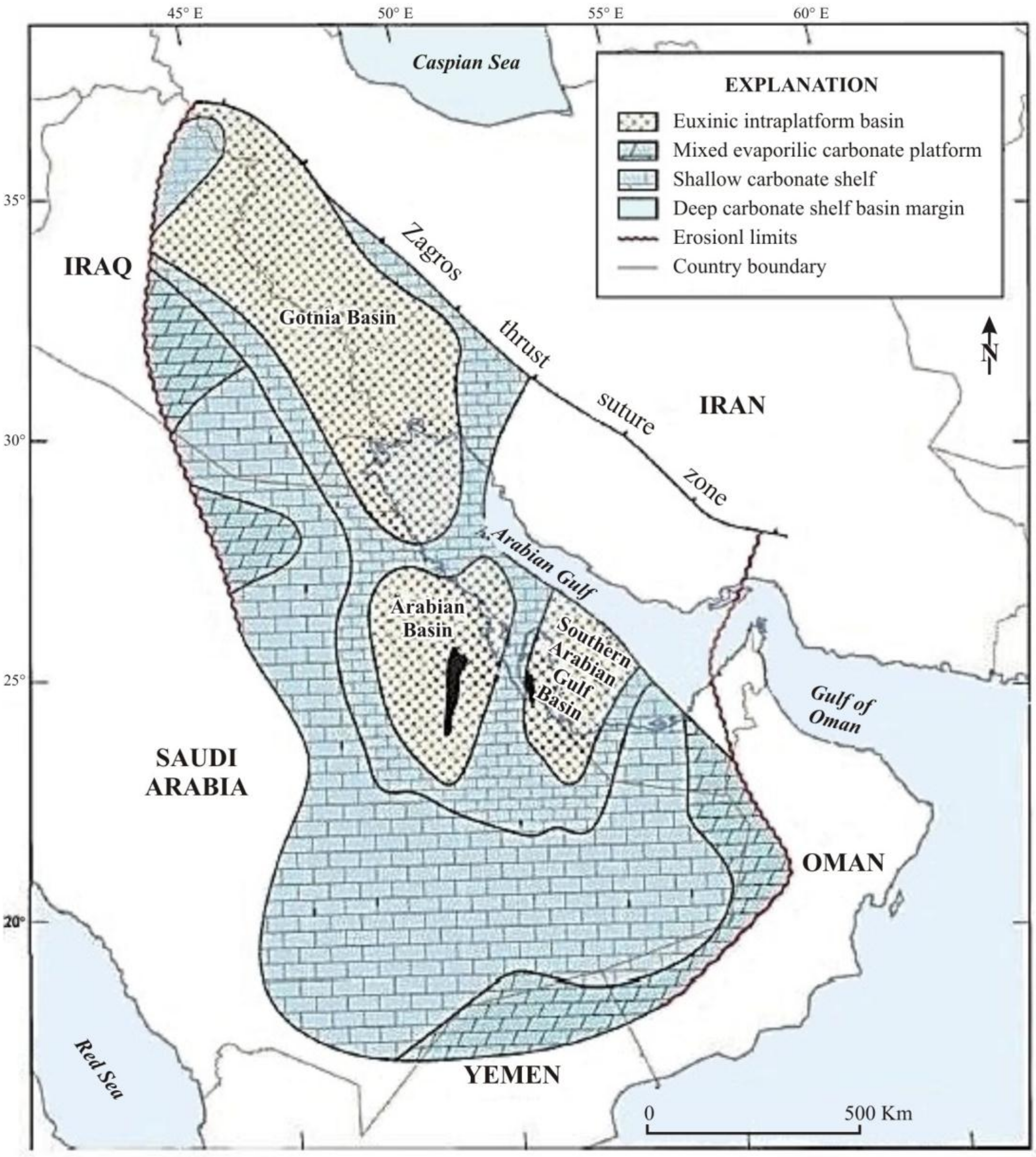

Fig.1: The Arabbian Gulf basin in which the Jurassic hydrocarbon source rocks accumulated (after Al-Sharhan and Kendall, 1986)

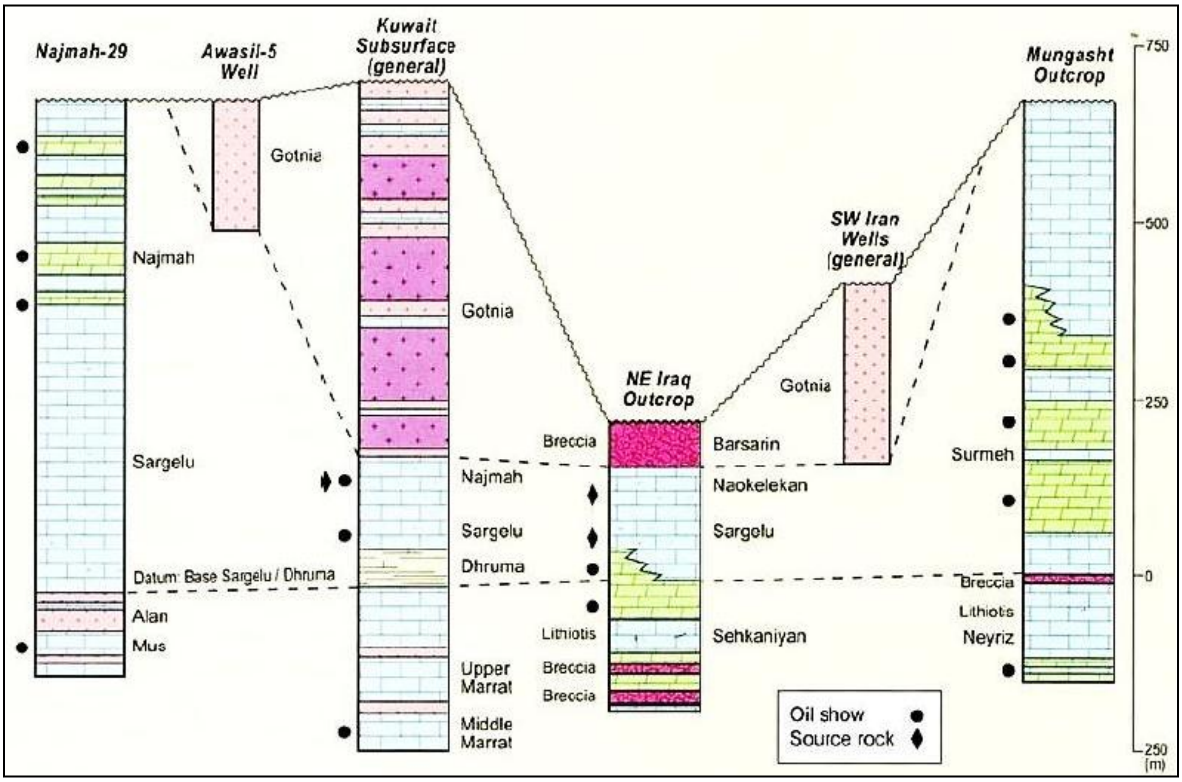

Fig.2: Stratigraphic columns of some sections in the Gotnia Basin (adapted from Goff, 2005)

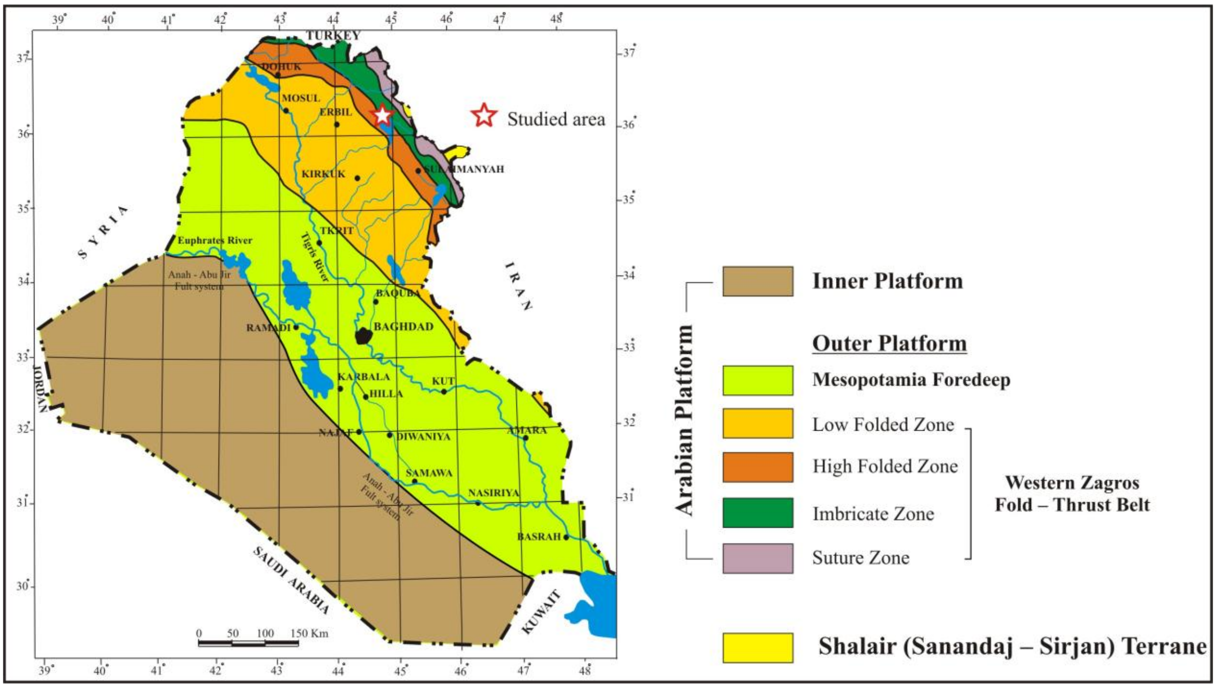

Fig.3: Tectonic Map of Iraq (after Fouad, 2015) and approximate location of the studied sections

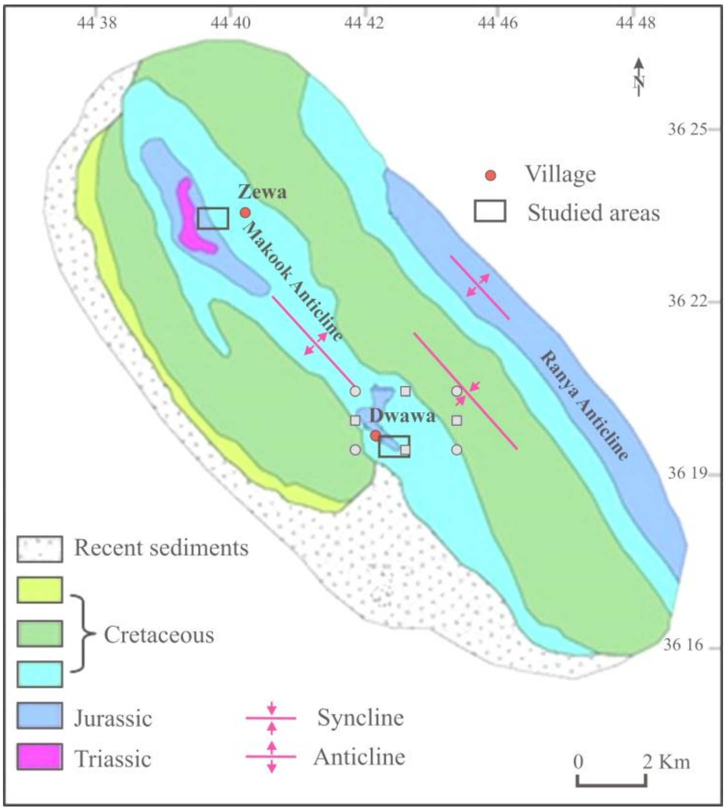

Fig.4: Geological map of the studied area (A modified extract from Sissakian, 2000) and location of the sampled sections

LITHOLOGY

- **Zewa Section**

The thickness of the Naokelekan Formation in this section is 15.3 meters, and can be divided, on the basis of lithology, into three parts (Fig.5): **1)** Lower part, black, bituminous shale interbedded with thin to medium bedded bituminous limestones and dolomitic limestone with disharmonic folds; **2)** Middle part, medium to thick bedded limestone with stylolites and dolomitic limestone rich in ammonite fossils; and **3)** Upper part, which is totally covered by the recent sediments in this section (Fig.6).

- **Dwawa Section**

The three parts of Naokelekan Formation are completely exposed in this section (Fig.7), with total thickness of about 13 meters, and the lithology is not so different from the Zewa section (Fig.8). The three parts of the formation in this section are:
1) Lower part, black bituminous shale (coal horizon) with thin to medium bedded limestone and dolomitic limestone; **2)** Middle part, medium to thick bedded fossiliferous dolomitic limestone (mottled bed) with stylolite structure; and **3)** Upper part, thin to medium bedded argillaceous limestone with dolomitic limestone and black shale with some load structures.

- **Stratigraphic Contacts**

The stratigraphic contacts of the Naokelekan Formation were supposed to be conformable, with some indications of breaks and unconformities found in some sections (Buday, 1980). In the two outcrop sections studied, the lower and upper contacts of the Naokelekan Formation are conformable and gradational with the underlying Sargelu Formation and the overlying Barsarin Formation (Figs.9A and B).

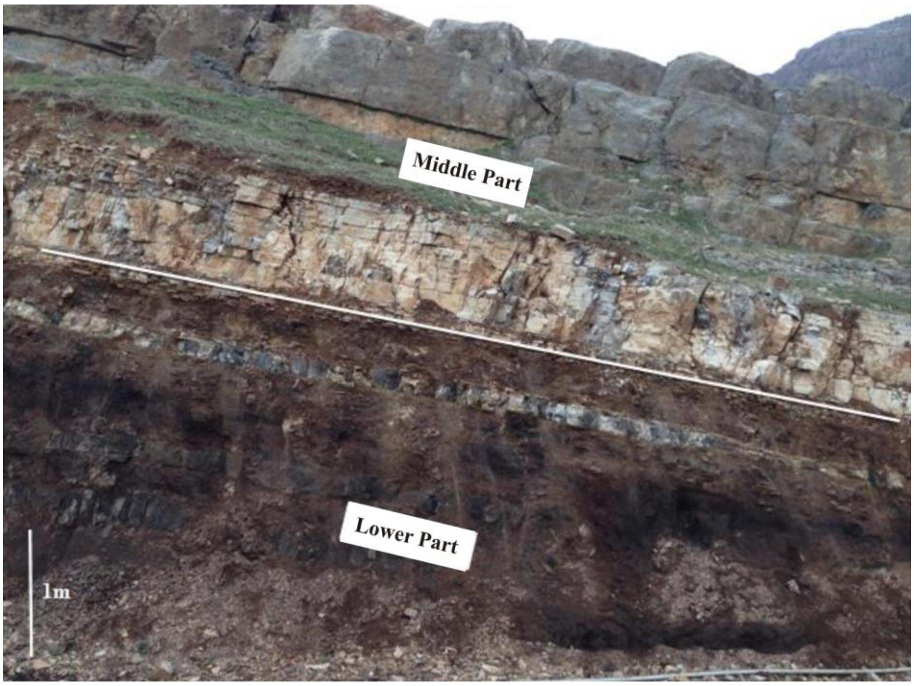

Fig.5: Outcrop of the Naokelekan Formation in the Zewa Village, the white line represents the contact between middle and lower parts of the formation

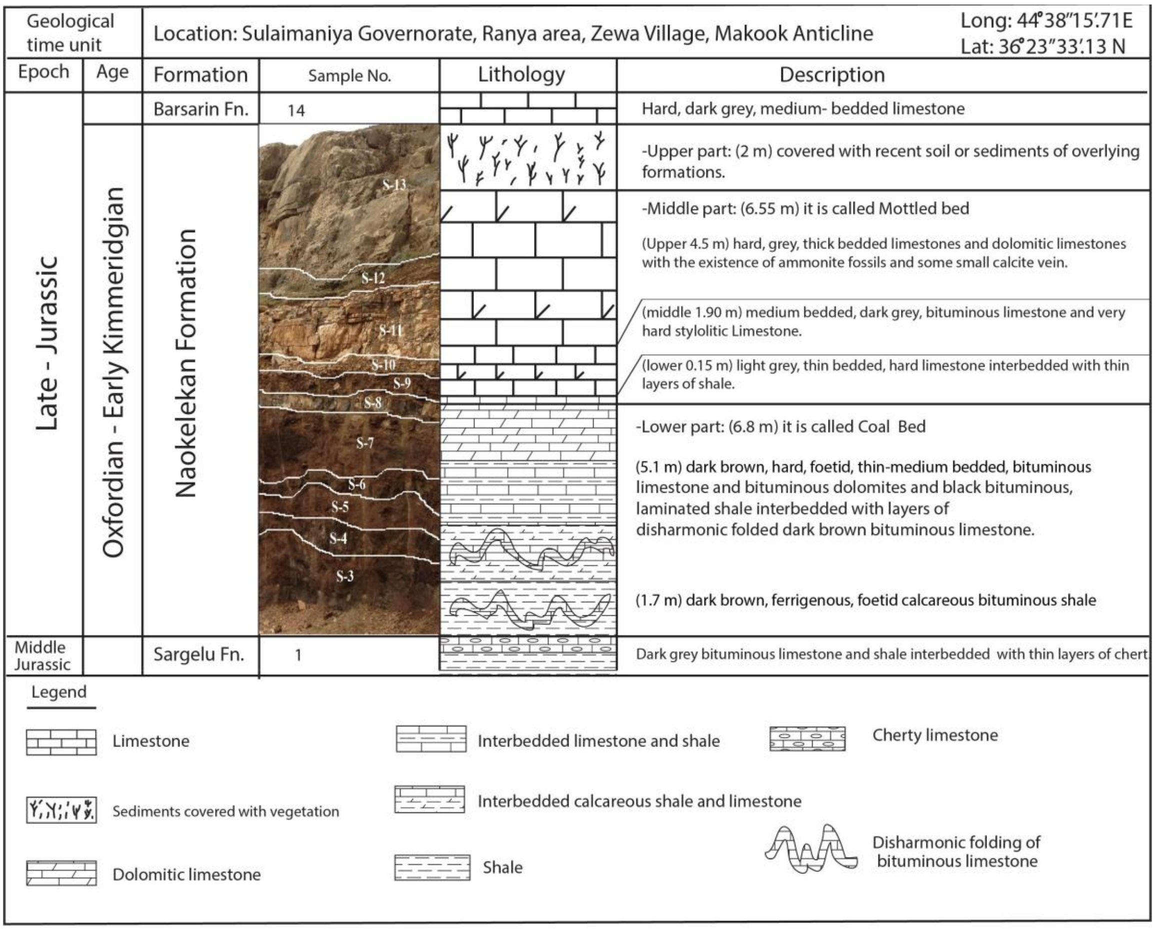

Fig.6: Stratigraphic column of the Naokelekan Formation at the Zewa section

Fig.7: Outcrops of the Naokelekan Formation in the Dwawa Village

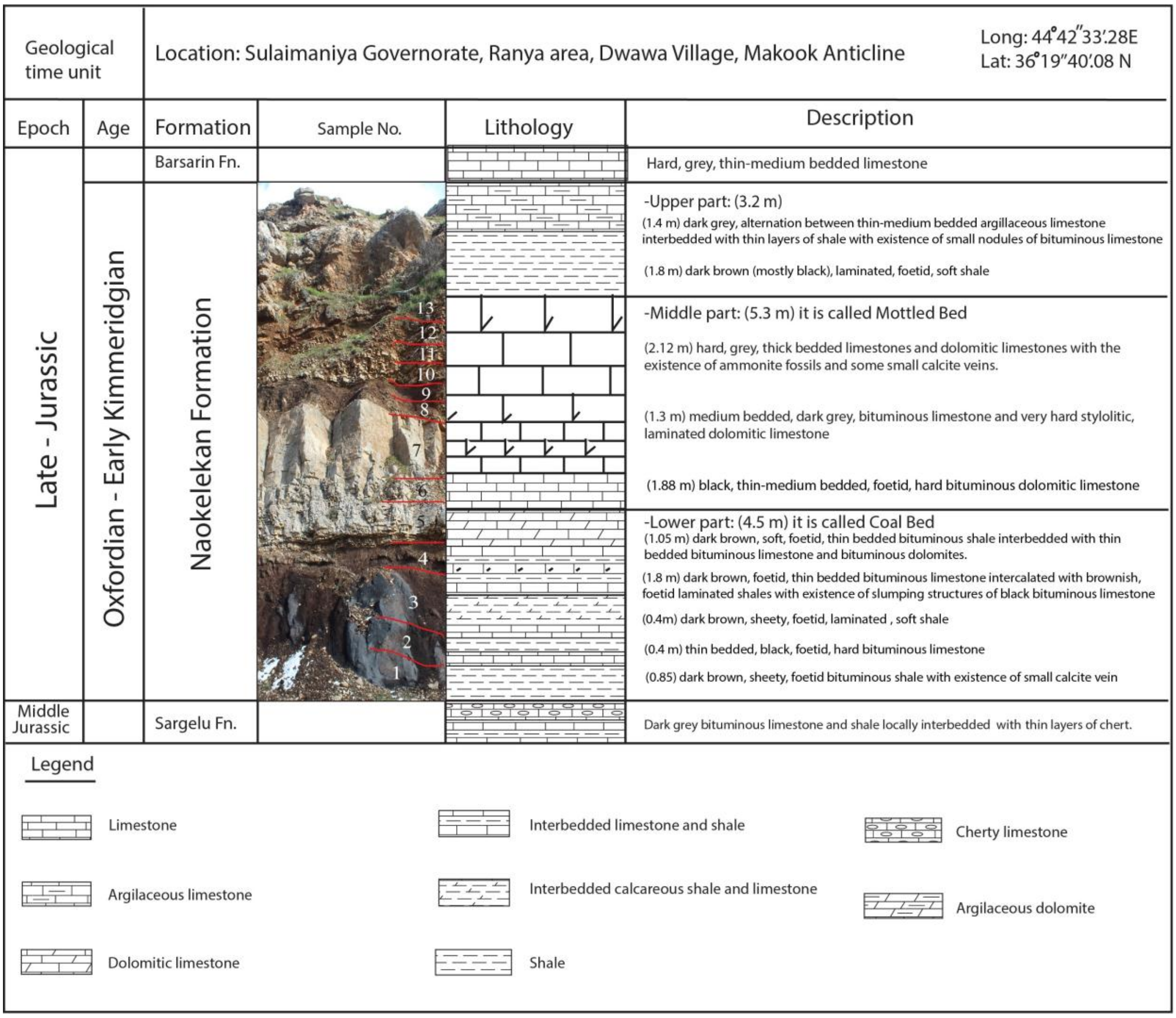

Fig.8: Stratigraphic column of the Naokelekan Formation at the Dwawa section

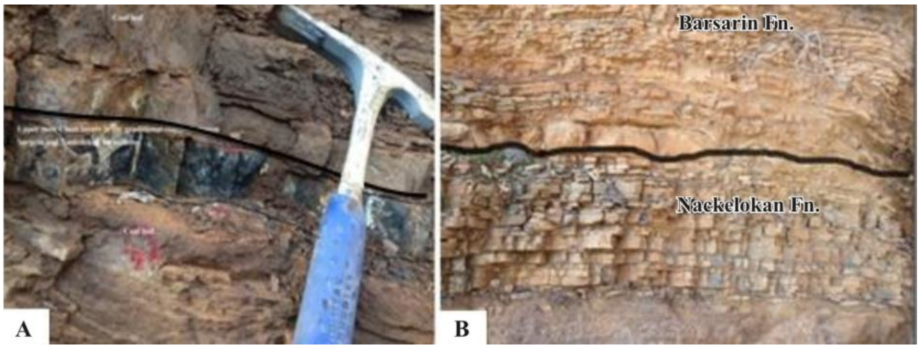

Fig.9: Conformable and gradational contact of lower (**A**) and upper (**B**) contacts of the Naokelekan Formation with the Sargelu and Barsarin formations, respectively at the Dwawa section

– **Lower contact:** Chert layers at the upper part of the Sargelu Formation can be used as indicator to isolate the lower part of Naokelekan Formation from the upper part of Sargelu Formation. Additionally, the abundant *Bositra* (previously known as *Posidonia*) and ammonites discriminate the Sargelu Formation from the overlying Naokelekan Formation (Wetzel, 1948; in Bellen *et al*., 1959; Abdula *et al*., 2015) (Fig.9A).

– **Upper contact:** In the Zewa section the upper contact of the Naokelekan Formation with the Barsarin Formation is covered, but in Dwawa section this contact is conformable and gradational. Thin to medium bedded, black bituminous limestones of the Naokelekan Formation pass to thin-medium bedded stromatolitic limestones of the Barsarin Formation (Fig.9B).

PETROGRAPHY

It was difficult to identify grains in the studied samples of the Naokelekan Formation due to intensive diagenetic processes that affected them. The size of skeletal grains is varying from about 1 mm to 2 cm. The type, size, shape, and distribution of skeletal grains are good indicators of the depositional environment (Flugel, 2010). The petrographic analysis revealed that the Naokelekan Formation consists mainly of micrite, various skeletal and less extent none skeletal grains. Below is a brief description of each of these components:

- **Skeletal grains**

Benthic (Miliolid) and pelagic foraminifera (Globigerina), ammonites, ostracods, pelecypods, gastropods, calcispheres of various sizes are the most common skeletal grains in the Naokelekan Formation.

- **Non-skeletal grains**

Peloids are the main non-skeletal grains in the studied samples. They range from silt- to sand-size. Peloids are characteristic constituents of carbonate sediments laid down in shoal and subtidal environments (Folk, 1980).

- **Micrite**

Micrite is represented by microcrystalline calcite and it is the most common groundmass in all microfacies of both studied sections.

- **Spray calcite cement**

Different types of spray calcite cements have been recognized throughout the studied samples including drusy, granular and blocky calcite cements.

MICROFACIES AND DEPOSITIONAL ENVIRONMENT

The present study utilized the classification of Dunham (1962) and its modified version by Embry and Klovan (1971) to characterize the microfacies in the Naokelekan Formation. Three main microfacies types are identified (Fig.10A – D) based on the relationship between the grains and groundmass type. These microfacies are as follow:

- **Lime-Mudstone Microfacies**

This microfacies occurs at different levels throughout the studied sections. Micrite is the main component, which is slightly affected by sparitization processes. The skeletal grains in these microfacies represent about 4 – 5 %. They contain ostracods, pelecypods, benthonic (Miliolids) and planktonic (Globigerina). This microfacies is the second major microfacies after the Wackestone Microfacies and constituents about 30% of the total thickness of the Naokelekan Formation. It is found in the three parts of the formation (Fig.10A).

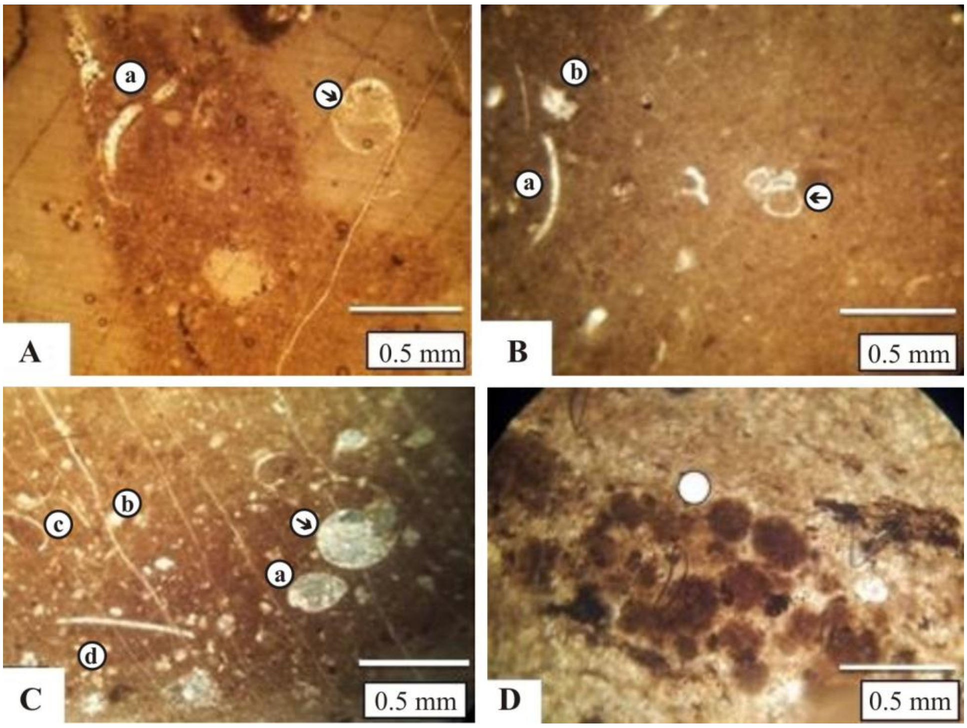

Fig.10: Photomicrographs showing types of microfacies in the Naokelakan Formation:
A) Lime-Mudstone Microfacies, (a) bivalve and (b) planktonic foraminifera, (PPL).
B) Lime-Wackstone Microfacies, (a) bivalve and (b) planktonic foraminifera, (PPL).
C) Lime-Wackestone/ Packstone Microfacies. Ammonite mold (arrow), (a) ostracod, (b) planktonic forams, (c) pelecypod and (d) calcisphere, (PPL).
D) Peloids in the Lime-Wackestone Microfacies, (PPL)

- **Lime-Wackestone Microfacies**

This microfacies consists of skeletal grains, usually represent between 15 and 20% of the constituents and present in a micritic matrix. The skeletal grains include: ammonites, foraminifers, gastropods, pelecypods, calcispheres and ostracods. Non-skeletal grains include peloids (Fig.10D). This microfacies is the most common microfacies and constitutes more than 50% of the whole thickness of the formation in the studied sections. It is found in all parts of the formation but more common in the middle and upper parts (Fig.10B).

- **Lime-Wackestone/ Packstone Microfacies**

This microfacies is characterized by predominant skeletal components (50 – 60 %) with micrite between the grains (Fig.10C). The skeletal grains include: ostracods, pelecypods and calcispheres. This microfacies constitutes about 20% of the total thickness of the studied sections of the Naokelekan Formation and found in the middle part.

DIAGENETIC PROCESSES

- **Micritization**

Micritization is an early diagenetic process which affects skeletal grains (Tucker, 1985). It is the most common diagenetic process affecting the skeletal fragments in the Packstone and Wackestones microfacies of the Naokelakan Formation (Fig.11A).

- **Cementation**

Many types of cements (granular, druzy and blocky) have been observed in the studied samples. These varieties occur in various microfacies filling inter-and intragranular pores and fractures and are considered in this study to be of late diagenetic origin (Fig.11B).

- **Neomorphism**

Calcitization is the main process of neomorphism in the studied samples. It occurs as changing of aragonite to calcite or high magnesium calcite recrystallized to low magnesium calcite and involves the complete dissolution of the precursor carbonates and the subsequent precipitation of calcite cement (Fig.11C).

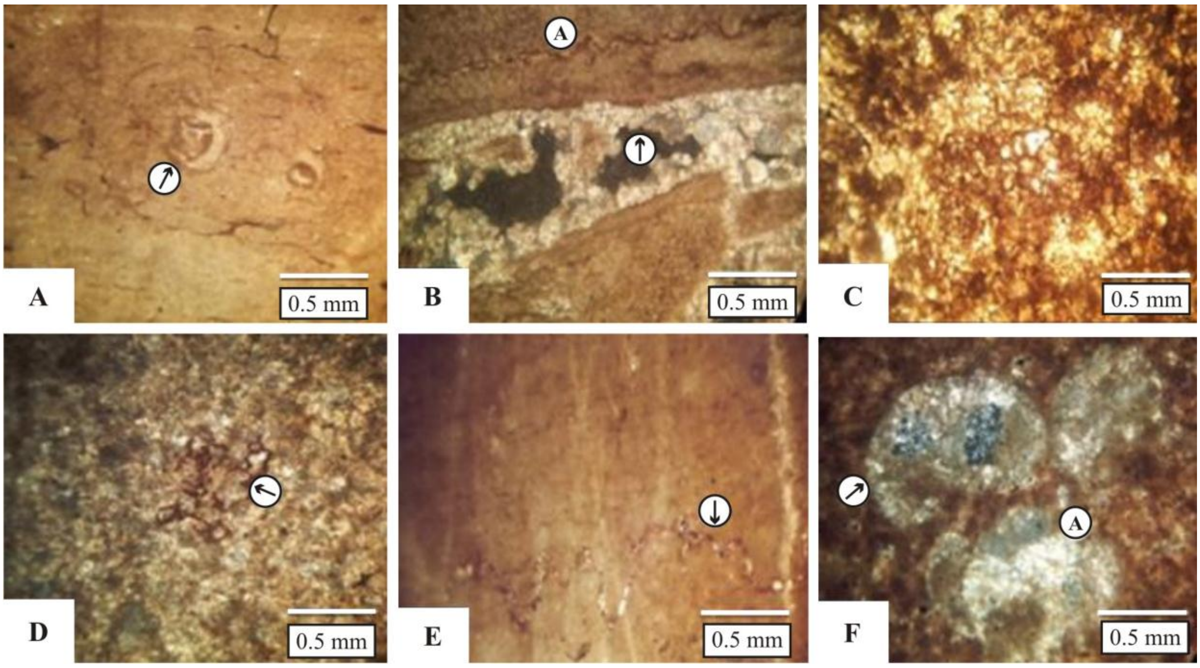

Fig.11: Photomicrographs showing diagenetic processes in the Naokelekan Formation in the studied sections. **A)** Micritization (arrow) on benthic foraminiferal (Miliolid), lower part, (PPL). **B)** Spary calcite cement as fracture-fill, middle part, (PPL). **C)** Neomorphisim, lower part, (PPL). **D)** Dolomitization, lower part, (PPL). **E)** Stylolite (arrow), middle part, (PPL). **F)** Biomoldic porosity, (arrow) ammonite filled by cement, lower part, (PPL)

- **Dolomitization**

The main types of dolomite found in the studied samples of the Naokelekan Formation are scattered fine-grained dolomite rhombs that occur within the mud-supported microfacies (Mudstone and Wackstone microfacies), and are often concentrated along stylolites surfaces. The fine grain size nature of the rhombs and their occurrence within the mud-supported facies indicate their early diagenetic origin (Fig.11D).

- **Chemical compaction and stylolite formation**

This process reflects the compaction due to the heavy lithostatic load, which eliminates porosity (Tucker, 1985). According to Friedman and Sanders (1978) and Flugel (2010) compaction has no direct relationship with early diagenetic cementation. Pressure solution results in the formation of dissolution surfaces and stylolites (Flugel, 2010). Stylolites in the Naokelekan Formation mostly take the form of sutured type and parallel to the bedding planes of limestone and dolomitic limestone. It is mostly observed in the middle part of the Naokelekan Formation (Fig.11E).

- **Dissolution**

Dissolution is found in the studied samples as one of the most important diagenetic processes affecting the Naokelekan Formation i. This process acted to dissolve the internal material of the skeletal grains and resulted in the formation of the observed moldic and/ or vuggy porosity (Fig.11F). The microfacies and diagenetic processes in the Naokelekan Formation in the studied sections are represented in Fig.12.

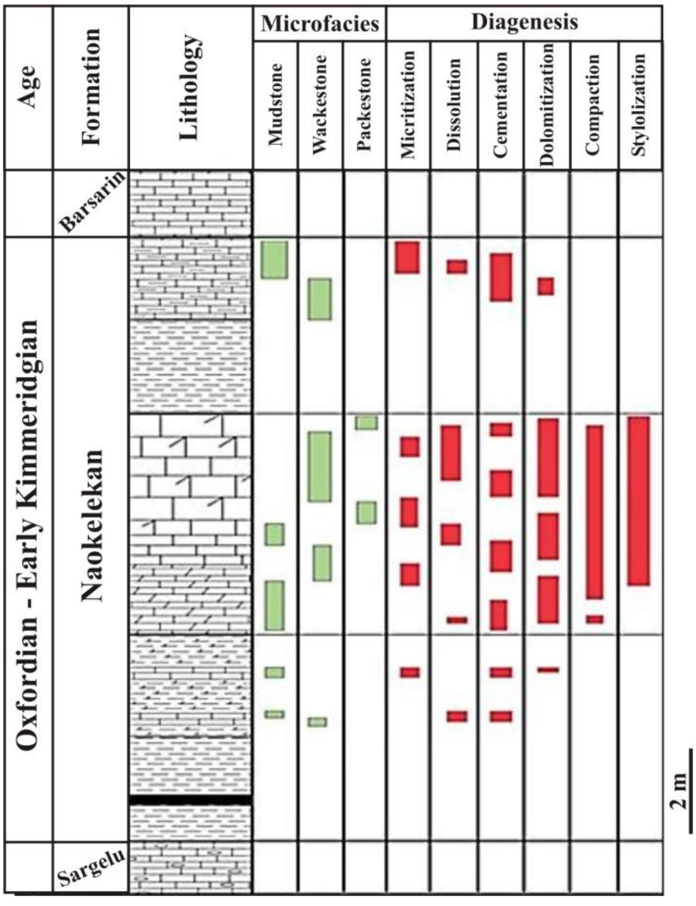

Fig.12: Microfacies and diagenetic processes of the Naokelekan Formation in the studied sections

DEPOSITIONAL ENVIRONMENT

Based on the groundmass composition, grains constituent and microfacies analysis of the studied samples, this study suggests that the Naokelekan Formation was deposited in a ramp-governed system. One reason for suggesting the ramp model is due to the absence of reef-building community organism in the Naokelekan Formation. This suggestion is supported by the microfacies analysis; the Lime Mudstone and Wackstone microfacies, with benthic foraminifers (Miliolids), ostracods and peloids, characterize restricted (subtidal lagoon) environment (Erdema and Tasgin, 2019). The presence of Miliolids, peloids with micrite indicate shallow, warm, brackish (sometimes hypersaline) and calm water environments (Erdema and Tasgin, 2019). The presence of argillaceous shale and bituminous limestones indicates anoxic/dysoxic (anaerobic/ dysaerobic) conditions of these facies. The Lime-Mudstone Microfacies is equivalent to RMF16 (Read, 1985; Flugel, 2010). It is related to restricted inner ramp environment, located above fair weather wave base. The Lime Wackestone Microfacies is equivalent to RMF18 (Read, 1985; Flugel, 2010). It is related to restricted inner ramp located above fair weather wave base. The Lime-Wackstone/ Packstone Microfacies, with abundance of ammonites, pelecypods, ostracodes, planktonic foraminifers and planktonic gastropods, are equivalent to RMF8 (Read, 1985; Flugel, 2010) and can be related to mid ramp, below fair weather wave base and above storm wave base (Fig.13).

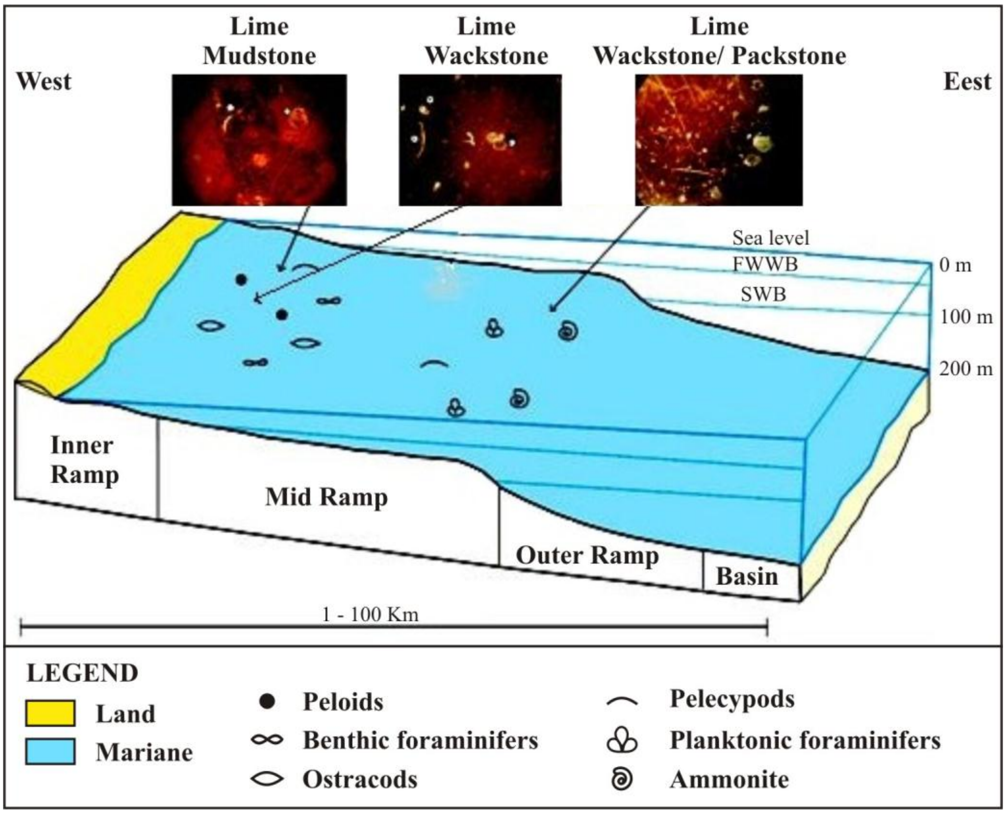

Fig.13: Model of the Inner and Mid Ramp depositional sub-environment of the Naokelekan Formation in the studied sections

CONCLUSIONS

In the two outcrop sections studied, the lower and upper contacts of the Naokelekan Formation are conformable and gradational with the underlying Sargelu Formation and the overlying Barsarin Formation. The three parts previously reported comprising the Naokelekan

Formation are identified and described in the studied sections. The lower and upper parts are composed of thin to medium bedded, dark grey, bituminous limestone, dolomitic limestones with bituminous shale. The middle part consists of dark grey, bluish, medium to thick bedded limestones and dolomitic limestones. The most prevailing microfacies are Lime-Mudstone, Lime-Wackestone and Lime-Packstone/ Wackestone. Various diagenetic processes have affected the limestones of the Naokelekan Formation, including micritization, neomorphism, dolomitization, dissolution, compaction and cementation. Based on petrographic study and microfacies analysis the Naokelekan Formation was mainly deposited within a ramp in two sub-environments: lagoon and shallow marine.

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About the authors

Arkan Othman Sharezwri graduated from Soran University, Erbil in 2016 with B.Sc. degree in Petroleum Geosciences. His major field of interest is Stratigraphy. He is working as Demonstrator at Soran University, Iraq.

e-mail: arkan.osman@hotmail.com

Mohammad Sadi Nourmohammadi graduated from University of Tabriz, Iran in 2006, with B.Sc. degree in Geology. He got his M.Sc. Sedimentology and Sedimentary Petrology in 2011 from Ferdowsi University of Mashhad in Iran. He joined Soran University in 2012 and currently, is working as lecturer in the Petroleum Geoscience Department. His major field of interest is Sedimentology.

e-mail: nourmohammadi.ms94@gmail.com

Rzger Abdulkarim Abdula is a Lecture at Soran University and adjacent Lecturer at Tishik University, Iraq. He is a Ph.D. holder at the Soran University and Gorge-August University, Gottingen, Germany jointly. He has held past positions as operations geologist with Talisman Energy Co. and as a geologist with RMG Engineers, Colorado Springs, CO, USA. He holds a BS in geology (1987) from the University of Salahaddin, Erbil, Iraq, and an MS in geology from the Colorado School of Mines.

e-mail: rzger.abdulkarim@tiu.edu.iq
Mailing address: Soran University, Kawa Street, Soran, Iraq