BIOSTRATIGRAPHIC ANALYSIS OF THE OLIGOCENE-EARLY MIOCENE SUCCESSIONS FROM SULAIMANI AREA, KURDISTAN REGION, IRAQ

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ABSTRACT

Three sections (Darzila, Hazar Kani and Basara) of the Oligocene –Early Miocene successions from Sulaimani area, Kurdistan region-NE Iraq, were measured and studied in order to interpret the biostratigraphic zonations at the Low and High Folded Thrust zones boundary, Low Folded Thrust zone, which are integrated with strontium stratigraphic dating. Accordingly, five biozones have been identified and they are: 1- Nummulites vascus- Nummulites intermedius- Nummulites fichteli Assemblage Zone (Shallow Benthic Zone, SBZ 22A) represents the Rupelian age, 2- Lepidocyclina dilatata- Nummulites vascus - Nummulites fichteli Assemblage Zone (SBZ 22B-Early Chattian), 3- Praerhapydionina delicata- Archaia kirkukensis Assemblage Zone (SBZ23) representing the Late Chattian age, 4- Austrotrillina howchini- Peneroplis evolutus Assemblage Zone (SBZ24), almost point to the Aquitanian age and finally 5- Austrotrillina asmariensis- Dendritina rangi Assemblage Zone (equivalent to SBZ25) representing the Burdigalian age. Based on the distribution of the larger foraminifera and strontium stratigraphic dating, the Baba Formation is of Early to Late Oligocene age (Rupelian-Early Chattian), while the Bajawan Formation is of Chattian age, in addition to that, the Anah Formation is of Early Miocene age (Aquitanian) and the Jeribe Formation is of Burdigalian age. It is worthy to mention that the Oligocene-Miocene boundary has been identified in the studied area as well as, the gap duration between different formations of the Kirkuk Group, and the gap durations due to the absences of Serikagni, Euphrates and Dhiban formations.

Keywords: Biostratigraphy; Sr Dating; Oligocene; Early Miocene; Foraminifera; Kurdistan

INTRODUCTION

This study clarifies the biostratigraphic framework of the Oligocene and Miocene age rock units represented by the Kirkuk Group and the Jeribe Formation, based on large benthic foraminifera, as well as Strontium (Sr dating) isotope data. The Kirkuk Group and the Jeribe Formation are considered as one of the largest and most important oil reservoirs in Iraq and the Middle East and have been in use since 1934 (Beydoun, 1988). Recent oil exploration in Kurdistan region (N-Iraq) show that interest is increasing towards High Folded Thrust Zone (HFTZ), in oil production from those units. The Kirkuk Group is bounded below by the Late Eocene Pila Spi Formation in most of the sections in the studied area, while the upper boundary is either the Early Miocene Jeribe Formation (Early Burdigalian) and/or the Lower Fars(Fatha) Formation (Middle-Late Burdigalian) (Bellen et al., 1959; Grabowski and Liu, 2010 and Lawa and Ghafur, 2015). The main aim of this research is to document the biostratigraphic zones, especially from large benthic foraminifera assemblages of the Kirkuk Group, members and the Jeribe Formation relationships, as well as dating them based on Sr isotope results, by measurement of the $^{87}\text{Sr}/^{86}\text{Sr}$ ratio, and comparison of the recognized assemblages with coeval assemblages from Iraq and Iran. Another target is the determination of the Oligocene-Miocene boundary and the gap duration between them in the studied area. Accordingly, this work goal is towards reconstructing coherent biostratigraphic framework for the recognized members of Kirkuk Group and the Jeribe Formation.

GEOLOGICAL SETTING

The study area is characterized by the main Northwest-Southeast (NW –SE) trend of the Zagros Fold-Thrust Belt (ZFTB), which is divided into several zones, that differ according to their structural style and sedimentary history. In Kurdistan region, they are subdivided into Imbricated Zone, High Folded Thrust Zone (HFTZ) and Low Folded Thrust Zone (LFTZ)(Lawa et al., 2013 and Omer et al., 2015), within which two thrusts can be distinguished, among them, the Mountain Front Fault and the High Zagros Fault (Fig. 1). These major thrusts are not rectilinear and are offset by major transverse lineaments, such as the Khanaqin and Lesser Zab Fault systems. The study area is located at the boundary between the LFTZ/HFTZ, and LFTZ from where the three sections have been studied. Due to the economic reasons, most of the previous studies were focused on the central part of the basin that is the Kirkuk Oilfield, while this work pays attention to the basin periphery areas. The deposition took place during Oligocene and Early Miocene on a carbonate

The map illustrates the geological structure of the Zagros region in Iraq, highlighting three primary tectonic zones and several major faults. The Low Folded Thrust Zone is shown in yellow, the High Zagros Folded Thrust Zone in green, and the Main Mountain Front Fault in blue. Key faults include the Lesser Zab Fault, High Zagros Fault, Main Mountain Front Fault, and Khanaqin Fault. Major cities and towns are marked, including Basra, Sulaimani, and Karbala. An inset map shows the location of the study area within Iraq and its neighbors (Turkey, Syria, Jordan, Saudi Arabia, Iran, Egypt). A scale bar indicates 5 km.

The Oligocene deposits on the platform include Kirkuk Group (Represented by nine formations, Anah, Azkand, Ibrahim, Bajawan, Baba, Tarjil, Shurau, Sheikh Alas, Palani ,and manifesting three sedimentary sequences) and the Miocene deposits represented by the Euphrates Group (Includes four formations, Serikagni, Euphrates, Dhiban, and Jeribe) (Liu et al., 2017). They show significant lateral and vertical facies variations from depocenter to the basin boundary, which

is from the Kirkuk Oilfield (LFTZ) towards the LFTZ/HFTZ boundary. Bellen et al. (1959) recorded Oligocene aged strata for the first time from Bamo and Sagerma mountains (at the L-HFTZ periphery) and placed the Oligocene-Miocene boundary between Kirkuk Group and Euphrates sequence and mentioned that the Bajawan Formation was deposited very close to the shoreline and consequently is very thin and conglomeratic. Behnam (1979) identified the Oligocene strata related to Kirkuk Group from Bamo Mountain at the LFTZ/HFTZ boundary. Several publications on the Kirkuk Group and the Jeribe Formation are published from outcrops and wells in Iraq, which deals with microfacies, depositional environment and biostratigraphy (Mohammed, 1983; Hadad, 1991; Bakkal and Al- Ghurari, 1993; El-Eisa 1992a, 1992b, 1993; Abid 1997; Al-Guburi and El-Eisa, 2002; Stevanovitic et al., 2003; Ghafor, 2004; Kharajian, 2008; Ghafur, 2011; Lawa and Ghafur, 2015 and Ghafour, 2015). Grabowski and Liu (2009 and 2010) showed the potential of Sr isotopes for use in dating these Cenozoic rocks in Kirkuk embayment. Bellen et al., (1959) placed the Oligocene-Miocene boundary between Ibrahim-Azkand-Anah sequence (Ibrahim sequence) and the Serikagni– Euphrates- Dhiban- Jeribe sequence (Euphrates Sequence). While AL-Banna (2008) placed that boundary between the second and third sedimentary cycles of the Kirkuk Group (between Tarjil and Ibrahim formations).

MATERIALS AND METHODS

More than 150 samples have been collected from the three stratigraphic sections (Darzila, Hazar Kani and Basara); one hundred thin sections were prepared and studied under a polarized microscope in detail for foraminiferal biostratigraphic analysis of the concerned formations. Thin sections were stained to distinguish between calcite and dolomite components. While cooking analysis used for the purpose of obtaining information about microfossils contents from 25 samples were prepared, but did not show any microfossils because it has been affected by intense diagenesis processes. Also, more than 20 thin sections prepared for nannofossils study, but the results of the nannofossils investigations were missed out because the carbonate samples are more affected again by the intensive diagenesis processes. In addition, fourteen (14) samples have been used for strontium isotope dating for age determination of Oligocene-Early Miocene formations depending on the stander chart (McArthur et al., 2012). The strontium data analysis has been done in the lab of the Institute of Soil Research (IBF, H91100) Franz Schwackhofer Haus, Peter- Jordan- Straße 821190, Wien- Austria. Determination of stratigraphic position and biostratigraphic interpretation

of Oligocene and Early Miocene successions at the High-Low Folded Thrust Zones boundary in the study area is based on the identification of large foraminifera assemblages which include perforate and imperforate benthonic larger foraminifer and other fauna. Benthic fauna assemblage is used also as an important tool for biostratigraphic zonation's and compared with the Sr dating results. Sr isotope dating by measurement of the $^{87}\text{Sr}/^{86}\text{Sr}$ ratio has been carried out on 14 samples in three surface sections. This method is based on the known variation in seawater $^{87}\text{Sr}/^{86}\text{Sr}$ through the Phanerozoic (Burke *et al.*, 1982; McArthur & Howarth, 2004). The majority of the analyses were made on whole rock samples, identified as the most effective method based on the limestone types and project scale. This methodology has also been used in this study and has improved the age control significantly. This technique was also applied to recalibrate the biostratigraphic zonation and propose a revision of the age assignment of the biostratigraphic zonation scheme. Therefore, Strontium isotope stratigraphy is used as an additional control for biostratigraphy correlation. The integration of the biostratigraphic tools with the $^{87}\text{Sr}/^{86}\text{Sr}$ dating has been used in this work to establish the Oligocene and Early Miocene framework. In addition to the strontium isotope data of Hazar Kani, Darzila and Basara sections provide significantly finer age resolution than that determined from biostratigraphy alone. The collected fourteen samples of carbonate depended on benthic foraminiferal abundance for measuring strontium ratios and almost all samples are fresh without diagenesis influences.

BIOSTRATIGRAPHY

It is worthy to mention that several authors studied the Oligocene- Miocene succession in Iraq and Kurdistan region from the biostratigraphic point of view. Bellen (1956) subdivided Kirkuk Group into three cycles with specific stratigraphic position as follow, reef/back- reef: the Bajawan Formation (*Archaias kirkukensis* and *Praerhapydionina delicata*) and the Anah Formation (*Miogypsinoidea*), fore-reef: the Baba Formation (*Lepidocyclina*, *Lepidocyclina/ Nummulites*, and Azkand Formation (*Miogypsinoidea*, *Miogypsinoidea/Lepidocyclina*); and finally offshore (*Globigerina*) Tarjil and Ibrahim formations. Mohammed (1983) studied the Kirkuk Group from the Kirkuk and Qarachuqe area and concluded that the last third cycle (Anah, Azkand and Ibrahim formations) may extend in age to Early Miocene (Aquitania). Majid and Veizer (1986) classified the Kirkuk Group in the Kirkuk Oil field into the Early and Middle Oligocene biozones, without referring to the unit of Late Oligocene age. Youhanna (1983) and El-Eisa (1992a) revised the

previously assigned upper biozone of the Late Oligocene, which was suggested by Bellen (1956) and Bellen et al. (1959), into the Early Miocene age using the planktic foraminifera genus *Globigerinoides* in the Kirkuk area. Abid and Sayyab (1989) restudied the various genera and species of the Anah Formation to ascertain that the age of this formation is Late Oligocene- Early Miocene. Al-Banna (1997) presents paleontological and stratigraphic data that resolved this controversial issue in the type section of the Ibrahim Formation and the type section of Serikagni Formation, and considered the position of the Oligocene–Miocene boundary between Tarjil and Ibrahim sequences. Other works done by Al-Banna and Al-Mutwali (2002) in Sinjar basin, supported the new position of the Oligocene–Miocene boundary and in conjunction with their Oligocene sequence stratigraphic results, they give good correlation across the entire Arabian plate. According to Al-Banna et al., 2002 and Al-Banna, 2008, the Oligocene-Miocene interval between the Tarjil and Ibrahim formations in western Mosul-Iraq showed that biotas of Anah, Azkand and Ibrahim formations were deposited in the Early Miocene, not Late Oligocene age. Also, Kharajiany (2008) studied Oligocene rock units in Aj-Dagh anticline based on identified index fossils; it confirmed the presence of Sheikh Alas, Shurau, Baba, Bajawan and Anah formations. Also Ghafur (2011) studied the Baba Formation (Late Oligocene) in Bai- Hassan, oil well- 25 from Kirkuk area. Lawa and Ghafur, (2015) studied Late Eocene and Early Miocene carbonates from Zagros Fold-Thrust Belt, based on the description of index fossils, they consider that the Kirkuk Group extended from Rupelian to Early Aquitanian age. While in this study, the foraminiferal biozonation has been integrated with Strontium isotope dating. This study based on the distribution of the benthic foraminifera especially the large ones, also from data in Figs. 2, 3, and 4. Consequently, five benthic foraminiferal biozones are recognized and belonging to the Oligocene- Early Miocene age. Biozonations in the study area are based on the work of Cahuzac and Poignants, 1997 and Serra-Kiel et al., 2016 (Table 1). The following biozones types from the three selected sections are described in detail from older to younger biozones from each formation:

1- *Nummulites vascus*- *Nummulites intermedius*- *Nummulites fichteli* Assemblage Zone

This biozone corresponds to Early Oligocene (Rupelian) in age. It is recorded from Baba Formation and recognized only in Hazar Kani section about 24 meters in thickness. It is characterized by the appearance and dominance of hyaline perforate foraminifera such as Nummulitids (*Nummulites intermedius* D' Archiac, *Nummulites vascus* Joly and Leymeric, *Nummulites fichteli* Michelotti,

and *Nummulites* sp.). Others benthic foraminifera are recognized too, like *Rotalia viennoti* Greig, *Praerhapydionina delicata* Henson, *Archaias kirkukensis* Henson, *Peneroplis* sp., *Ditrupa* sp., *Textularia* sp. valvulinids, Miliolids and calcareous red algae. In addition to the shallow benthic foraminifera, several macrofossils are recorded and dominated like echinoids, coral, bryozoan, bivalves, and gastropods. (Plate 1, Figs.1, 2, 3, 4, 5, 6, 7, 8 and 9). This biozone type is correlated with the shallow benthic zone (SBZ22A), according to Serra-Kiel *et al.*, (2016) and Cahuzac and Poignants, (1997), and with studies inside Iraq (Tables 1 and 2) (Fig. 2).

Table 1. Biozone types of the study area are based on Cahuzac and Poignant (1997) and Serra Kiel *et al.*, (2016)

Age		Cahuzac and Poignant (1997)		Serra Kiel <i>et al.</i> , 2016	Biozonation
		No	Biozone		
Miocene	Burdigalian	SBZ25	<i>Borelis melo curdica</i> - <i>Miogypsina</i>		<i>Austrotrillina asmariensis</i> - <i>Dendritina rangi</i> Assemblage Zone
	Aquitanian	SBZ24	<i>Austrotrillina howchini</i> - <i>Miogypsina</i> - <i>M. dehaartii</i>	<i>Miogypsinoide</i> <i>s bantamensis</i>	<i>Austrotrillina howchini</i> - <i>Penerolis evolutus</i> Assemblage Zone
Oligocene	Chattian	SBZ23	<i>Miogypsinoide</i> - <i>Eulepidina</i>	<i>Miogypsinoide</i> <i>s complanatus</i>	<i>Praerhapydionina</i> <i>delicata</i> - <i>Archaias</i> <i>kirkukensis</i> Assemblage Zone
		SBZ22B	<i>Nummulites vascus</i> - <i>Nummulites fichteli</i> - <i>Eulepidina</i>	<i>Nummulites</i> <i>vascus</i> - <i>Nummulites</i> <i>fichteli</i>	<i>Lepidocyclina dilatata</i> - <i>Nummulites vascus</i> - <i>Nummulites fichteli</i> Assemblage Zone
	Rupelian	SBZ22A	<i>Eulepidina formosoides</i>		<i>Nummulites vascus</i> - <i>Nummulites intermedius</i> - <i>Nummulites fichteli</i> Assemblage Zone

2- *Lepidocyclina dilatata*- *Nummulites vascus* - *Nummulites fichteli* Assemblage Zone

This biozone corresponds to the lower part of the Late Oligocene (Early Chattian) in age. It is recorded from the Baba Formation and recognized only in Darzila section about 28 meters in thickness. It is characterized by the first appearance and dominance of *Lepidocyclina* (*Eulephidina*)

dilatata Michelotti and *Lepidocyclina* (*Eulephidina*) *elephantina* Lemoine and Douville. They are also combined by the last occurrence of hyaline perforate foraminifera such as *Nummulites intermedius* D' Archiac, *Nummulites vascus* Joly, *Nummulites fichteli* Michelotti, and *Nummulites* sp., .It is worthy to mention that, others large foraminifera like, *Hetrostegina assillina* Blau, *Sphaerogypsina globulus* Reuss, *Operculina complanata* Defrance in Blainville , *Operculina* sp., also appeared for the first time in this zone but with low diversity and of common to rare in abundance. In this zone, few planktic foraminiferal species are recorded with rare appearances and represented by *Globorotalia opima* Bolli. Calcareous green and red algae with echinoids are recognized in this zone (Plate1 and 2, Figs. 10, 11, 12, 13, 14, 15) This zone is correlated with the shallow benthic zone (SBZ22B), of Serra-Kiel et al., (2016), and Cahuzac and Poignants,(1997) and with studied inside Iraq (Tables 1 and 2) (Fig.3).

3- *Praerhapydionina delicata*- *Archaias kirkukensis* Assemblage Zone

This biozone corresponds to Late Oligocene (Chattian) in age and also confirmed by strontium dating. It is recorded from the Bajawan Formation and recognized in three sections (Darzila and Hazar Kani and Basara) range between (4m-35m) in thickness. It is characterized by the occurrence of *Praerhapydionina delicata* Henson, *Praerhapydionina* sp., Miliolids (*Austrotrillina howchini* Shlumberger, *Austrotrillina paucialveolata* Grimsdale, *Archaias hensoni* Henson, *Austrotrillina* sp., *Quinqueloculina* sp., *Pyrgo* sp., *Triloculina* sp., *Spiroloculina* sp., and *Spirolina cylindrecata* sp.), *Rotalia viennoti* Greig, *Dendritina rangi* D'Orbigny, *Peneroplids* (*Peneroplis evolutus* Henson, *Peneroplis thomasi* Henson, *Peneroplis farsensis* Henson and *Peneroplis* sp.), *Archaias kirkukensis* Henson, *Archaias hensoni* Smout and Eame, *Archaias* sp., *Textularia* sp., valvulinids, echinoids, bryozoan, gastropoda and pelecypods, as well as bioclasts of calcareous green and red algae (Plate 2, Figs. 6, 7, 8, 9, 10, 11, 12 and 13). This biozone represents the top of Oligocene and can be correlated with the shallow benthic zone (SBZ23), according to Serra-Kiel et al., (2016) and Cahuzac and Poignants, (1997) (Tables 1 and 2) and (Figs 2, 3 and 4).

4- *Austrotrillina howchini*- *Peneroplis evolutus* Assemblage Zone (SBZ24).

This biozone corresponds to Early Miocene (Aquitainian) in age and also emphasized by strontium stratigraphy dating (Table 2). It is recorded from the Anah Formation and recognized in Darzila and Hazar Kani sections range between (2m-5m) in thickness, but it is not recorded from Basara section.

This zone is characterized by the dominance of *Austrotrillina howchini* Schlumberger and *Peneroplus evolutus* Henson, almost associated with larger benthic foraminifera represented by *Austrotrillina* spp. Also, other miliolids are abundant too like *Pyrgo* sp., *Quinqueloculina* sp., and *Triloculina* sp.

Fig. 2. Distribution range chart of Oligocene- Early Miocene benthic foraminifera biozones from Hazar Kani section, Sulaimani area, Iraq

Plate 1. Figs. 1& 2 *Nummulites intermedius*, HK, S. NO8, XP, 3 *Miliolids* (A), *Nummulites*. sp. (B), HK, S. NO 8, XP, 4 *Nummulites fichteli*, HK, S.NO.9, XP, 5 *Triloculina* sp. HK, S.NO.9, XP 6 *Archaias kirkukensis* (A), *Austrotrillina* sp., HK, S.NO.8, XP, 7 *Nummulites*. sp. (A), pelecypods shell (B), HK, S.NO.8, XP, 8 Coral, HK, S.NO.8, XP, 9 *Ditrupa* sp. HK, S.NO.10, XP, 10 *Nummulites vascus*, DR, S.NO.14, XP, 11 *Nummulites intermedius*, DR, S.NO.14, XP, 12 *Nummulites fichteli*, DR, S.NO.14, XP, 13 *Nummulites intermedius* (A). Red algae (B), DR, S.NO.2, XP, 14 *Hetrostegina assillinoids*, DR, S.NO.5, XP.

Table 2. Biostratigraphic correlations with other studies inside Iraq

Oligocene				Miocene		Epoch
Rupelian		Chattian		Aquitania	Burdigalian	Stage
	SBZ22A	SBZ22B	SBZ23	SBZ 24	SBZ 25	SBZONES
<i>Dentrop hyllum, Austrotr illina</i>	<i>Archaias kurkukensis- P. delicata Nummulites- Lepidocyclina</i>		<i>Lepidocyclina- Miogypsinoidea</i>	<i>Borelis melo curdica</i>	<i>Ostrea latimarginata</i>	Bellen et al., (1959)
<i>Subterra inphylla Subterra</i>	<i>Archaias kurkukensis -P. delicata</i>		<i>Miogypsinoidea</i>	Not studied	Not studied	Muhamma d (1983)
<i>inphylla thomasi Austrotr illina</i>	<i>Archaias kurkukensis- P. delicata Nummulites vascus- Lepidocyclina</i>		<i>Meandrospina-Miogypsina- Austrotrillina howchini- Miogypsinoidea-Lepidocyclina</i>		<i>Borelis melo curdica-B. melo melo- Miogypsina globulina</i>	Abid (1997)
<i>N. intermedius N. fichteli</i>	<i>Praerhapydionina delicata- Austrotrillina howchini- Peneroplis evolutus</i>			Not studied	Not studied	Al-Banna et al., (2010)
<i>Nummulites fichteli</i>	<i>Praerhapydionina delicata</i>			<i>Borelis melo melo- Austrotrillina howchini</i>	<i>Borelis melo melo-Borelis melo curdica</i>	Lawa and Gafur (2015)
Not studied	<i>Nummulite s vascus- N. intermedius</i>	<i>Lepidocycli na (Eulepidina)</i>	<i>Praerhapydionina delicata -Archaias kirkukensis</i>	<i>Austrotrillina howchini- P. evolutus</i>	<i>Austrotrillina asmariensis- Dendritina</i>	This study

Fig. 3. Distribution range chart of Oligocene- Early Miocene benthic foraminifera biozones from Darzila section, Sulaimani area, Iraq

Plate 2. Fig. 1. *Lepidocyclina(Eulepidina) dilatata*, DR, S. NO14, XP, 2 *Lepidocyclina(Eulepidina) elephantine*, DR,S. NO14, 5, XP, 3 *Lepidocyclina(Eulepidina) dilatata* (A)*Sphaerogypsina globulus*(B) DR, S. NO11,XP, 4 *Nummulites intermedius* DR, S.NO.8, XP, 5 *Nummulites vascus* DR, S.NO.8, XP, 6 *Valvulinids*, BA, S.NO.12, XP, 7 *Rotalids viennoti*, BA S.NO.15, XP, 8 Red algae, DR, S.NO.22, XP, 9 *Triloculina* sp. DR, S.NO.23, XP, 10 *Miliolids* sp. HK, S.NO.14, XP, 11 *Praerhapydionina delicata*, DR, S.NO.17, XP, 12 Gastropoda shell, DR, S.NO.17, XP, 13 Green algae (B), DR, S.NO.17, XP, 14 *Austrotrillina howchini* DR, S.NO.B1, XP, 15 *Peneroplis evolutus* , DR, S.NO.B1, XP

The most common Peneroplids are represented by the following species like, *Peneroplis evolutus* Henson, *Peneroplis thomasi* Henson, *Peneroplis farsensis* Henson, and *Peneroplis* sp.. In addition to that, several benthic foraminifera are present like *Praerhapydionina delicata* Henson, *Archaias kirkukensis* Henson, *Rotalia viennoti* Greig, *Dendritina rangi* D, Orbigeny, *Amphistegina* sp., valvulinids. This zone also characterized by the dominance patchy reef coral, calcareous green algae, calcareous red algae, bivalves, echinoids and gastropods (Plate 2, Figs. 14, 15 and Plate 3- Figs. 1, 2, 3, 4, 5, 6, 7). This biozone type correlates with the Shallow Benthic Zone SBZ24, according to Serra-Kiel et al., (2016) and Cahuzac and Poignants, (1997), also compared with studies inside Iraq (Tables 1 and 2) and (Figs. 2 and 3).

5- *Austrotrillina asmariensis*- *Dendritina rangi* Assemblage Zone (SBZ25):

This biozone is equivalent to Late Early Miocene (Burdigalian) in age and also emphasized by strontium stratigraphy dating (Tables 2 and 3), as well as its stratigraphic position on the top of the previous biozones and lithostratigraphic units. It is recorded from the Jeribe Formation and recognized in Darzila and Hazar Kani sections range between 2m-10m in thickness, but not recognized from Basara section. It is characterized by the last appearance of several large benthic foraminifera like *Austrotrillina howchini* Schlumberger, *Austrotrillina asmariensis* Adam, *Austrotrillina* sp., *Praerhapydionina delicata* Henson *Archaias kirkukensis* Henson, *Dendritina rangi* D, Orbigeny, *Amphistegina* sp., *Rotalia viennoti* Greig, *Rotalia* sp., Miliolids sp., *Pyrgo* sp., *Triloculina* sp., *Quinqueloculina* sp., *Textularia* sp., Peneroplids (*Peneroplis thomasi* Henson, *Peneroplis evolutus* Henson, *Peneroplis farsensis* Henson, and *Peneroplis* sp.), valvulinids, echinoids, calcareous green algae, bivalves and gastropods (Plate 3, Figs. 8,9,10,11,12,13,14,15). This biozone type correlated with the shallow benthic zone SBZ25 according to Serra-Kiel et al., (2016) and Cahuzac and Poignants, (1997), also compared with studies inside Iraq (Tables 1 and 2, Figs. 2 and 5).

RESULTS AND DISCUSSION

Strontium Dating

The numerical ages of the samples were determined from the measured $^{87}\text{Sr}/^{86}\text{Sr}$ value on the $^{87}\text{Sr}/^{86}\text{Sr}$ Lowess curve calibrated by McArthur et al., (2012) (Table 3 and Fig. 5). Buchm et al., (2010) mentioned that the rapid increase in the seawater $^{87}\text{Sr}/^{86}\text{Sr}$ ratio during the Oligocene to

Middle Miocene, strontium isotope stratigraphy can potentially resolve accurate age profiles through the section, to identify the presence of stratigraphic gaps, and the sedimentation rates.

Fig. 4. Distribution range chart of Oligocene- Early Miocene benthic foraminifera biozones from Basara section

The studied samples from the upper part of the Bajawan Formation, in the three sections (Darzila, Hazar Kani and Basara) indicates an age range from 23.67 Ma to 24.75 Ma , and that means they are of Chattian age based on the latest chronostratigraphic chart by which is determine the extension of the Chattian age from 27.82 to 23.03Ma . Accordingly, the recorded interval of the upper part of Bajawan Formation is related almost to the latest part of the Chattian age and represented by the biostratigraphic zone and nominated as *Praerhapydionina delicata*- *Archaias kirkukensis* Assemblage Zone (SBZ23). De Man et al., (2010) recorded the Rupelian and Chattian boundary at an interval from between 29.2 Ma and 27.0 Ma, at the stratotypes in the southern North Sea. The boundary between Baba and Bajawan formations recorded as a gap, manifested by the disappearances of *Lepidocyclina dilatata*- *Nummulites vascus* - *Nummulites fichteli* Assemblage Zone (SBZ 22B) in Hazar Kani section, but in Darzila section by the disappearances of *Nummulites vascus*- *Nummulites intermedius*- *Nummulites fichteli* Assemblage Zone (SBZ 22A), as well as by total disappearance of shallow benthic zones (SBZ 22A, and SBZ22B) from Basara section. While the biostratigraphic zonations of the upper part of the Baba Formation represented by *Lepidocyclina dilatata*- *Nummulites vascus* - *Nummulites fichteli* Assemblage Zone (SBZ22B) of Early Chattian age. The Anah Formation is recorded from two sections only (Darzila, Hazar Kani) and disappears from Basara section. The strontium isotope analysis and their corresponding ages point to interval time ranging between 20.37 Ma to 20.80Ma and this represents Aquitanian age, which extends from 23.03Ma to 20.44Ma (Table.3 and Fig. 5).Therefore, the recognized Anah Formation almost represents the upper part of the proper Anah Formation and corresponds to the - *Austrotrillina howchini*- *Peneroplis evolutus* Assemblage Zone (SBZ24), which almost point to the Aquitanian age. Taking into consideration the strontium dating and biostratigraphic zonation of both Bajawan and Anah formations. The Oligocene (Chattian) and Miocene (Aquitanian) boundary can be placed between them (Bajawan and Anah) with gap interval extending from 23.67 Ma to 20.37 Ma and the gap duration about 3.30 Ma. This gap combined and confirmed by the presence of unconformity surface about 2.5 m thick in Darzila section (Fig. 5). Accordingly, the strontium isotope data from the Bajawan Formation at Hazar Kani, Darzila and Basara sections, provide an age about 24.19Ma corresponding to Late Oligocene (Chattian). The isotopic study of four samples from Hazar Kani and Darzila sections yield an age of 20.56Ma corresponding to Early Miocene (Aquitanian) and it is represented by the Anah Formation.

Plate 3. Figs.1 *Austrotrillina* sp. (A), *Meandropsina anahensis* (B). DR,S. NO.B1, 5, XP 2 *Peneroplis farsensis* DR, S. NOB1, XP, 3 Pelecypods fragments DR,S. NO.B2, 5, XP, 4 *Lithophyllum* sp. DR, S. NOB2,XP, 5 *Spiroloculina* sp. HK, S.NO.20, XP, 6 *Gastropoda* , HK, S.NO.19, XP, 7 Coral, DR, S. NO. C1, XP, 8, *Austrotrillina* sp. DR, S.NO.36, XP, 9 *Austrotrillina asmariensis*. DR, S.NO.36, XP, 10 *Archaias kirkukensis* , DR, S.NO.36, XP, 11 *Valvulinids* , DR, S.NO.36, XP, 12 *Amphistegina* sp. DR, S.NO.31, XP, 13 *Pyrgo* sp. DR, S.NO.31, XP, 14 *Gastropoda* shell (A), *Austrotrillina* sp. (B), HK, S.NO.23, XP, 15 *Miliolids*., HK, S.NO.23, XP

The Jeribe Formation at Hazar Kani and Darzila sections of younger age, which is about 19.56Ma, and corresponding to Early Miocene (Burdigalian) age. The strontium dating results also emphasized the disappearance of the Jeribe Formation from Basara section and recognized from other two sections (Darzila, Hazar Kani) (Table 3, and Fig. 5).

Table 3. Strontium isotope analysis of the study sections, corresponding ages and subzones types

Formation	S. No	$^{87}\text{Sr}/^{86}\text{Sr}$	Age (Ma)	EPOCH	Type of subzones
Jeribe	HK22	0.70878728	19.61	Burdigalian	SBZ 25 <i>Austrotrillina asmariensis</i> - <i>Dendritina rangi</i> Assemblage Zone
	HK24	0.70877271	19.35		
	DR31	0.70873509	19.66		
	DR36	0.70873096	19.62		
Anah	HK18	0.70864874	20.37	Aquitania	SBZ 24 <i>Austrotrillina howchini</i> - <i>Peneroplis evolutus</i> Assemblage Zone
	HK20	0.70875595	20.42		
	DRA2	0.70862007	20.80		
	DRB2	0.70860182	20.65		
Bajawan	HK9	0.70838407	24.75	Chattian	SBZ 23 <i>Praerhapydionina delicata</i> - <i>Archaias kirkukensis</i> Assemblage Zone
	HK20	0.70836556	24.46		
	DR20	0.70842124	24.43		
	DR23	0.70839384	24.20		
	BA6	0.70852413	23.67		
	BA8	0.70842414	23.68		

The recorded age ranged between 19.35Ma to 19.66Ma that is the Burdigalian age, which extends from 20.44Ma to 15.97Ma. Therefore, the recorded age of the Jeribe Formation mostly indicates the Early Burdigalian age only and does not cover the whole Burdigalian and that emphasized by the *Austrotrillina asmariensis*- *Dendritina rangi* Assemblage Zone (SBZ25) which is equivalent to *Borelis melo curdica* biozone, and not recorded in the studied sections, due to the fact that the studied sections are located at the basin periphery. The upper boundary of the Jeribe Formation with the overlying Fatha Formation marked as unconformity surface also emphasized by the Jeribe Formation age as Burdigalian. The recording of *Ostrea latimarginata* and *Ostrea subangulata*, which indicate Langhian age from the Fatha Formation in Basara and Hazar Kani sections also improve the Sr dating of the Jeribe Formation.

Fig. 5. $^{87}\text{Sr} / ^{86}\text{Sr}$ ratio and the age of the studied samples from low-high folded thrust boundary, Kurdistan region, Iraq (Calibrated with McArthur, et al., 2012 chart)

CONCLUSIONS

1. The integration of the biostratigraphy zonation with the strontium isotope results indicates new ages for the studied sections at the boundary between the Low and High Folded Thrust zone.
2. The distribution of larger benthic foraminifera in the studied sections revealed five biozones. These biozones are (*Nummulites vascus*- *Nummulites intermedius*- *Nummulites fichteli* Assemblage Zone (Rupelian), *Praerhapydionina delicata*- *Archaias kirkukensis* Assemblage Zone (Chattian), *Austrotrillina howchini*-*Peneroplis evolutus* Assemblage Zone (Aquitania), *Austrotrillina asmariensis*- *Dendritina rangi* Assemblage Zone (Burdigalian)) are present in Hazar Kani section, biozone types in Darzila section are (*Lepidocyclina dilatata*- *Nummulites vascus* - *Nummulites fichteli* Assemblage Zone (Early

Chattian), *Praerhapydionina delicata*- *Archaias kirkukensis* Assemblage Zone (Chattian), *Austrotrillina howchini*- *Peneroplis evolutus* Assemblage Zone (Aquitanian), *Austrotrillina asmariensis*- *Dendritina rangi* Assemblage Zone (Burdigalian), But only one zone was recorded in Basara section, that is *Praerhapydionina delicata*- *Archaias kirkukensis* Assemblage Zone (Chattian).

3. The disappearance of several biozones like *Borelis melo melo* and *Bole melo curdica* might be controlled by the section location at the sedimentary basin periphery. That is at the boundary of (L/HFTZ), and manifesting the paleoshoreline during the Aquitanian. The *Austrotrillina asmariensis*- *Dendritina rangi* Assemblage Zone type almost corresponds with *Borelis melo curdica* which is not recorded in this work and related to many reasons, such as depositional environment, paleoecology factors as well as the paleogeography of sedimentary basin.
4. The recorded biostratigraphic zonations and lithostratigraphic units, indicates and prove the disappearance of the Euphrates, Serikagni, and Dhiban formations, in the studied sections.
5. The Oligocene (Chattian)-Miocene (Aquitanian) boundary was placed between Bajawan and Anah formations with gap duration extending to 3.30 Ma, that is emphasized by strontium dating.
6. Based on stratigraphic zonation, the Baba Formation represented (Rupelian- Early Chattian). While, based on stratigraphic zonation and Strontium dating the Bajawan Formation (Chattian), Anah Formation (Aquitanian), and Jeribe Formation (Burdigalian) in age. Based on the appearance of *Ostrea latimarginata* and *Ostrea subangulata*, the age of the lower part of the Fatha Formation is Langhian age.
7. The thickness reduction of Oligocene and Early Miocene in the studied area mostly controlled by paleoshoreline of the sedimentary basin, therefore the biostratigraphic zone shows variations from those in the depocenter (Kirkuk embayment).
8. The boundary between Baba and Bajawan formations is characterized by the disappearance of the shallow benthonic zone SBZ 22B in Hazar Kani and Basara sections, which indicates longer gap interval than that in Darzila section. The boundary between Bajawan and Anah formation is characterized by unconformity surface of conglomeritic nature, indicating Oligocene (Chattian)/Miocene (Aquitanian) Boundary at age equivalent

from 23.67 Ma to 20.37Ma, which is corresponding to duration (3.30 Ma). The boundary between Anah and Jeribe formations is characterized by the disappearance of Euphrates, Serikagni, Dhiban formations. Therefore, there are no depositions in most parts of Middle to Late Aquitanian age and that is emphasized by the presence of gap duration between Anah and Jeribe formations, indicating Miocene (Aquitanian)-Miocene (Burdigalian) Boundary at age equivalent from 20.37Ma to 19.35Ma, which is corresponding to duration (1.02 Ma). The disappearance of the Jeribe Formation in Basara section and appearance of thick conglomerates as the incised valley, points to greater and longer gap between Bajawan Formation and the overlying Fatha Formation (Langhian) which is corresponding to duration 7.7 Ma.

9. This study also revealed that the proper Kirkuk Group as well as Euphrates and Dhiban formations disappearance from the L-HFTZ boundary and they die out at the majority of High folded thrust zone.
10. The combined application of larger foraminifera and strontium dating provides the recognition of two parallel sequences of events during the Oligocene- Middle Miocene interval. The first deals with the patchy distributions of the Kirkuk group at the L-HFTZ boundaries. The second is the turnover from carbonate predominated deposits to clastic predominated deposit at the Burdigalian- Langhian boundary that corresponds to the Early middle Miocene boundary, which is reflecting the increase of the intensity of the deformation between Arabian and Iranian plates.

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