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Nannofossil distribution in the late Jurassic-Naokelekan and Barsarin Formations, Miran Oil field, well-2-, Kurdistan, Northeastern Iraq

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Abstract

The Naokelekan and Barsarin Formations of the Upper Jurassic are studied in the oil well Miran -2- at the Sulaimani area of Kurdistan. The study is focused on the determination of nannofossil contents and age of both rock units. Based on the calcareous nannofossil marker species, twelve cutting samples were selected from both formations in that well. The lithology of the Naokelekan Formation is dominated by black shale, and some white rock fragments, while the lithology of the Barsarin Formation is characterized by high abundance of dark-grey and grey limestone towards bottom, where the ratio of milky- white limestone is increased upward. The nannofossil species that identified for the first time here *are Conusphaera mexicana, Polycostella senaria, Nannoconus compressus, Helenea staurolithina, Watznaueria britannica, Watznaueria barnesiae, Lotharingius hauffii, Faviconus multicolumnatus* and *Parhabdolithus robustus.* This assemblage proved the Late Jurassic; the index nannofossils and biostratigraphic zonation indicated that the age of the Naokelekan Formation is dated back to Early Tithonian, and the Barsarin Formation to late Early-Middle Tithonian. Preservation of the calcareous nannofossils in the well is bad to moderate. The calcite grains are re-crystallized and caused difficulty in the identification.

Introduction

The Upper Jurassic rock units (Naokelekan and Barsarin Formations) in Kurdistan were studied mainly in terms of lithology and potentiality for generating hydrocarbons ([11]; [22]; [3]; [8]; [10]; [1]; [20]. Most of the Jurassic formations are characterized by mature organic matter and considered the significant source rocks in Kurdistan of Iraq, and the Arabian Peninsula. There is no detailed study discussing the calcareous nannofossil distribution of these rocks to determine the accurate age as well as the depositional environment. However, there are few recent study of [4]; [2]; [24]. The main purpose of this study is investigation of the calcareous nannofossils of the Upper Jurassic Naokelekan and Barsarin Formations to shed light on the age of both units in the Miran Oil Field.

Geologic Setting

From the Upper Jurassic to Late Cretaceous, sea level had a number of fluctuations in conjunction with a slow subsidence. Due to those processes, Neo-Tethys had been created in which a large, shallow intra-shelf basin on the passive margins of the Arabian plate was formed [21]. In addition, the Late Jurassic tectonic activities along the Arabian plate margins were controlled the paleogeography of the Late Jurassic succession; the Jurassic tectonic activities were taken place earlier than the opening of the Southern Neo-Tethys. During the Late Jurassic (Tithonian), although the sea level continued to rise, sedimentation rates appear to have kept pace and finally exceeded the rate of folding, with consequent development of extensive shoal and sabkha environments where extensive evaporates accumulated (Fig.1), which are correspond to the Arab reservoirs and Arab Hith and Gotnia Basin[7].

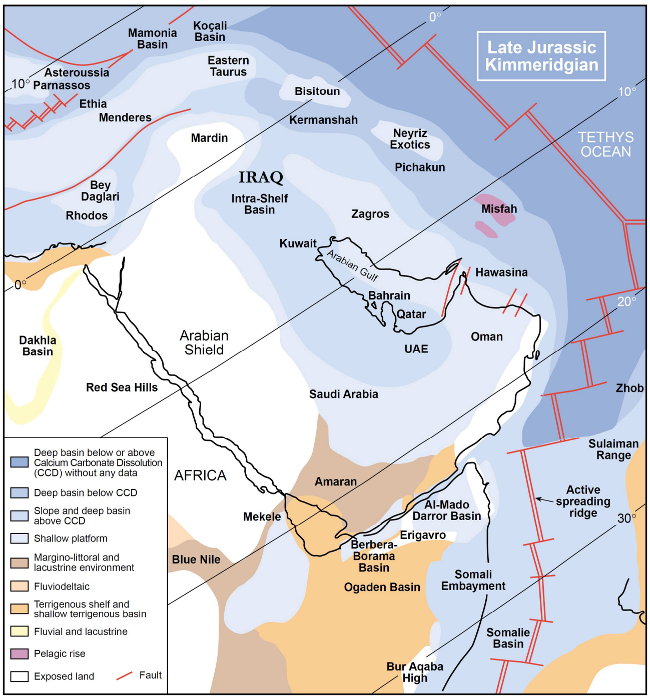


Fig.(1): Paleoenvironment and tectonic reconstruction of the Kimmeridgian (from Al-Husseini, 1997), [7].

It seems that the periodic isolation of the intra- shelf basin was created because of differential subsidence in the Neo-Tethys. In the Kurdistan region, the eastern basin succession is characterized by deposition of thin condensed Sargelu, Naokelekan and Barsarin Formations that are underlie by uppermost Sehkaniyan Formation. Meanwhile, the basinal units of the Alan Formation then the Sargelu Formation, accompanied by the Najmah, Gotnia and Barsarin Formations, are the central basin of that succession [18]. In an euxinic intra- basinal platform (Gotnia basin of the Arabian Plate margins), the Naokelekan Formation was deposited in the Late Jurassic. Moreover, a continuous subtle subsidence of extensional origin resulted in a creation of an euxinic marine source rocks and evaporites that deposited in the Gotnia basin [18]. According to [14], the Barsarin Formation is a lagoonal evaporitic origin, which is indicated partly by the presence of anhydrites and oolitic in the beds in some specific sections. The Barsarin Formation may be a basin-floor evaporates facies [23]. Furthermore, the Barsarin Formation designates the Kimmeridgian-Tithonian interval in Kurdistan, in which anhydrites and intercalated limestones formed that controlled by the oscillating sea level. In addition, based on its stratigraphic position, the Barsarin Formation is below the Chia Gara Formation and above the Naokelekan Formation of the Late Tithonian and the Kimmeridgian- Oxfordian ages respectively ([18]; [3]; [19]. [2] concluded that the age of Naokelekan Formation is Callovian-Upper Oxfordian. He also found *Cyclagelosphaera margerelii* that indicates restricted marine environment while the *Watznaueria barnesiae* points to high latitude geographic location of depositional basin which was warm water that was characterized by low-nutrient.

The Miran Block is located northwest of the city of Sulaimani, Kurdistan region, northern Iraq. Tectonically, this Block lies within the western part of the High Folded Zone, which elongated from NW to SE direction. The Miran Block is about 1050km^2, with 70km long and 15km wide (Fig.2). On the Miran west structure, two wells (M1and M2) have been drilled and completed, the third well (M3) has been drilled in the same structure, but afterward has been suspended and on the Miran East structure, the fourth well

(M4) has been drilled and completed by the Heritage Oil Company ([16([16]; [15]. The studied well (M-2) is located at coordinants longitude: 35°40́19.17E and latitude: 45°03́13.695N.

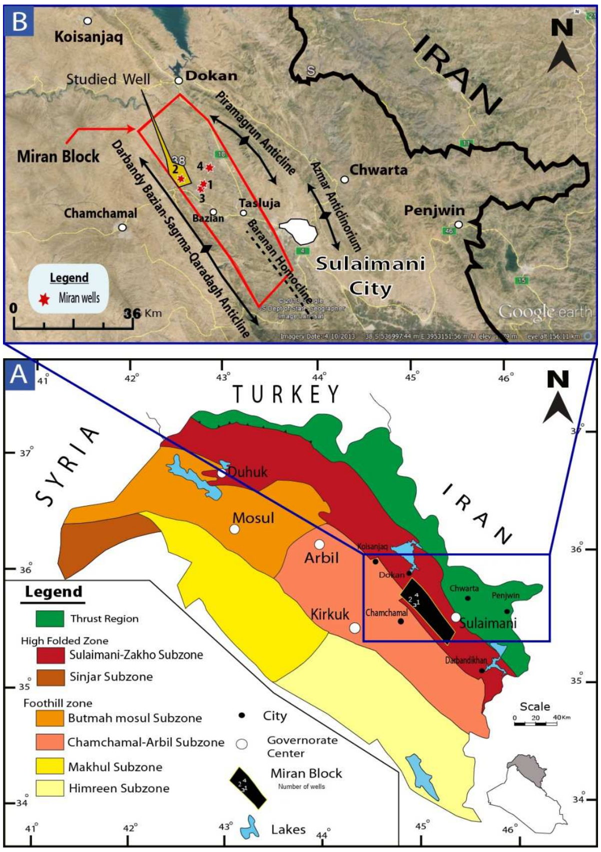


Fig.(2): Location map of the Miran Block, it includes the oil well M-2 in Kurdistan (after Mohialdeen *et al*. 2018).

Methodology and Sampling

[19] studied the same selected samples in order to determine the biomarkers within the bitumen after extraction the organic matter from the rocks. Twelve cutting samples (six from each formation) were obtained from the Ministry of Natural Resources of Kurdistan Regional Government, Erbil. The thickness is ranged between depths 2370-2315 meters. The samples were cleaned from impurities and washed with distilled water to remove dirt. The washed samples were kept in oven for 24 hours to be dried at the temperature 40°C. Then a small quantity of each sample was put on a glass slide and was examined under polarizing microscopy with high objective lens. All preparations and identification processes were done at the Department of Geology, College of Science, University of Sulaimani.

The current study is depended on smear-slide preparation. The samples were achieved from the cuttings of both formations at the interval five meters. The smear- slides were made for studying the calcareous nannofossils. For this preparation, a fine powder of the sample was put on a glass slide, and the powder moistened with distilled water to form a paste, and then spread over the slide to uniform thickness. After that, the slide was placed on a hot plate for drying. After drying, it was cooled, glued and covered with suitable glass cover by applying some pressure with a plastic or wood stick to firm the powder to the slide surface. The polarizer petrologic microscopy was used for the nannofossil identification due to their fine-calcite structures. The calcite crystals that form hetero- and holococcoliths often have differently oriented optic axes that produce distinctive extinction patterns under cross polarized microscopy. Transmitted and cross-polarized light are regularly used.

Stratigraphy

The stratigraphy of the Naokelekan and Barsarin Formations in the Miran oil well (M-2) are described as follows:

1. Naokelekan Formation

The Naokelekan Formation was identified and described by Wetzel and Morton (1950: *in* [11]) at the Naokelekan Village near Rawanduz district, northeast of Iraq. This formation is about 14m thick in the type section [11], who claimed that the lithology of the Naokelekan Formation from top to bottom comprises of laminated shaly limestone, hard and dark-grey limestone (4m), thin bedded and extremely bituminous limestones and dolomites (7m) and intercalated bituminous calcareous shale (coal horizon).

Moreover, paleontological study and coal horizons were used to determine the age of the formation. [11] indicated the Naokelekan Formation is upper Oxfordian to lower Kimmeridgian. However, proofs for the Callovian were not found. Additionally, the contacts of the formation are conformable. [5] the formation as mature source rock within oil zone at the Banik Village. This is also concluded by [8] in the Deresh area.

Many studies have been done on the organic matter content in the Naokelekan Formation focusing on the type of kerogen and stages of maturity (such as [6]; [10]; [1]; [20]. They concluded that the formation shows high TOC percent and types II and III kerogens are the main components of organic matter. [2] studied the Naokelekan Formation from thirteen surface sections and concluded that the age of the formation is Callovian to upper Oxfordian.The Naokelekan Formation in the studied well (M-2) is about 30m. It is thick and generally composed of brown to dark limestone rich in carbonaceous material. Sometimes, it bears few layers of dark shale (Fig.3).

2. Barsarin Formation

Wetzel and Morton (1950: *in* [11]) defined the Barsarin Formation for the first time. The type locality and type section of the Formation are located in the Balambo-Tanjero zone at the Barsarin Village near Rawanduz district of northeast Iraq. The Barsarin Formation is 20m thick and the lithology is consisted of limestone, dolomitic limestone, argillaceous, contorted and brecciated beds at the type section. Dissolution of anhydrite beds are the source of the breccia beds [11].

As consequences of dolomitization and recrystallization, fossils are absent in surface and subsurface units [18]. (Hamza and Issac,1971: *in* [14]) studied the contacts of the Barsarin Formation in the type area. They concluded that the contact is appeared to be conformable; however, the ferruginous and detrital beds marked the base of this formation in the Northern Thrust Zone.

The first appearance of stromatolites indicates the beginning of the Barsarin Formation as detected in outcrops by [22]. [3] and [10] studied both formations Naokelekan and Barsarin from the Ranya area, Sulaimani, and they found out that the formations were contained kerogen types II, III, and IV and they are thermally mature. [9] referred to both formations among the Jurassic source rocks as potential sources of oil.

The upper contact of the Barsarin Formation with Chia Gara Formation is sharp and mostly conformable, no indication for unconformity has been found in the Ranya area, Sulaimani, Kurdistan. The Barsarin Formation in well M-2 is about 30m thick and mostly composed of dark limestone and carbonaceous dark shale. In the study samples, because of mechanical breakdown of the cuttings and fine grains, no stromatolites were determined (Fig.3). According to [10], the age is not demonstrated; possibly Upper Jurassic? Kimmeridgian, possibly Lower or Middle Kimmeridgian (i.e. Lower Tithonian), since it occurs below Middle Tithonian and above Lower Kimmeridgian ammonite faunas. [24] studied the Jurassic/ Cretaceous boundary, and they determined the contact within the Chia Gara Formation based on ammonites, nannofossils and calpionellids at the Banik Village (Zakho area, Duhok Governorate, Kurdistan), this determination designates the age of the Barsarin Formation to be older than the Cretaceous.

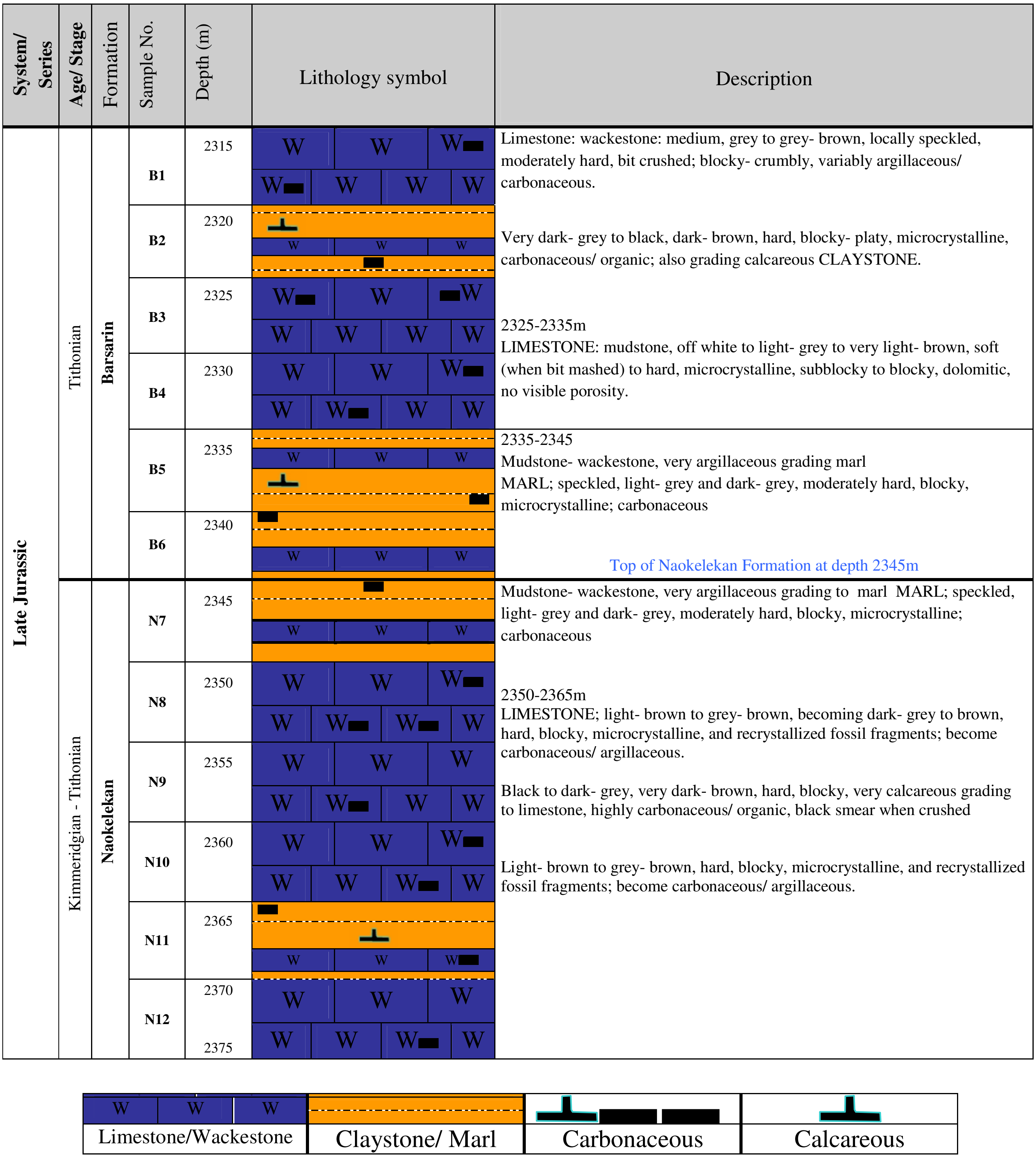


Fig. (3): General stratigraphic column for the interval of the Jurassic succession in well M-2, Miran Oil Field, Sulaimani and the location of studied samples (Modified from Mohialdeen *et al.* 2018).

Calcareous nannofossil distribution

Calcareous nannofossils are skeletal remains of the golden brown algae, these remains are accumulated on the basin floor that ranged from shallow to deep water and are preserved as fossils. The accurate examination of the study samples indicates the presence of some species of calcareous nannofossils in the Naokelekan and Barsarin Formations. However, the diagenetic processes such as dolomitization and recrystallization deformed the shapes of the calcite crystals and the calcareous nannofossils, but an assemblage of calcareous nannofossils has been revealed under polarized microscopy. Beside, [20] concluded that marine planktonic algal and bacterial precursors of organic matter were preserved in the

Naokelekan and Barsarin Formations using the unimodal distribution of n-C14-n-C20, and sterane. The recognized calcareous nannofossils that appeared in this study are: *Conusphaera mexicana, Polycostella senaria, Nannoconus compressus, Helenea staurolithina, Watznaueria britannica, Watznaueria barnesiae, Lotharingius hauffii, Faviconus multicolumnatu*s and *Parhabdolithus robustus.* The assemblage is shown in Fig.(5). The biostratigraphical zonation of these species is compared to the lithostratigraphic column of the oil well to determine the age of both formations as discussed below.

Biozonation and age determination

Conusphaera mexicana Trejo, 1969

Short diagnosis:

Tapering nannoliths with steeply sloping rim and central area filled with a core of radially arranged elements, which in light microscope shows relatively uniform birefringence with an axial extinction line; it most commonly seen in side view **(Figs. 5J & 5L)**.

Geological Range:

Last occurrence: within NJT17b and CC1 subzones (145.01-145.01Ma, top in Tithonian stage).

First occurrence: within NJT15a subzone (149.09-151.50Ma, base in Tithonian stage).

Polycostella senaria Thierstein, 1971

Short diagnose:

Stellate nannolith with around 6 rather irregular rays with 6 ridges **(Fig. 5B)**.

Geological Range

Last occurrence: within Early Berriasian Substage (143.57-145.01Ma, top in Berriasian stage).

First occurrence: in lower part of NJT17b subzone (148.9Ma, in Tithonian stage).

Helenea staurolithina Worsley, 1971

Short diagnosis:

It is normally to broadly elliptical coccoliths with a narrow central area, which spanned by an axial cross. The long axis of the central area is equal to or greater than one-half of the coccolith length [14]). **(Fig.5M)**.

Geological Range:

Last occurrence: within Hauterivian Stage (130.77-133.88Ma, top in Hauterivian stage).

First occurrence: within NJT17b Stage (145.01-152.06Ma, base in Tithonian stage).

Nannoconus compressus Bralower and Thierstein in Bralower *et al.* 1989

Short diagnosis:

Rectangular to oval with narrow canal, small to medium sized (3-8μm) nannoconid with rectangular to oval outline and very narrow canal. Wall cycles are flat **(Fig.5K)**.

Geological Range:

Last occurrence (top): within Tithonian Stage (145.01-152.06Ma, top in Tithonian stage).

First occurrence (base): within Tithonian Stage (145.01-152.06Ma, base in Tithonian stage)

Watznaueria britannica (Stradner, 1963) Reinhardt, 1964

Short diagnosis:

Watznaueria with narrow central-area spanned by a transverse bar. It is the dominant- distributed coccolith in Middle and Upper Jurassic assemblages, becoming rarer in the lower Cretaceous **(Fig.5H)**.

Geological Range:

Last occurrence: within UC1a subzone (100.03-100.45Ma, top in Cenomanian stage).

First occurrence: within NJT9 zone (169.69-170.10Ma, base in Bajocian stage).

Watznaueria barnesiae (Black *in* Black and Barnes, 1959) Perch-Nielsen, 1968

Short diagnosis:

Watznaueria with central-area that is closed or very narrow, with no central area structures **(Fig.5D)**.

Geological Range:

Last occurrence: within Late Maastrichtian Substage (66.04-69.91Ma, top in Maastrichtian stage).

First occurrence: within NJT9 zone (169.69-170.10Ma, base in Bajocian stage).

Lotharingius hauffii Grün and Zweili in *Grün et al.*1974
Short diagnosis:
It is a small, broadly elliptical *Lotharingius* with narrow central area spanned by spine-bearing axial cross **(Fig.5A)**.
Geological Range
Last occurrence: within NJT12a subzone (165.55-166.40Ma, top in Callovian stage).
First occurrence: at base of NJT5a subzone (185.5Ma, in Pliensbachian stage).
Faviconus multicolumnatus Bralower *in* Bralower *et al.*, 1989
Short diagnosis:
Tall, narrow columnar nannoliths formed from stacks of calcite laths around a narrow axial canal. It may occur as linked groups of multiple columns **(Fig.5C)**.
Geological Range:
Last occurrence: within Early Berriasian Substage (143.57-145.01Ma, top in Berriasian stage).
First occurrence: near base of NJT15b subzone (157.9Ma, in Oxfordian stage).
***Parhabdolithus robustus* Noël, 1965**
Short diagnosis:
Parhabdolithus with broad, parallel-sided, bluntly terminated spine. Spine usually terminates just above the rim, and does not exceed twice the rim height **(Figs.5G & 5I)**.
Geological Range:
Last occurrence (top): at top of NJT4a subzone (100% up, 189.1Ma, in Pliensbachian stage).
First occurrence (base): in lower part of NJT2b subzone (20% up, 195.9Ma, in Sinemurian stage).
Carinolithus magharensis (Moshkovitz and Ehrlich, 1976) Bown, 1987
Short diagnosis:
Trumpet-shaped coccoliths with minute, disc-like proximal shield and very narrow stem-like distal shield that flares distally to form a hexagonal structure **(Fig.5F).**
Geological Range:
Last occurrence (top): in mid part of NJT11 subzone (167.2Ma, in Bathonian stage)
First occurrence (base): within NJ8a subzone (171.79-174.59Ma, base in Toarcian stage)

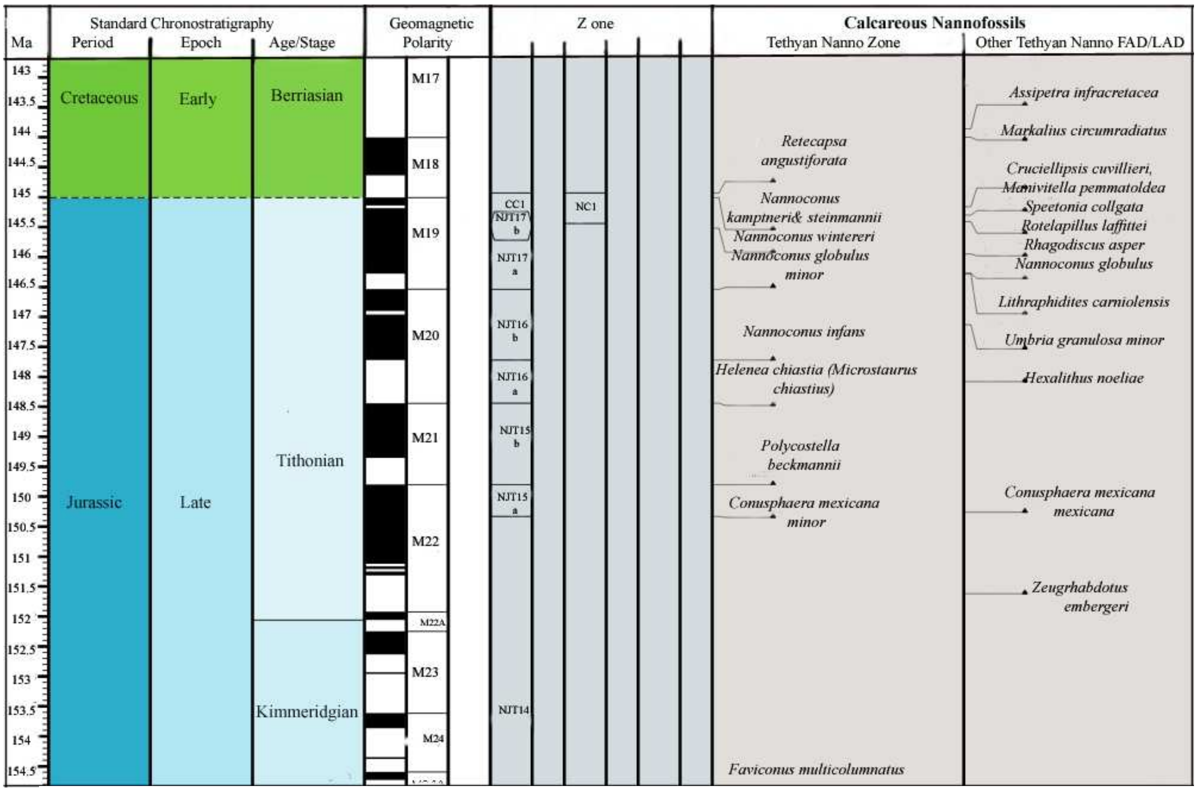


Fig.(4): Standard calcareous nannofossil zonations through the Late Jurassic-Early Cretaceous, (from the International Nannoplankton Association (INA) website, 2013). http://ina.tmsoc.org/Nannotax3/ntax-charts.html.ersity, [17].

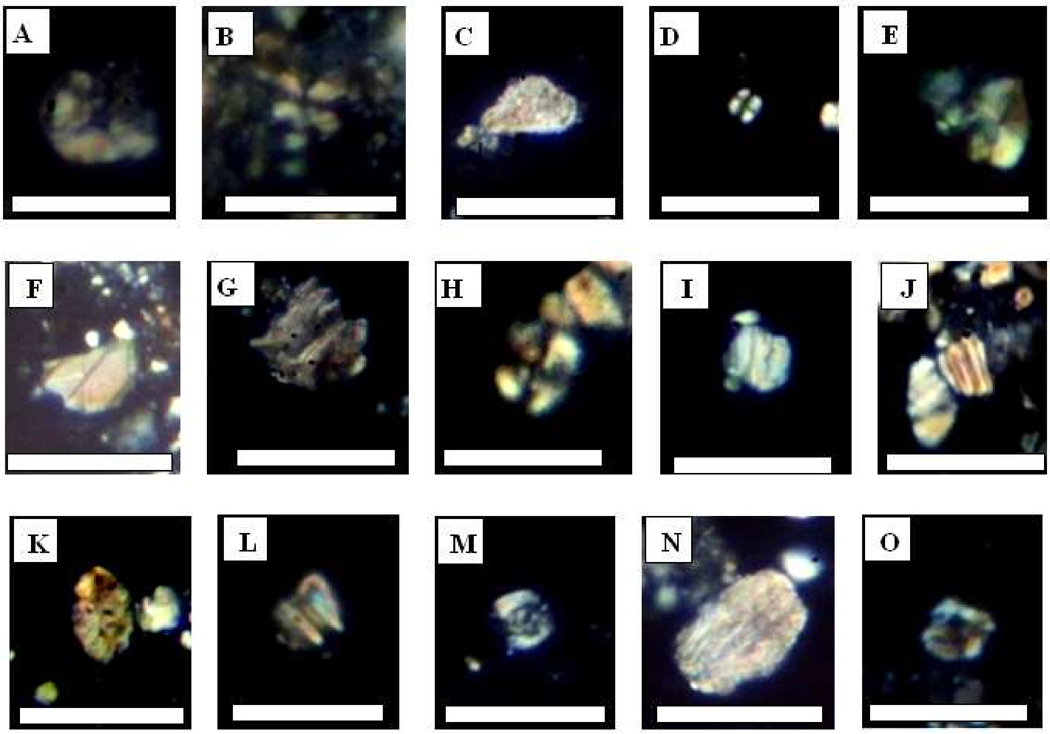


Fig.(5): Some genera/species of calcareous nannofossils that encountered in the cutting samples of the Naokelekan and Barsarin formations.

A. *Lotharingius hauffii,* slide No.B1, 40X. **B.** *Polycostella senaria*, slide No.B1, 40X.
C. *Faviconus* sp., slide No.B1, 40X. **D.** *Watznaueria barnesiae*, slide No.B2, 40X.
E. *Nannoconus* sp, slide No.B3, 40X. **F.** *Carinolithus magharensis*, slide No.B3, 40X.
G. *Parhabdolithus robustus*, slide No.B3, 40X. **H.** *Watznaueria britannica*, slide No.B4, 40X.

I. *Parhabdolithus robustus*, slide No.B6, 40X. **J.** *Conusphaera mexicana*, slide No.N7, 40X.
K. *Nannoconus compressus,* slide No.N7, 40X. **L.** *Conusphaera mexicana,* slide No.N10, 40X.
M. *Helenea staurolithina*, slide No.B6, 40X. **N.** Undefined sp., slide No.N11, 40X.
O. Undefined sp., slide No.B6, 40X.

Discussion

As previously mentioned, the age of the Naokelekan and Barsarin Formations are still controversial and are required more study. This preliminary research uses an accurate tool (nannofossils), which is one of the somehow newest attempts for determining the age of both formations. There is no nannofossil study for both studied formations to date age, however paleontological study of [10] indicated that the Naokelekan Formation is upper Oxfordian to lower Kimmeridgian. They also stated that the age of the Barsarin Formation is not demonstrated; possibly Kimmeridgian, possibly lower or middle Kimmeridgian (i.e. lower Tithonian). The current study of calcareous nannofossil revealed that the age of the Naokelekan Formation is the Early Tithonian and the age of the Barsarin Formation is the Early- Middle Tithonian; all the other studies depended either on stratigraphic positions or some fossil contents. But here, the age determination is depended on the calcareous nannofossils. The determination of the age is based on the first occurrence of the marker species *Conusphaera mexicana*, since its first appearance is the early Tithonian stage (Zone NTJ15a; 149.09-151.50Ma; Bown and Cooper 1998: *in*[11]) as illustrated in the Fig.(4). The first appearance of this species here was coincided the Sample N11 (Figs.5J and 5L, 6-9), the Sample N11 represents the upper part of the Naokelekan Formation (the lower part of the Naokelekan Formation is considered here to be located at the latest Kimmeridgian stage). The percent abundance of the Fig.9 shows maximum radiation of this species at the Naokelekan Formation (Figs.6-9).

The second species is *Polycostella senaria* (Fig.5M); its first appearance is at Sample B3, which represents the upper part of the Barsarin Formation. This sample represents the middle-late Tithonian, that's Zone NTJ17 (Figs.6-9).The upper part of the Barsarin Formation and its contact with the Chia Gara Formation are still within the Tithonian age since the species of the Early Cretaceous have not determined. Beside, the study of [24] found some nannofossil species within the Chia Gara Formation, which is overlie the Barsarin Formation, such species are *Nannoconus globulus globulus* (Bronnimann), *Cruciellipsis cuvillieri* (Manivit) and *Nannoconus, Wintereri* Bralower and Thierstein and *Nannoconus steinmannii minor* Deres and Acheriteguy. They attributed this assemblage of the Chia Gara Formation to Tithonian-Berriasian (Jurassic/ Cretaceous) boundary.

The third important species is *Nannoconus compressus* (Fig.5K) has a short range in the late Tithonian (145.01-152.06Ma, base in Tithonian stage; [14]). It appeared at the sample N7, which represents the boundary between the Naokelekan and Barsarin Formations (Figs.6-9).These three important marker species indicate the age of the Naokelekan and Barsarin Formations as Tithonian. The samples of the Naokelekan Formation (N7-N12) are dated back to the Early Tithonian and (B1-B6) are dated back to the Early- Middle Tithonian of the late Jurassic.

Conclusion

The preliminary as well as the first study of calcareous nannofossils were done for the Naokelekan and Barsarin Formations within the Miran Oil well (M2). The biostratigraphical zonation of these nannofossils attributed the age of the Early Tithonian to the Naokelekan Formation and the Early- Middle Tithonian for the Barsarin Formation. It was based on the first appearance of some biomarker species such as *Conusphaera mexicana, Polycostella senaria, Nannoconus compressus* and *Helenea staurolithina* that belong to the Early-Middle Tithonian.

Acknowledgments

The authors would like to acknowledge the Ministry of Natural Resources of Kurdistan Regional Government/Iraq to supply the samples for this study.

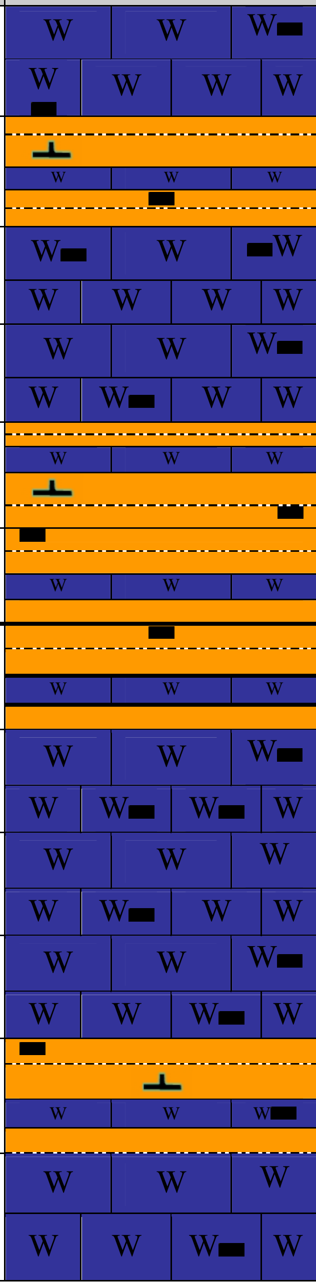
Period	Age	Nanno. Zone	Formation	Sample No.	Depth (m)	Lithology symbol	*Conusphaera mexicana*	*Polycostella senaria*	*Carinolithus magharensis*	*Watznaueria britannica*	*Watznaueria barnesae*	*Parhabdolithus robustus*	*Nannoconus compressus*	*Helenea staurolithina*
Late Jurassic	Tithonian	NJT17	Barsarin	B1	2315		1	2	4	0	4	0	0	0
				B2	2320		3	1	2	0	5	0	0	1
				B3	2325		5	2	18	0	5	1	1	0
		NJT16		B4	2330		5	0	20	2	3	0	0	0
				B5	2335		2	0	4	1	1	0	0	0
				B6	2340		6	0	3	0	2	0	0	0
			Naokelekan	N7	2345		19	0	1	0	4	0	1	0
		NJT15		N8	2350		3	0	0	0	1	0	0	0
				N9	2355		5	0	1	1	3	0	0	0
				N10	2360		16	0	2	0	7	0	0	0
				N11	2365		2	0	0	0	7	1	0	0
	Kimmeridgian	NJT14		N12	2370 2375		0	0	0	0	9	0	0	0

Fig. (6): Calcareous nannofossil zonation chart of the oil well Miran-2-/ numerical

Graphical					
Numerical	N (0)	R (1-3)	M (4-6)	C (7-9)	F(≥10)
Abundance	None	Rare	Moderate	Common	Frequent

Period	Age	Nanno. Zone	Formation	Sample No.	Depth (m)	Lithology symbol	*Conusphaera mexicana*	*Polycostella senaria*	*Carinolithus magharensis*	*Watznaueria britannica*	*Watznaueria barnesae*	*Parhabdolithus robustus*	*Nannoconus compressus*	*Helenea staurolithina*
Late Jurassic	Tithonian	NJT17	**Barsarin**	**B1**	2315		R	R	M	N	M	N	N	N
				B2	2320		R	R	R	N	M	N	N	R
				B3	2325		M	R	F	N	M	R	R	N
		NJT16		**B4**	2330		M	N	F	R	R	N	N	N
				B5	2335		R	N	M	R	R	N	N	N
				B6	2340		M	N	R	N	R	N	N	N
			Naokelekan	**N7**	2345		F	N	R	N	M	N	R	N
		NJT15		**N8**	2350		R	N	N	N	R	N	N	N
				N9	2355		M	N	R	R	R	N	N	N
				N10	2360		F	N	R	N	M	N	N	N
				N11	2365		R	N	N	N	M	R	N	N
	Kimmeridgian	NJT14		**N12**	2370 2375		N	N	N	N	N	N	N	N

Fig. (7): Calcareous nannofossil zonation chart of the oil well Miran-2-/ numerical

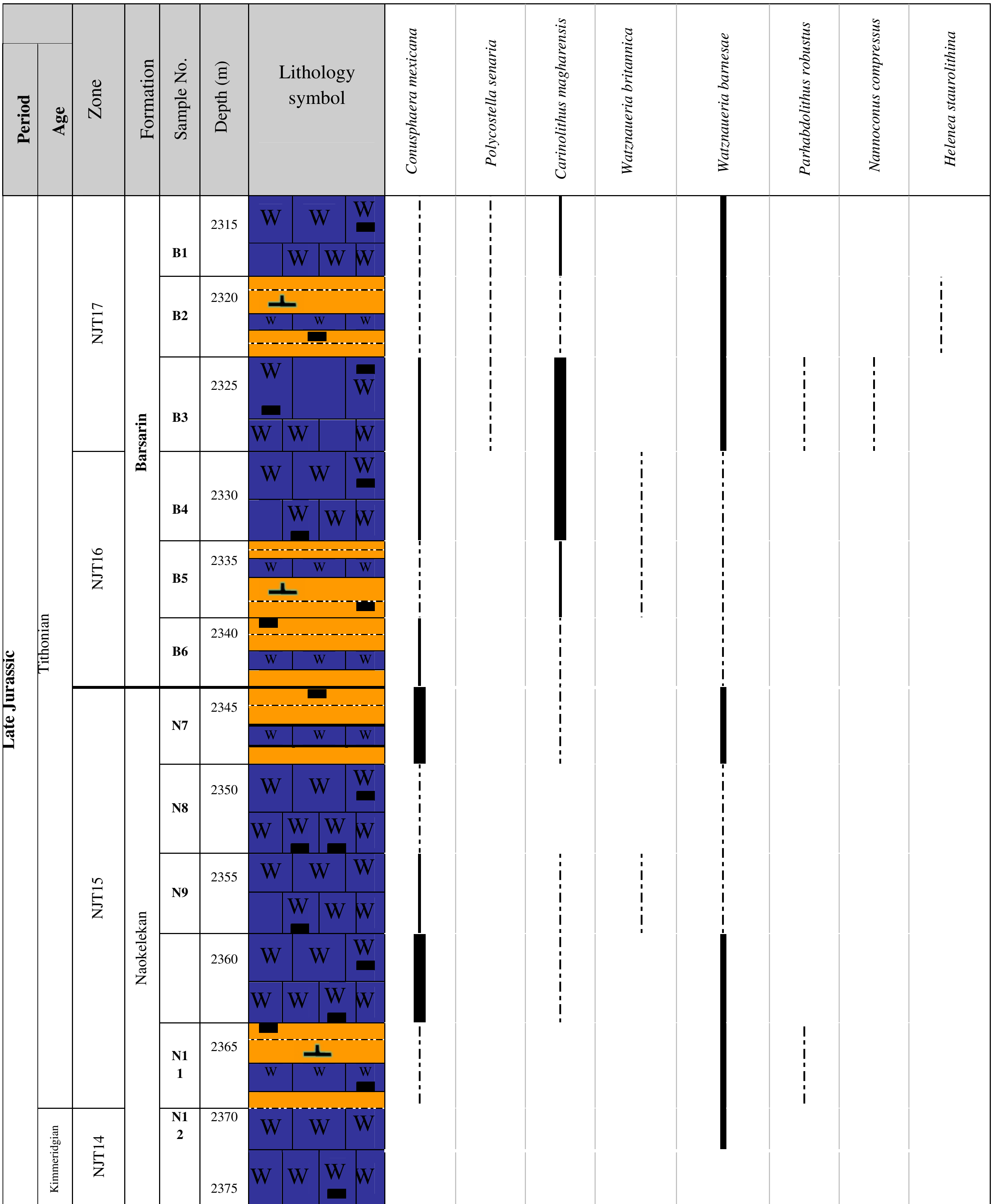


Fig. (8): Calcareous nannofossil zonation chart of the oil well Miran-2-/ graphical

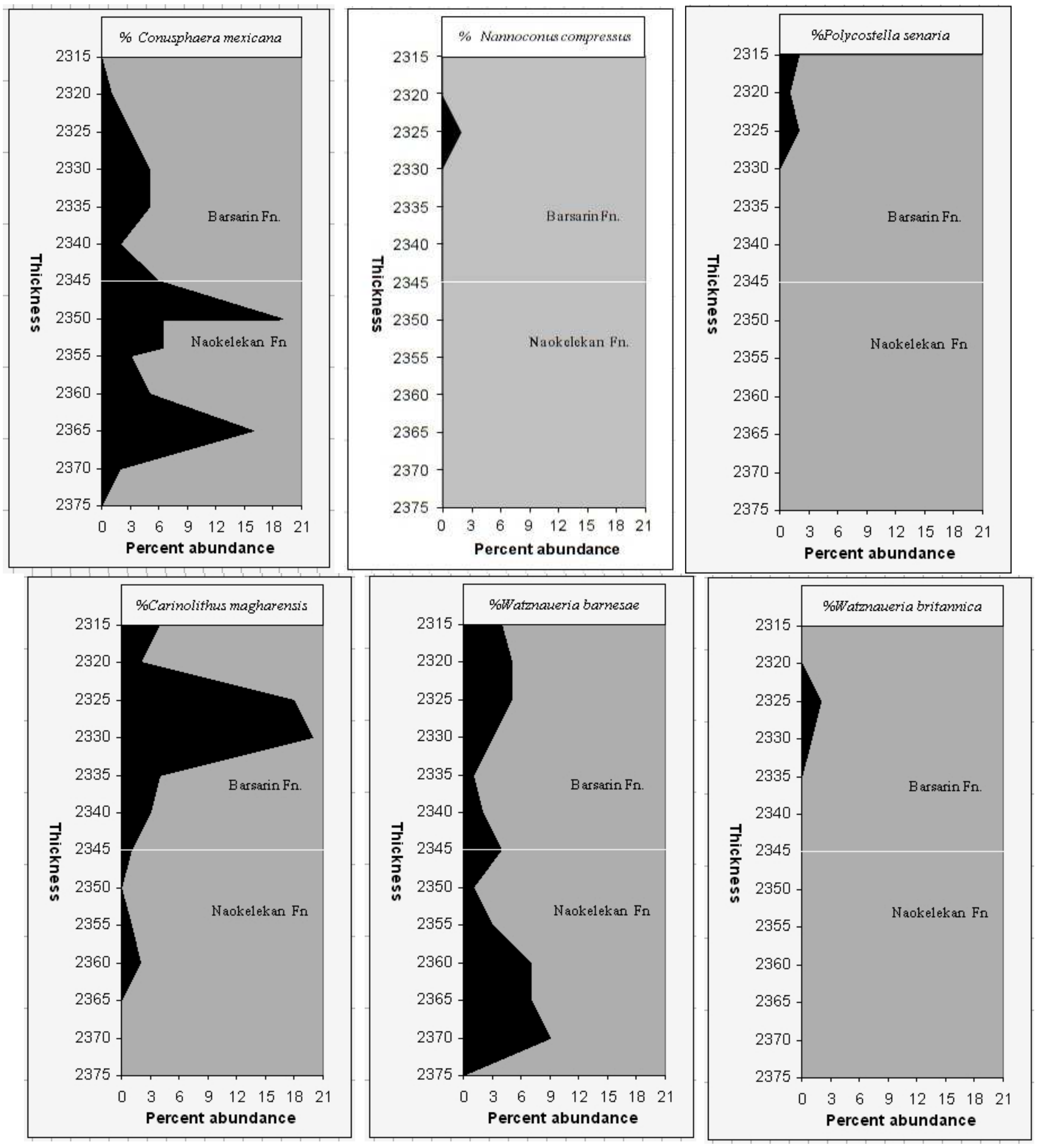


Fig.(9): Percent abundance of selected individual nannofossil species of the Kimmeridgian-Tithonian of the Miran oil well-2- between intervals 2375-22315m.

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