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Biozonation (benthic foraminifera) of Mishrif Formation at Majnoon and Zubair oil fields, southern Iraq

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Abstract: The Mishrif Formation represents a carbonate succession that deposited in major parts of the Arabian Plate during the Cenomanian stage. The formation is rich in fossils including foraminifera, rudists, and algae. This study includes determination of the biozones and biostratigraphic limits of three boreholes sections of Mishrif Formation (Cenomanian) from Majnoon and Zubair oil fields in southern Iraq within the Mesopotamian Basin. A new biostratigraphic scheme is introduced based on the study of benthic foraminifera that occur in the complete succession of Mishrif Formation. Depending on the vertical distribution of benthic foraminifera, four biozones in the studied sections have been established, they include: 1 - Miliolids Abundance Biozone that is characterized by the first appearance of miliolids to first appearance of *Nezzazata conica*, and include rudist, gastropoda, pelecypoda and algae, 2 - *Nezzazata simplex – Nezzazata conica* Concurrent Biozone (Middle Cenomanian) is distinguished by the first appearance of *Nezzazata simplex, Nezzazata conica, Praealveolina cretacea*, and *Pseudorhapydionia laurinensis*. Other associated benthic foraminifera include *Nezzazata concave*, *Praealveolina tenuis, Chrysalidina* sp., *Cuneolina pavonia*, *Multispirina iranica*, *Biconcava bentori*, *Qataria dukhani*, *Dicyclina schlumbergari*, *Tabrina beingstani*, *Cisalveolina* sp., and *Carinoconus iraqiensis.* 3 - *Pseudorhapydionian laurinensis – Praealveolina cretacea* Concurrent Biozone (Early Late Cenomanian) is identified by the last occurrence of *Nezzazata simplex* with the first occurrence of *Psudorhapydionian laurinensis*, and *Praealveoilina cretacea,* and the last occurrence of both taxa. This biozone also shows the occurrence of *Cisalveolina fallax, Tabarian bingstani, Carinoconus iraqiensis, Spiroloculina* sp., *Chrysalidina gradata, Biconcava bentori, Qataria dukhani, Pseudotexularella* sp., and *Dicyclina schlumbergari.* 4 - *Pseudolituonella reicheli-Chrysalidina gradata* Concurrent Biozone (Latest Cenomanian) is marked by the first and last occurrence of *Pseudolituonella reicheli* and *Chrysalidina gradate.* Other diagnosed foraminifera include: *Spiroloculina* sp., *Rotalia* sp., *Pseudorhapydionia* sp., *Quinquelaculina* sp., *Nummulculina heimi,* and *Discorbis* sp. Based on the stratigraphic ranges of the available fossils of the studied sections, the age of Mishrif Formation is estimated to be of Middle-latest Cenomanian.

Keywords: Iraq, Mishrif Formation, Cenomanian, foraminifera

INTRODUCTION

The Cenomanian-Early Turonian Mishrif Formation is one of the most significant carbonate reservoirs in Iraq and the Middle East (Al-Sharhan, 1995; Aqrawi *et al.,* 2010; Mahdi & Aqrawi, 2014).

Many researchers have focused and interpreted the biostratigraphy, sequence stratigraphy and reservoir quality of Mishrif Formation as follow: Rabanit, 1952; Owen & Naser, 1958; Chatton & Hart, 1961; James & Wynd, 1965; Al-Naqib, 1967; Elf. Iraq company, 1970; Gaddo, 1971; Al-Khersan, 1975; Al-Siddiki, 1978; Agip company, 1980; Thomas, 1980; Reulat, 1982; Belarabi, 1982; Sherwani, 1983; Al-Nuaimy, 1990; Al-Jumaily, 2001; Mahdi, 2004; Al-Dulaimi, 2011; Al-Dulaimy & Al-Sheikhly, 2013; Mahdi & Aqrawi, 2014 and Ya Deng *et al.,* 2016.

Based on the distribution of benthonic and planktonic foraminifera, Brun *et al.* (1975) established a biostratigraphic zonation scheme in Buzurgan, Faqa, and Abu Ghurab oilfields, which are located in the north of Majnoon oil field. The biostratigraphic scheme includes three major zones as follow (from bottom to top):

1 - *Hedbergella gr. washitensis* zone: The upper limit of this zone represents the last appearance of *Hedbergella gr. washitensis.* The zone occupies the bottom of Mishrif Formation. Therefore, the lower limit of this zone extends towards Rumaila Formation. Other associated fauna include *Oligostegina, Hedbergella* sp. and *Asterohedbergella asterospinosa*. According to Brun *et al.* (1975), a Middle Cenomanian age is assigned to this zone.

2 - *Praealveolina gr. cretacea* zone: This zone represents a large and important biostratigraphic unit in the Mishrif Formation. The lower limit falls within the first occurrence of *Praealveolina cretacea*. It coincides with the lower boundary of the Mishrif Formation where the *Hedbergella gr. washitensis* is absent in some wells. This large zone is divided into two subzones. The lower one is characterized by the occurrence of *Ovalveolina* sp. and *Neoiraqia convexa.* The upper subzone is mainly

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made up of the following assemblages: *Praealveolina gr. cretacea*, *Pseudotextulariella* IRK sp2, *Cyclodomia iranica*, *Pseudocyclammina rugosa*, *Discorbis* IRK sp2. Brun *et al.* (1975) assigned a Middle-Late Cenomanian age to this zone.

3 - *Dicyclina schlumbergeri-Cisalveolina* spp. zone: It is characterized by the association of *Dicyclina schlumbergi* and *Cisalveolina* spp. A Late Cenomanian-Early Turonian age is considered for this zone by Brun *et al.* (1975).

The lithology of Mishrif Formation at the studied sections is characterized by gray-brown limestone with pelecypod and gastropod shells, with high occurrence of foraminiferal limestone and rudist debris. The formation is variably dolomitized.

The contacts of the formation are conformable both with the underlying Rumaila Formation and overlying Khasib Formation.

The formation is equivalent to the upper part of the Magwa Formation (the Mishrif Fm.) in Kuwait, to the Sarvak Formation in the Zagros Iran, to the lower part of Judea Formation in the central and northeast Syria, and to Mardin Formation in southeast Turkey (Jassim & Goff, 2006).

STUDY AREA

The study area is located in the south of Iraq, and it includes two oil fields, Majnoon and Zubair (Figure 1), the Majnoon oil field is located about 60 km northwest of Basra city and the Zubair oil field is located about 20 km south of Basra city.

METHODS AND MATERIALS

In order to determine the biostratigraphy of Cenomanian-Turonian strata in southern Iraq, three borehole sections of Mishrif Formation were selected, which are named: Majnoon-2 (MJ-2), Zubair-43 (ZB-43) and 47 (ZB-47) (Figure 1).

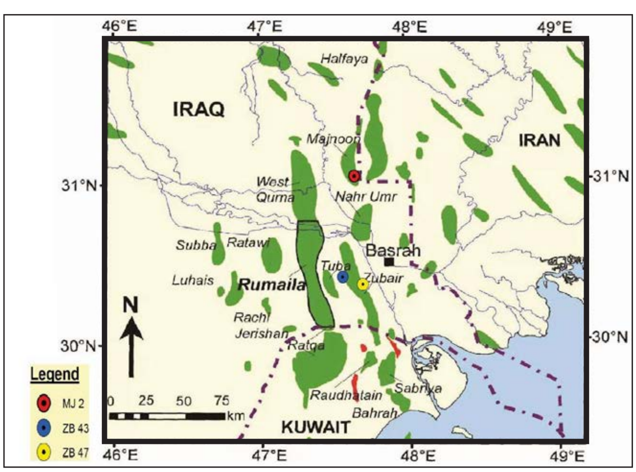

Figure 1: Location map of the studied area showing wells Majnoon-2, Zubair-43 and 47, southern Iraq, Basra district (modified from Iraq National Oil Company, INOC).

Different cores were sampled for micropaleontology and petrographic study. A total of 90 samples were collected from the three sections and 150 thin sections were prepared from the core samples in the laboratory. Microscopic study was provided in Baghdad University, College of Science, Department of Geology. The biozones of Mishrif Formation is determined according to the vertical distribution of benthic foraminifera.

Ultimately, the biozones distribution was compared to previous works and other biostratigraphic studies of Tethyan realm (e.g., Al-Khersan, 1975; Bernaus & Masse, 2006; Al-Dulaimy & Al-Sheikhly, 2013).

GEOLOGICAL SETTING

Majnoon and Zubair oilfields are located in the southern Mesopotamian Basin, where more than 3000 m of Cretaceous sediments were deposited under the influence of tectonic, eustatic and climatic controls (Sadooni & Aqrawi, 2000). The Mesopotamian basin is subdivided into tectonic subzones, which are characterized by structural highs and lows with different trends. The structures are formed by the deformation of the northeastern Tethyan margin of the Arabian Plate during Cenomanian–Early Turonian (Jassim & Goff, 2006).

During the Cretaceous, the basin was part of a widespread carbonate platform located on the NE passive margin of the Arabian Plate (Murris, 1980). This margin was characterized by shallow, warm waters of Neo-Tethys (Sharland *et al.*, 2001). During the Middle Cenomanian-Turonian period sea-level changes together with regional tectonic deformation of the Arabian Platform controlled the availability of accommodation space and therefore the depositional profile during development of Late Cretaceous sequence. These factors planned the maximum flooding surfaces and sequence boundaries which have been identified (Sharland *et al.*, 2001; Farzadi, 2006).

The sediments were deposited on platforms within an inner shelf basin on the passive margin of the Arabian Plate (Ziegler, 2001). High organic accumulations with rich carbonate deposits controlling the growth and development of many positive elements and structures such as Mishrif, Ahmadi, and Rumaila formations were built-up as result of these changes (Van Buchem *et al.*, 2002).

The shallow depositional conditions are dominant in Majnoon oil field, where thick lagoonal successions were deposited indicating higher accommodation space in the eastern part of the Mesopotamian Basin. At Zubair oil field, the deposition of Mishrif Formation was affected by tectonic activity as demonstrated by growth of rudist biostromes and shoal facies along crestal parts of Zubair structure, in addition to the presence of forced regressive succession at the uppermost part of Mishrif Formation (Mahdi *et al.*, 2013; Mahdi & Aqrawi, 2014).

The carbonate production in the Mesopotamian basin resulted in thick succession of pelagic basinal facies to reefal and foraminiferal-rich shelf facies. The Mishrif Formation (Middle Cenomanian-Early Turonian) has carbonate sequence sediments rich in rudists, algal, coral reef, and benthonic foraminifera formed above structure within the Mesopotamian basin (Ziegler, 2001). The type section of Mishrif Formation occurs in well Zubair-3 (at Zubair oil field), which was selected by Rabanit (1952). In this well, the Mishrif Formation was subdivided into the following lithologic units (from bottom to top):

1 Unit G: Algal (Permocalculus) limestone with miliolids, *Begia* sp., *Cisalveolina* sp. foraminifera.
2 Unit F: Limestone, porous, oil stained, leached out fossils, contain calcite veins, miliolids, *Begia* sp., *Cisalveolina* sp., *Dicyclina* sp., *Taberina* sp., *Praealveolina* sp.
3 Unit E: Marl, locally chalky.
4 Unit D (lower): Limestone, porous, partly very shelly and foraminiferal, contains bands of rudists; foraminifera include *Cisalveolina* sp., *Begia* sp., *Dicyclina* sp., *Dictyoconus* sp., and miliolids.
5 Unit D (upper): Limestone, dense, detrital, with gastropods, rotalids, sponge spicules, partly pseudo-oolitic, rare chalky streaks and green shale interbeds.
6 Unit C: Marl, algal (Permocalculus), with green-black shale.
7 Unit B: Limestone, fine grained, fractured or stylolized, marly, partly pseudo-oolitic, microbrecciated with streaks of marl at base.
8 Uppermost unit: Limestone, fine grained, limonitic, freshwater with charophytes, marl; interbedded with black shale.

The depositional environments for the Mishrif have wide range starting with fresh water in the upper Mishrif to the deep marine environment at the lower Mishrif (Aqrawi *et al.*, 2010). The carbonate facies of the formation reflect various depositional environments including deep marine, shallow open marine, rudist biostrome, shoal, back-shoal, lagoon, and tidal flat (Mahdi *et al.*, 2013; Mahdi & Aqrawi, 2014). The benthic foraminifera in lagoonal facies are diverse, including miliolids, alveolinids, textularids, and Nezzazata. The abundance of these fauna and their association with mud-supported facies indicate low-energy conditions below wave base in the subtidal zone (Mahdi *et al.*, 2013).

The rudist facies passes into deeper water open-marine facies, near Luhais, Ratawi and Afaq (Al-Khersan, 1975) and also from Majnoon and Buzurgan fields. Similar facies are present all around the northern end of the Gulf (Ziegler, 2001). The beginning of sea withdrawal is represented by an extensive evaporate pan, Kifl Formation, in response to the epiorogenic movements which acted through Cenomanian-Turonian time span producing a subaerial unconformity (Melhi & Diah, 1984).

The lower boundary of the Mishrif Formation is represented by the change from the basinal Rumaila Formation to the shallow open marine. The upper boundary with the Khasib Formation is truncated by an unconformity surface separating the Middle from Late Cretaceous. Chatton & Hart (1961), Al-Sayyab (1984) and Ziegler (2001) suggested that the upper unconformable boundary of the formation represents the end of the Cenomanian-Turonian cycle. The overlying Khasib Formation represents transgressive, basinal Upper Turonian–Coniacian succession in Iraq (Dunnington, in van Bellen *et al.*, 1959-2005; Darmoian, 1975). Evidence of exposure and erosion along the Mishrif-Khasib boundary include the occurrence of karstic conglomerates and breccias, extensive dissolution and cement zones, and fresh-water algal limestones (e.g. Al-Khersan, 1973; Al-Siddiki, 1978; Sadooni, 2005; Mahdi *et al.*, 2013). The same contact represents the upper boundary of the middle Cretaceous Wasia Group, which has a regional extent and reported throughout the Arabian Plate, and resulted from tectonic uplift and Mid-Turonian eustatic sea-level fall (Sharland *et al.*, 2001). In central parts of the Mesopotamian Basin, this boundary of is conformable with the overlying Kifl Evaporite Formation (Turonian) (Al-Naqib, 1967).

The Austrian orogeny caused the beginning of sea regression represent by an extensive of evaporate sediments pan (Kifl Formation) which is response to the epiorogenic movements acted through the Cenomanian-Turonian period leading to a subaerial unconformity (Melhi & Diah, 1984). This lead to decreasing the rate of subsidence and developed the maximum sea level fall.

During the deposition of Mishrif Formation, the palaeogeography of the Mesopotamian Basin was characterized by two high energy margins, where rudist biostromes were developed (Aqrawi *et al.*, 2010). These margins rimmed an intrashelf basin, which was dominated by mud-rich facies, and has been referred to as the Najaf Basin (Aqrawi *et al.*, 2010).

BIOSTRATIGRAPHY

The vertical distribution of identified benthonic foraminifera of the stratigraphic study of the Mishrif Formation supports four biozones for the studied sections. Detailed biostratigraphical study of these biozones is shown as follow:

Biozone no. 1 (miliolids abundance biozone)

This biozone is investigated from the base of the Mishrif Formation which ranged 5-11 meters in thickness (Figures 2, 3 and 4). It is characterized by high occurrence of miliolids wackestone-packestone with fragments of rudist, gastropoda, pelecypoda and algal remains. Miliolids biozone is marked by the first appearance of miliolids to first appearance of *Nezzazata conica*, *N. concava* (Plate 3, A) and other benthic foraminifera.

Biozone no. 2 (*Nezzazata simplex – Nezzazata conica* concurrent biozone)

The lithology aspect of this biozone is comprised of light to dark gray thick to medium-bedded limestone. It

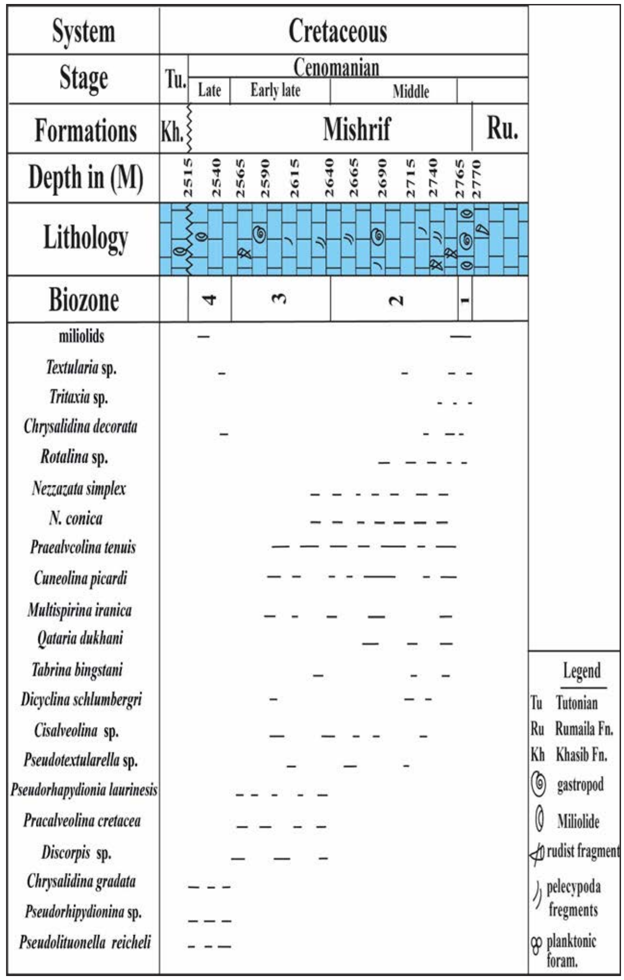

Figure 2: Biostratigraphy of the Cenomanian succession of Mishrif Formation at Majnoon well-2.

is characterized by rudist bioclast to bioclast packstone-grainstone with algal, Mollusca fragments. The thickness of this biozone is illustrated in Figures 2, 3 and 4, which extended over the miliolids biozone.

The biozone *Nezzazata simplex – Nezzazata conica* is recognizable in the middle portion of these sections and is marked by the first appearance of *Nezzazata simplex* (Plate 1, F) and Plate 2, D) and *Nezzazata conica* and the first appearance of *Praealveolina cretacea* (Plate 2, E&F) and *Pseudorhapydionia laurinensis* (Plate 3, H).

Common foraminifera of this biozone consist of *Nezzazata concave* (Plate 3, A), *Preneroplise* sp., *Praealveolina tenuis, Chrysalidina* sp., *Cuneolina pavonia, Nezzazata* sp. (Plate 1, H), *Nezzaztinella picardi* (Plate 1,G), *Multispirina iranica* (Plate 1,C), *Biconcava bentori, Qataria dukhani* (Plate 1, A), *Dicyclina schlumbergari* (Plate 1, D), *Tabrina beingstani, Cisalveolina* sp. (Plate 3, E), and *Cisalveoina fallax* in the three sections including recording of *Carinoconus iraqiensis* from well Zb-47.

Nezzazata simplex and *Nazzazata conica* have been recorded before from middle Cenomanian sequence of some parts of middle east (Iran, Turkey, Egypt and Jordan) by many researchers (e.g., Husinec *et al.*, 2000; Schulze *et al.*, 2005; Shahin, 2007; Sari *et al.*, 2009; Filkorn & Scott, 2011; Orabi *et al.*, 2012; Ghanem & Kuss, 2013; Afghah & Fadaei, 2014; Orabi & Hamad, 2018). Velić & Vlahovic (1994) documented the above taxa from Croatia.

Filkorn & Scott, 2011; Orabi *et al.*, 2012; Ghanem & Kuss, 2013; Afghah & Fadaei, 2014 and Orabi & Hamad, 2018 documented the *Nezzazata simplex*, *N. conica*, *Cuneolina* Cenomanian sequence. Husinec (2000) reported *Daxia cermana* and *Nezzazata simplex* from Cenomanian succession of southwestern Sinai (Egypt) (Afghah & Fadaei, 2014), and documented range of these taxa from lower to middle Cenomanian.

Tasli *et al.* (2005) suggested *Biconcava bentori* and *Pseudorhapydoinina dubia* as biozone for Middle and Upper Cenomanian strata of south Turkey. Velić (2007) recorded similar biostratigraphic data from Karst Dinaridos south east Europe. Ghanem & Kuss (2013) have documented *Pseudorhipidionia casertana* from Middle Cenomanian *Chrysalidina gradata* partial range zone of Northwest Syria (Orabi & Hamad, 2018).

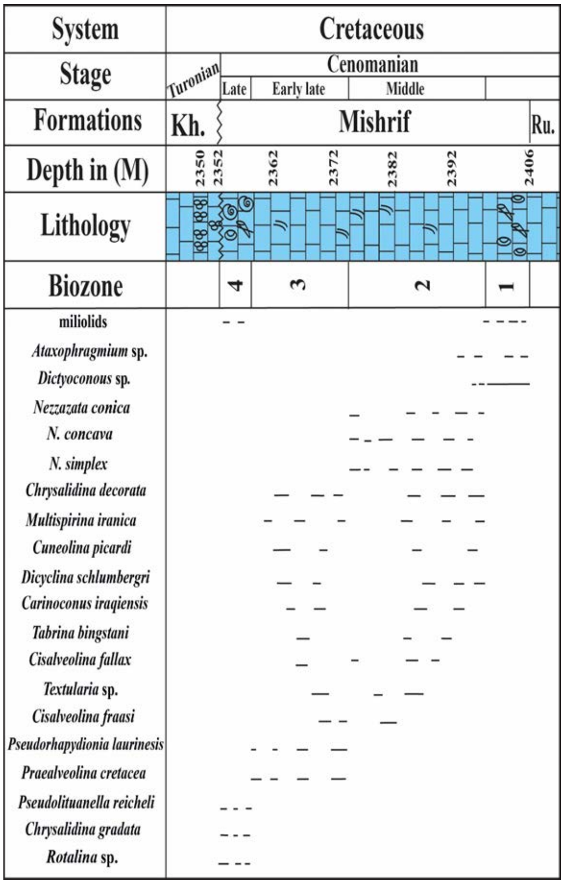

Figure 3: Biostratigraphy of the Cenomanian succession of Mishrif Formation at Zubair well 43.

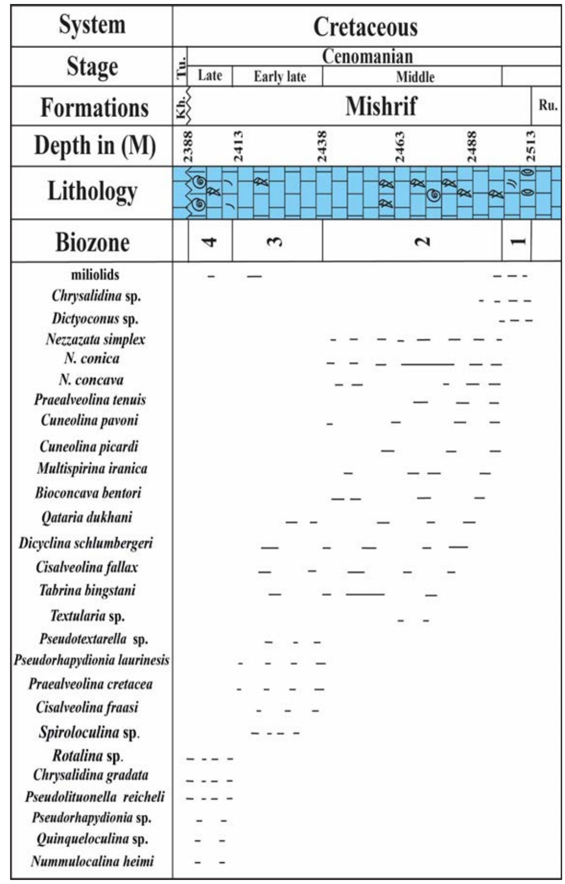

Figure 4: Biostratigraphy of the Cenomanian succession of Mishrif Formation at Zubair well 47.

Orabi & Hamad (2018) determined several benthic taxa were comparable with Middle Cenomanian *Psededomia drorimensis* rang zone of Ogg (2004), among those, *Nezzazatinella picardi*, *Nezzazata simplex*, *Praealveolina tenuis* and *Cuneolina pavonia.*

Hamaoui (1965; 1966) illustrated the last occurrence of *Thomasinella* recorded in Middle Cenomanian age from Israel deposit. Weidich & Al-Harithi (1990) recorded the presence of *Thomasinella punica* in Jordan sediments indicating Middle Cenomanian (Orabi & Hamad, 2018).

Afghah & Fadaei (2014) determined the *Nezzazata conica, Chrysalidina* Assemblage zone as Middle Cenomanian age in south west Iran. Afghah & Fadaei (2014) confirmed *Nezzazata conica - Nezzazata simplex* Assemblage Zone Middle Cenomanian in Zagros area from Iran. Aguilera–Franco (2003) documented *Nezzazata conica* from Cenomanian sequence of southern México. Sari *et al.* (2009) recorded the *Nezzazata conica* as Middle to Upper Cenomanian sequence in the southwestern area of Turkey. Various recording of *Nezzazata simplex* taxon range zone have been documented in the Middle to Late Cenomanian strata of south west Turkey. Bernaus & Masse (2006) recorded the new species *Carinoconus iraqiensis* sp. associated with *Praealveolina cretacea* as indicator for Middle Cenomanian in southern of Iraq.

According to Al-Naqib, 1967; Gaddo, 1971 and Brun *et al.*, 1975 the occurrence of *Nezzazata simplex* is an indicator for Early Cenomanian – Late Cenomanian deposits at southern Iraq. El-Naggar & Al-Rifaiy (1973) suggested the age of the Mishrif Formation of southern Iraq as Late Cenomanian depending on *Praealveolina tenuis* and documented the *Biconcava bentori* as an indicator for Cenomanian – Turonian in southern Iraq. Al-Dulaimy & Al-Sheikhly (2013) determined the age of the Mishrif Formation in southern Iraq as Cenomanian – Early Turonian depending on *Nezzazata simplex, Parealveolina tenuis, Biconcava bentori* and *Cisalveoina fallax.*

Likewise, biostratigraphic data on *Nezzazata simplex* and *Nezzazata conica* are acceptable proof for the assignment of Middle Cenomanian age of this Zone.

Biozone no. 3 (*Pseudorhapydionian laurinensis, Praealveoilina cretacea* concurrent biozone)

This zone is characterized by grey medium bedded of thick bedded rudist limestone with fragments of bivalve, gastropod and ostracod. The thickness of this biozone is illustrated in Figures 2, 3 and 4.

This zone shows the last occurrence of *Nezzazata simplex* corresponding with first occurrence of *Psudorhapydionian*

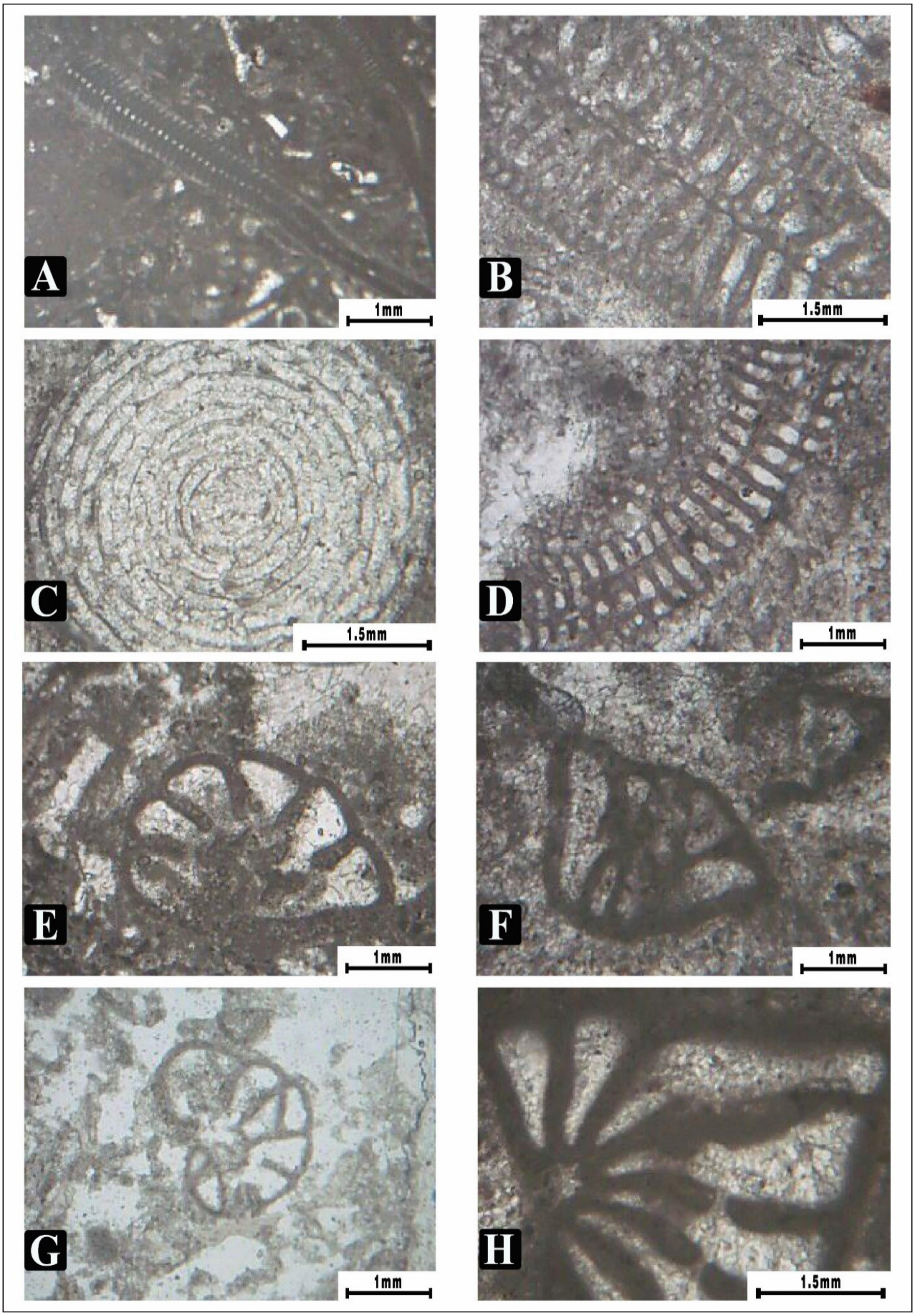

Plate 1: (A) *Qataria dukhani*, (B) *Pseudotexularella* sp., (C) *Multispirina iranica*, (D) *Dicyclina schlumbergri*, (E) *Nezzazatinella picardi*, (F) *Nezzazata simplex*, (G) *Nezzazatinella picardi*, (H) *Nezzazata* sp.

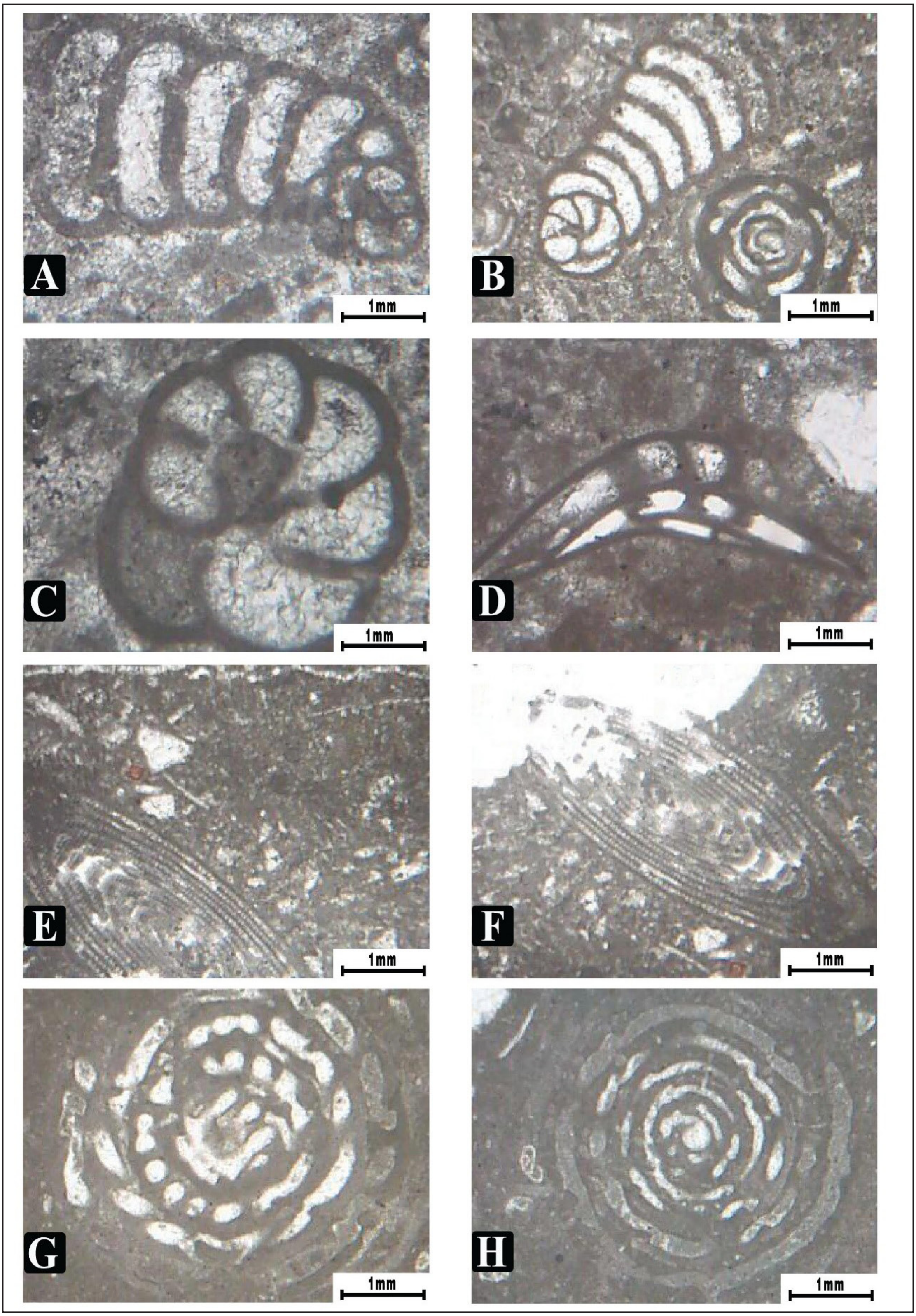

Plate 2: (A&B) *Pseudolituonella reicheli*, (C) *Nezzazatinella picardi*, (D) *Nezzazata simplex*, (E&F) *Praealveolina cretacea*, (G&H) *Nummulocalina heimi*.

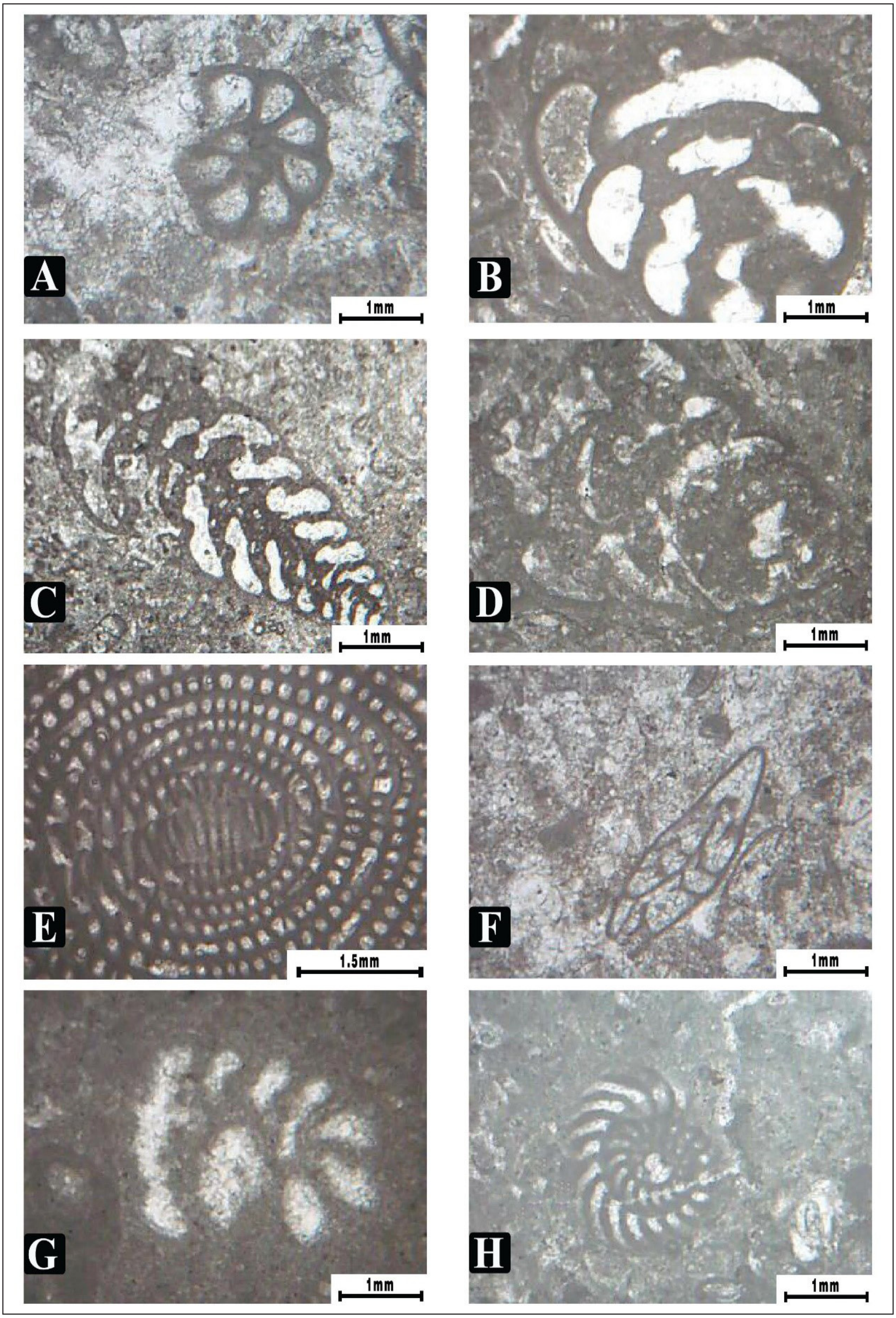

Plate 3: (A) *Nezzazata concava*, (B, C&D) *Chrysalidina gradata*, (E) *Cisalveolina* sp., (F) *Nezzazata simplex*, (G) *Nezzazatinella picardi*, (H) *Pseudorhapydionia laurinensis*.

laurinensis (Plate 3, H), and *Praealveoilina cretacea* (Plate 2, E&F) and the last occurrence of the two taxa. The investigated foraminifera association of this biozone include: *Cisalveolina fallax, Tabarian bingstani, Carinoconus iraqiensis, Spiroloculina* sp., *Rotalia* sp., *Chrysalidina gradata* (Plate 3, B, C&D), *Biconcava bentori, Qataria dukhani, Pseudotexularella* sp. (Plate 1, B), and *Dicyclina schlumbergari.*

The *Praealveoilina cretacea* is an index for Late Cenomanian of Egypt (Orabi & Hamad, 2018). Ghanem & Kuss (2013) documented the first occurrence of *Praealveolina cretacea* as indicator for Upper Cenomanian of the Northwest Syria.

Velić (2007) described *Psudorhapydionian laurinensis, Cisalveolina fraasi* and *Pseudorhapydionia casertana* from the Upper Cenomanian deposits in southeastern Europe. Afghah & Fadaei (2014) recorded the *Nezzazata concave* and *Praealveolina cretacea* Assemblage zone as a Late Cenomanian age in south Zagros Iran. Bender (1974) and Dilley (1985) distinguished the *Praealveolian cretacea* from the Late Cenomanian sequence of Jordan. Schroeder & Neumann (1985) mentioned that the presence of *Praealveolian cretacea* and *Chrysalidina gradata* indicate the middle – Late Cenomanian age in Mediterranean area.

Al-Dulaimy & Al-Sheikhly (2013) recorded the occurrence of *Praealveolian cretacea* from the Cenomanian – Early Turonian deposit in southern Iraq.

According to the foraminiferal constituent of this biozone, its age is Early Late Cenomanian.

Biozone no. 4 (*Pseudolituonella reicheli, Chrysalidina gradata* concurrent biozone)

Generally, this biozone is characterized by medium to thick bedded dark gray limestone with bivalve fragments, ostracod, few rudist fragments and miliolids (Figures 2, 3 and 4).

This biozone of the three sections is marked by the first occurrence of *Pseudolituonella reicheli* (Plate 2, A&B) and *Chrysalidina gradata* and the last occurrence of these taxa. The thickness of this zone illustrated in Figures 2, 3 and 4. The diagnosed foraminifera of this zone include: *Spiroloculina* sp., *Rotalia* sp., *Pseudorhapydionia* sp., *Quinquelaculina* sp., *Nummulculina heimi* (Plate 2, G&H), and *Discorbis* sp.

Guŝić *et al.,* 1988; Fucek *et al.,* 1990*;* Guŝić & Jelaska, 1990; Velić & Vlahovic, 1994; Husinec *et al.,* 2000; Korbar *et al.,* 2001 and Afghah & Fadaei, 2014 documented the *Chrysalidina gradata* from the Late Cenomanian of different localities.

Velić (2007) recognized the *Chrysalidina gradata* from Middle and Upper Cenomanian deposit in Southeastern Europe. In Turkey the Cenomanian – Turonian boundary is recognized by last occurrence of *Chrysalidina gradata* and *Pseudolituonella recheli* (Sari *et al.,* 2004).

Brčić *et al.* (2017) determined the middle to late Cenomanian age of Milna Formation by the presence of benthic foraminifera that include Broekina (*Pastrikella*) *balcanica* Cherchi *et al.*, *Chrysalidina gradata* D'orbigny, *Pseudorpydionin dubia*, *Vidalina radoicicae*.

Al-Jumaily (2001) recorded the *Chrysalidina gradata* and *Pseudolituonella reicheli* as Upper Cenomanian from southern Iraq. In present study this zone indicates a Late Cenomanian age according to foraminifera constituents.

CONCLUSIONS

Previous studies assigned a Cenomanian-Early Turonian age for Mishrif Formation, while the current study shows that the age of the formation is Middle-late late Cenomanian, which indicates the absence of Turonian succession in the study area as evidenced by the absence of benthic foraminifera and occurrence of planktonic foraminifera in their place that belong to Khasib Formation. This is due to the truncation of Turonian biostratigraphic zones by erosion, and therefore most of Turonian successions are absent in the eastern Arabian Plate region (Harris *et al.,*1984). During Turonian, the erosion process lasted several million years in the Arabian Plate (Scott, 1990), and it is related to tectonic activity and a global eustatic fall in sea level (Sharland *et al.,* 2001). The effect of these events is recorder in the uppermost part of Mishrif Formation in Majnoon and Zubair oil fields (Mahdi *et al.*, 2013; Mahdi & Aqrawi, 2014).

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AUTHOR CONTRIBUTIONS

SIMA and YKI carried out the identification of foraminifera and biostratigraphic interpretation. Writing original draft, editing, and reviewing were done by FTA.

CONFLICT OF INTEREST

The authors have no conflicts of interest to declare that are relevant to the content of this article.

REFERENCE

Afghah, M. & Fadaei, H.R., 2014. Biostratigraphy of Cenomanian succession in Zagros area, south west of Iran. Geosciences Journal, 19, 257–271.

Agip, 1980. Halfaya field, petrographic and sedimentlogical study of the Mishrif Formation. OEC Library, Baghdad. Unpublished report.

Aguilera-Franco, N., 2003. Cenomanian–Coniacian zonation (foraminifers and calcareous algae) in the Guerrero-Morelos basin, Southern Mexico. Revista Mexicana de Ciencias Geological, 20, 202–222.

Al-Dulaimi, S.I., 2011. Upper Cretaceous rudist reef and associated microfossils of Aqra Formation / northern Iraq. Unpublished Ph.D. thesis, University of Baghdad, Iraq. 113 p.

Al-Dulaimy, R.T. & Al-Sheikhly, S.S., 2013. Biostratigraphy of Mishrif Formation from well Amarah-1 southwestern Iraq. Iraqi Bull. Geol. Mining, 9, 1-14.

Al-Jumaily, S., 2001. Facies and depositional environment of the Mishrif Formation in selected oilfields, S. Iraq. PhD thesis, Baghdad University, Iraq. (In Arabic).

Al-Khersan, H.F., 1973. Mishrif Formation-Regional study. INOC Library, Baghdad. 82 p. (Unpublished report)

Al-Khersan, H.F., 1975. Depositional environments and geologic history of the Mishrif Formation in southern Iraq. Ninth Arab Petroleum Congress, Dubai, Paper 121 (B-3). 18 p.

Al-Naqib, K.M., 1967. Geology of the Arabian Peninsula - southwestern Iraq. United States Geological Survey Professional Paper, 560-G, 1-54.

Al-Nuaimy, K.M., 1990. Study of large foraminifera in Middle Cretaceous (Albian-Cenomanian) of Iraq. University of Baghdad, Iraq. Unpublished Ph.D. thesis.

Al-Sayyab, A.S., 1984. Paleoenvironment and biostratigraphy, for fourth classes. College of Science, University of Baghdad, Iraq. 561 p.

Al-Sharhan, A.S., 1995. Facies variation, diagenesis and exploration potential of the Cretaceous rudist-bearing carbonates of the Arabian Gulf. AAPG Bulletin, 79, 531-550.

Al-Siddiqi, A.A.M., 1978. Subsurface geology of southeastern Iraq. 10th Arab. Pet. Cong., Tripoli – Libya, paper No. 141 (b-3). 47 p.

Aqrawi, A.A.M., Goff, J.C., Horbury, A.D. & Sadooni, F.N., 2010. The Petroleum Geology of Iraq. Scientific Press, Beaconsfield, Bucks, UK. 424 p.

Belarabi, I., 1982. Sedimentary environment and distribution of facies in Mishrif Formation, southern Iraq. Unpublished M.Sc. thesis, University of Baghdad, Iraq. 82 p. (in Arabic).

Bender, F., 1974. Geology of Jordan. Borntraeger, Berlin. 196 p.

Bernaus, J.M. & Masse, P., 2006. *Carinoconus iraqiensis* (Foraminifera), a new orbitolinid from the Cenomanian Mishrif Formation of the oil fields of southeastern Iraq. Micropaleontology, 52(5), 471-476.

Brčić, V., Glumac, B., Fuček, L., Grizelj, A., Horvat, M., Posilović, H. & Mišur, I., 2017. The Cenomanian–Turonian boundary in the northwestern part of the Adriatic Carbonate Platform (Ćićarija Mtn., Istria, Croatia): characteristics and implications. Facies, 63. Article 17.

Brun, J.A., Grosdidier, E. & Reulet, J., 1975. Sedimentological and micropaleontological study of Fauqi no. 1 well. OEC Central Laboratories (unpublished report).

Chatton, M. & Hart, E., 1961. Revision of the Tithonian to Albian of Iraq. IPC Report no. 1/141, INOC Library, Baghdad.

Darmoian, S., 1975. Stratigraphy and micropaleontology of the upper Cretaceous Aruma Supergroup, southwestern Iraq. Journal of the Geological Society Special Issue, 89-116.

Dilley, F.C., 1985. Cretaceous correlations in the Hamza Wells 1-5. National Resources Authority Palaeontological Report 6, Amman, Jordan. 62 p.

Elf-Iraq, 1970. Sedimentlogical study of the Mishrif reservoir, Buzurgan no. 2 well. INOC Library, Baghdad. (Unpublished report).

El-Naggar, Z.R. & Al-Rifaiy, I.A., 1973. Stratigraphy and microfacies of the type Magwa Formation of Kuwait, Arabia: Part 2: Mishrif Limestone Member. American Association of Petroleum Geologists Bulletin, 57, 2263–2279.

Farzadi, P., 2006. The development of Middle Cretaceous carbonate platforms, Persian Gulf, Iran: Constraints from seismic stratigraphy, well and biostratigraphy. Petroleum Geoscience, 12, 59-68.

Filkorn, H.F. & Scott, R.W., 2011. Microfossils, paleoenvironments and biostratigraphy of the Mal Paso Formation (Cretaceous, upper Albian), State of Guerrero, Mexico. Revista Mexicana de Ciencias Geológicas, 28, 175-191.

Fucek, L., Gusic, I., Jelaska, V., Korolija, B. & Ostric, N., 1990. Stratigrafija gornjokrednih naslaga jugoistocnog dijela Dugog otoka i njihova korelacija s istovremenim naslagama otoka Braca. Geoloski Vjesnik, 43, 23-33.

Gaddo, J.Z.H., 1971. The Mishrif Formation paleoenvironment in the Rumaila/Tuba/Zubair region of South Iraq. Journal of the Geological Society of Iraq, 4, 1-12.

Ghanem, H. & Kuss, J., 2013. Stratigraphic control of the Aptian-Early Turonian sequences of the Levant Platform, Coastal Range, Northwest Syria. GeoArabia, 18, 85-132.

Guŝić, I., Jelaska, V. & Velic, I., 1988. Foraminiferal assemblages, facies, and environments in the Upper Cretaceous of the island of Brac, Yugoslavia. Revue de Palébiologie 2, Benthos'86, 447-456.

Guŝić, I. & Jelaska, V., 1990. Stratigrafija gornjokrednih naslaga otoka Braca u okviru geodinaske evolucije Jadranske karbonatne platforme. Djela Jugoslavenske akademije znanosti i umjetnosti 69, Institut za geoloska istrazivanja, Zagreb. 160 p.

Hamaoui, M., 1965. Biostratigraphy of the Cenomanian Type Hazera Formation. Geological Survey of Israel, Report Pal. 3/65, 1-27.

Hamaoui, M., 1966. Microfossils from Cenomanian sections in the Negev. Geological Survey of Israel Report Pal. 3/66, 1-12.

Harris, P.M., Frost, S.H., Seiglie, C.A. & Schneider- mann, N., 1984. Regional unconformities and depositional cycles, Cretaceous of the Arabian Peninsula. In: J.S. Schlee (Ed.), Interregional unconformities and hydrocarbon accumulations. AAPG Memoir, 36, 67—80.

Husinec, A., Velic, I., Fucek, L., Vlahovic, I. & Maticec, D., 2000. Mid Cretaceous Orbitolinid (foraminiferida) record from the islands of Cres and Losinj (Croatia) and its regional stratigraphic correlation. Cretaceous Research, 21, 155-171.

James, G.A. & Wynd, J.G., 1965. Stratigraphic nomenclature of Iranian oil consortium agreement area. American Association of Petroleum Geologists Bulletin, 49, 2182-2245.

Jassim, S.Z. & Goff, J.C., 2006. Geology of Iraq. Dolin, Prague and Moravian Museum, Srno. 341 p.

Korbar, T., Fuček, L., Husinec, A., Vlahović, I., Oštrić, N., Matičec, D. & Jelaska, 2001. Cenomanian carbonate facies and rudists along shallow intraplatform basin margin – the island of Cres (Adriatic Sea, Croatia). Facies, 45, 39-58.

Mahdi, T.A., 2004. Sequence stratigraphy and reservoir characterization of Mishrif Formation in Dujaila, Kut, Amarah and Rifaiy fields, Unpub. M. Sc. thesis, Universityof Baghdad, Baghdad. 160 p.

Mahdi, T.A., Aqrawi, A.A.M., Horbury, A. & Sherwani, G.H., 2013. Sedimentological characterization of the mid-Cretaceous Mishrif reservoir in southern Mesopotamian Basin, Iraq. GeoArabia, 18(1), 139-174.

Mahdi, T.A. & Aqrawi, A.A.M., 2014. Sequence stratigraphic analysis of the Mid-Cretaceous Mishrif Formation, southern Mesopotamian Basin, Iraq. Journal of Petroleum Geology, 37, 287-312.

Melhi, A.A.H. & Diah, M.S., 1984. Review for the Upper Cretaceous

Sequence NW Iraq. I.N.O.C., Northern Petroleum Organization, Geological Laboratories, Baghdad. (Unpublished report).

Murris, R.J., 1980. Middle East stratigraphic evolution and oil habitat. AAPG Bull., 64, 597-618.

Ogg, J.G., 2004. Mid-Late Cretaceous Charts. In: F.M. Gradstein, J.G. Ogg & A.G. Smith (Eds.), A geologic time scale. Cambridge University Press, New York. 589 p.

Orabi, O.H. & Hamad M.M., 2018. Biostratigraphic implications of the Cenomanian larger benthic foraminifera of Gebel Arief El Naqa, Egypt. Egyptian Journal Of Geology, 62, 463-476.

Orabi, O.H., Osman, R.A., El Qot, G.M. & Afify, A.M., 2012. Biostratigraphy and stepwise extinctions of the larger foraminifera during Cenomanian (Upper Cretaceous) of Gebel Um Horeiba (Mittla Pass), west-central Sinai. Egypt Revue de Paléobiologie, 31, 303-312.

Owen, R.M. & Naser, S.N., 1958. The stratigraphic of Kuwait - Basrah area. In: L.G. Weeks (Ed.), Habitat of oil, a symposium. AAPG publication, 1252-1278.

Rabanit, P.M.V., 1952. Rock units of Basrah area. Basra Petroleum Company, Iraq National Oil Company archives. (Unpublished report).

Reulet, J., 1982. Carbonate reservoirs in a marine shelf sequence, Mishrif Formation, Cretaceous of the Middle East. In: A. Reekman & C.M. Friedman (Eds.), Exploration for carbonate petroleum reservoirs, Elf-Aquitaine. John Wiley and Sons, New York, 165-73.

Sadooni, F.N., 2005. The nature and origin of Upper Cretaceous basin-margin rudist build-ups of the Mesopotamian Basin, southern Iraq, with consideration of possible hydrocarbon stratigraphic entrapment. Cretaceous Research, 26(2), 213-224.

Sadooni, F.N. & Aqrawi, A.A.M., 2000. Cretaceous sequence stratigraphy and petroleum potential of the Mesopotamian Basin, Iraq. In: Scott, B. & Al Sharhan, A.S. (Eds.), Middle East models of Jurassic/Cretaceous carbonate systems. SEPM Special Publication, 69, 315-334.

Sari, B., Steuber, T. & Özer, S., 2004. First record of Upper Turonian rudists (Mollusca, Hippuritoidea) in the Bey Dailar carbonate platform, Western Taurides (Turkey): taxonomy and strontium isotope stratigraphy of Vaccinites praegiganteus (Toucas, 1904). Cretaceous Research, 25, 235-248.

Sari, B., Sari, K., Tasli, K. & Ozer, S., 2009. Benthonic foraminiferal biostratigraphy of the Upper Cretaceous (Middle Cenomanian-Coniacian) sequences of the Bey Doglari carbonate platform, western Taurides, Turkey. Turkish Journal of Earth Sciences, 18, 395–425.

Schroeder, R. & Neumann, M., 1985. Les grands Foraminifères du Crétacé Moyen de la région méditerranéenne. Géobios, mémoire Spécial, 7, 1-160.

Schulze, F., Kuss, J. & Marzoak, A., 2005. Platform configuration, microfacies and cyclicities of the Upper Albian to Turonian of west-central Jordan. Facies, 50, 505–527.

Scott, R.W., 1990. Chronostratigraphy of the Cretaceous carbonate shelf, southeastern Arabia, In: A.H.F. Robertson, M.P. Searle & A.C. Ries (Eds.), The geology and tectonics of the Oman region. Geological Society London Special Publication, 49, 89-108.

Shahin, A., 2007. Oxygen and carbon isotopes and foraminiferal biostratigraphy of the Cenomanian-Turonian succession in Gabal Nezzazat, southwestern Sinai, Egypt. Revue de Paléobiologie, 26, 359–379.

Sharland, P.R., Archer, R., Casey, D.M., Davies, R.B., Hall, S.H., Heward, A.P., Horbury, A.D. & Simmons, M.D., 2001. Arabian Plate sequence stratigraphy. GeoArabia Special Publication 2, Gulf PetroLink, Bahrain. 371 p.

Sherwani, G.H., 1983. Depositional environment and stratigraphic relationships of Mishrif Formation and equivalents in selected boreholes, southern and middle Iraq. Unpublished M.Sc. Thesis, University of Baghdad. 119 p.

Sherwani, G.H. & Mohammed, I.Q., 1993. Sedimentological factors, controlling depositional environment of Ceomenian Mishrif Formation, southern Iraq. Iraqi Geological Journal, 26(3), 122-134.

Tasli, K., Ozer, E. & Koc, H., 2005. Benthic foraminiferal assemblages of the Cretaceous platform carbonate succession in the Yavca area (Bolkar Mountains, S. Turkey). Biostratigraphy and Paleoenvironments, 39, 521–533.

Thomas, F.N., 1980. Biostratigraphy and microfacies of the Mishrif Formation in west Qurna-1 well and Gir Bir Formation in Mushorah-1 well, Iraq. INOC, Baghdad. Unpublished report.

van Bellen, R.C., H.V. Dunnington, R. Wetzel & D.M. Morton, 1959-2005. Lexique stratigraphique international, 03 10 Asie, (Iraq). Reprinted by permission of CNRS by Gulf PetroLink, Bahrain. 333 p.

van Buchem, F.S.P., Bernard Pittet, Heiko Hillgärtner, Jürgen Grötsch, Abdullah I. Al Mansouri, Ian M. Billing, Henk H.J. Droste, W. Heiko Oterdoom, Mia van Steenwinkel, 2002. High-resolution sequence stratigraphic architecture of Barremian/Aptian carbonate systems in northern Oman and the United Arab Emirates (Kharaib and Shu'aiba formations). GeoArabia, 7, 461-500.

Velić, I. & Vlahović, I., 1994. Foraminiferal assemblages in the Cenomanian of the Buzet-Savudrija area (northwestern Istria, Croatia). Geologica Croatica, 47, 25-43.

Velić, I., 2007. Stratigraphy and palaeobiogeography of Mesozoic benthic foraminifera of the Karst Dinarides (SE Europe). Geologica Croatica, 60, 1-113.

Weidich, K.F. & Al-Harithi, T., 1990. Agglutinated foraminifera from the Albian and Cenomanian of Jordan. In: Hemleben, C., Kaminski, M.A., Kuhnt, W. & Scott, D.B. (Eds.), Paleoecology, biostratigraphy, paleoceanography and taxonomy of agglutinated foraminifera. NATO ASI Series C, 327, 587-619.

Ya Deng, Rui Guo, Zhongyuan Tian, Wenhao Tan, Yingjie Yi, Zhenyong Xu, Cong Xiao, Xunchen Cao, Liang Chen, 2016. Geologic features and genesis of the barriers and intercalations in carbonates: A case study of the Cretaceous Mishrif Formation, West Qurna oil field, Iraq. Petroleum Exploration and Development, 43(1), 149-157.

Ziegler, M.A., 2001. Late Permian to Holocene paleofacies evolution of the Arabian Plate and its hydrocarbon occurrences. GeoArabia, 6(3), 445-504.

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