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ORIGINAL PAPER

Stratigraphy of the Oligocene-Early Miocene successions, Sangaw area, Kurdistan Region, NE- Iraq

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Abstract

Lithostratigraphy and biostratigraphy of the Darzila section from Low Folded Zone, Ashdagh Mountain, Sangaw area, Kurdistan Region, Northeastern Iraq, is investigated. Forty-three species from twenty-nine genera of large benthic foraminifera (LBF) in addition to non-foraminifera fossils such as echinoid fragments, bryozoan, red algae, green algae, bivalve, and coral are recognized from the studied section. Based on the recognized large benthic foraminifera, it is subdivided into six biozones: *Nummulites vascus - Nummulites fichteli* Assemblage Zone, *Eulepidina dilatata - Nephrolepidina marginata* Concurrent-Range Zone, *Praerhapydionina delicata- Peneroplis evolutus-* Concurrent Range Zone, *Meandrospina anahensis - Austrotrillin asmariensis* Interval Zone, *Ammonia beccarii –Austrotrillina howchini* Assemblage Zone, and *Dendritina rangi- Rotalia viennoti* Assemblage Zone. Both suggest an Oligocene to Early Miocene age. Each of these biozones represents certain lithostratigraphic units, which are Sheikh Alas, Baba, Bajwan, Anah, Jeribe, and Fatha formations. The recognized biozones were correlated with comparatively well-known biozones from other parts of the tethys region which showed a good comparison between the biostratigraphic zones established in this study with other studies.

Keywords Large benthic foraminifera (LBF) · Lithostratigraphy · Biostratigraphy · Oligocene-Miocene · Kurdistan Region · Northeastern Iraq

Introduction

Generally, the major hydrocarbon reserves in Iraq are accumulated in the Oligocene carbonate successions, which represented by Kirkuk Group. Therefore, this area as Oligocene exposure and hosts major hydrocarbon reserves in the Kurdistan region-Northern Iraq; this is why investigations into this succession started a long time ago, especially for oil exploration. Henson (1948, 1950), one of the earliest researcher, had recorded Oligocene-Miocene succession in the Kirkuk area. According to Bellen et al. (1959), the Kirkuk Group comprises nine formations, which are (Shaurau, Bajwan, Anah, Azkand, Baba, Shekh Alas, Ibrahim, Tarjil, and Palani). It represents a sequence of reef controlled the sediment of Oligocene age, in which three separate cycles can be distinguished (Table 1-A), while Ditmar et al. (1971) divided the Oligocene sequence based on the facies into Lower and Upper Sequence carbonate, each sequence consists of back reef/reef, fore reef, and basin facies (Table 1-B). Van Bellen (1956) illustrated that the Oligocene-Miocene boundary is situated between Ibrahim and Serikagni formations, also Bellen et al. (1959) studied the age of many formations depending on their stratigraphic position rather than paleontological evidence. Other researchers state that this dating the above formations does not match correctly with the European Oligocene and Miocene dating (Al-Banna et al. 2010). According to the later article, the Oligocene-Miocene boundary is located between the Tarjil and Ibrahim formations and two sedimentary cycles represent Oligocene; the first cycle embraces Palani, Sheikh Alas, and Shurau formations (Rupelian) which deposited in upper bathyal to intertidal environments, the second cycle includes Tarjil, Baba and Bajwan formations (Chattian), and the third cycle represents Anah, Azkand, and Ibrahim formations (Aquitanian) (Fig. 1). The Oligocene strata extend toward neighboring countries such as Turkey and are represented by red mudstone and claystone with nodular and massive gypsum, known as

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Table 1 A, Lithostratigraphic units of Kirkuk Group subdivisions, based on age, facies, and relationships between reef/back reef-fore reef and offshore facies (Bellen et al. 1959). B, Oligocene lithostratigraphic units and facies (after Ditmar et al. (1971)

A

Age		Sed. Cycle	Facies: Reef/ Back Reef	Facies: Fore Reef	Facies: Off shore
Oligocene	Late	Upper	Anah Formation	Azkan Formation	Ibrahim Formation
	Middle	Middle	Bajwan Formation	Baba Formation	Tarjil Formation
	Early	Lower	Sharau Formation	Shekh Alsa Formation	Palani Formation

B

Age	Sed. Cycle	Facies: Reef/ Back Reef	Facies: Fore Reef	Facies: Off shore
Oligocene	Upper	Anah and Bajwan Formations	Azkand and Baba Formations	Ibrahim and Tarjil Formations
	Lower	Shaurau Formation	Shekh Alkas Formatio	Palani Formation

Sed. Cycle --- Sedimentary Cycle

Selimiye Formation (Tekin 2001), while in SE. Turkey, are not recorded (Egeran 1951).

In Iran, the Oligocene units were determined from North and Northwest as reefal carbonate facies (Ditmar et al. 1971)

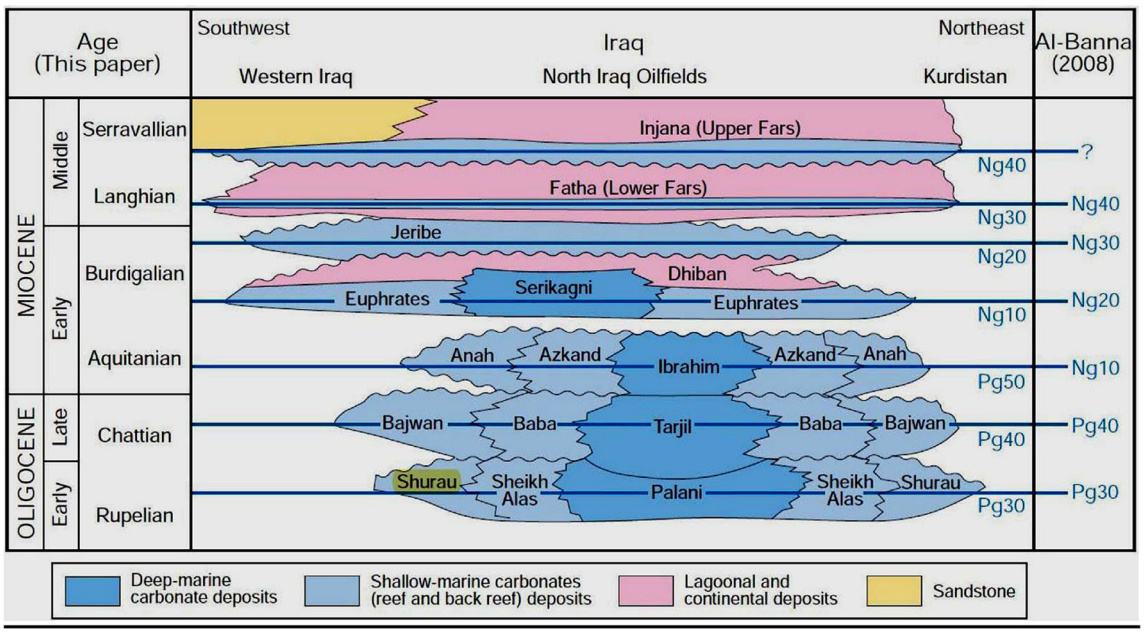

Fig. 1 Tertiary sequence stratigraphy of Iraq. The Oligocene/Miocene boundary was tentatively interpreted as occurring between the Tarjil and Ibrahim sequences. Revised boundary the positions of Van Bellen et al. (1959–2005), and maximum flooding surfaces (MFS) of (Sharland et al. 2004) are after Al-Banna (2008)

represented by Asmari and Khamir formations which are correlated to Early-Middle Oligocene Formations in Iraq. Buday (1980). The absence of Oligocene deposits over most of Kuwait (Mukhopadhyay Al-Sulaimi et al. 1996), due to the sea regressive at the end of Eocene, and an occurrence of widespread unconformity and finally in Saudi Arabia, the Oligocene strata are missed (Jones and Rocy 1994) in Boukhary et al. (2005). The first biostratigraphic study of the Oligocene–Miocene succession of Iraq was reported by Henson (1948, 1950), and studied by Van Bellen (1956), Bellen et al. (1959) and revised by Adams (1968), Al-Sayyab and Al-Hamdani (1990) described the biostratigraphy of the part of Oligocene and Miocene successions. Also, Lawa and Ghafur (2015) studied biostratigraphy of Oligocene–Miocene succession in Sangaw and Garmian area.

The main aims of this study are to study the lithostratigraphic units of the studied section, to identify the large benthic foraminifera (LBF) assemblages of each lithostratigraphic unit, to study biostratigraphy and age determination of the studied section, and finally to make regional correlation of the recognize biozones with other studies.

Geological setting

This study is focusing on the Oligocene-Early Miocene rocks of the Darzila section, near the Ashdagh Mountain, Sangaw area, near Darzila village, Kurdistan Region, Northeastern Iraq. Forty meters of this section is sampled and located at latitude (N: 35° 08‾ 36.4‾), and longitude (E: 45° 17‾ 21.3‾), about 15 km South-East of Sangaw town, (Fig. 2). Darzila section is located at South-East limb of Ashdagh anticline, in the Darzila Gorge (Fig. Fig. 3). The studied area is located within Low folded zone, specifically in (Butmah-Chamchamal) subzone, which is represent the NE unit of the foothill zone, and its topographically is the highest part of the zone (Jassim and Goff 2006). The NE boundary of this zone lies along SW flanks of the anticlines of the high folded zone that includes Haibat Sultan and Qara Dagh. According to Jassim and Goff (2006), Oligocene sediments are absent on the Butma- Chamchamal Subzone, on the High Folded Zone, over most of the southwest part of the Balambo-Tanjero Zone, and on the Northern Thrust Zone. The large uplift during the Oligocene time in NE of Iraq and in the west of Iraq causes none deposition of Oligocene sediments over most of the Rutba Subzone, the Salman Zone, and on the Zubair and Euphrates Subzone of the Mesopotamian Zone, while the highest thickness of the Oligocene sequence is more than 370 m thick between Kirkuk and Kor Mor structure in NE Iraq (Jassim and Goff 2006).

Previous works

In Iraq and exactly during the late twentieth century (exactly 1948–1990), rich microfossils associations are collected and recorded from outcrops and subsurface of the Oligocene and Miocene formations by different authors. Due to economic importance, the Oligocene succession attracted many researchers to study its stratigraphic units in a different locality. Henson (1948, 1950) recorded the Oligocene-Miocene successions, which described the main limestone of the Kirkuk Group. Ghafur (2012) investigated sedimentology and reservoir characteristics.

The Oligocene-Early Miocene carbonates (Kirkuk Group) of southern Kurdistan are in Ashdagh area. Kharajiany et al. (2014) studied the Oligocene and Miocene Rock beds in Mamlaha anticline at about 20 km to west of the Darzila section. Lawa and Ghafur (2015) studied sequence stratigraphy and biostratigraphy of the prolific late Eocene, Oligocene, and early Miocene carbonates in the Sangaw area and they recorded the following formations in Ashdagh area (Sheikh Alas, Baba, Bajwan, Anah, Azkand, Euphrates, Jeribe, and Fatha formations), with six biozones from eight outcrops and seven wells as in Ashdagh, Sangaw- Kalar, Segerma, and Bamo covering almost Garmian district. Ghafor and Ahmad (2019) studied the biostratigraphy and paleoecology of Anah Formation in the Pungalla village, Sangaw area, Sulaimaniya, Northeastern Iraq. Ahmad (2020) studied the systematic description and biostratigraphy of Pungalla and Darzila sections in Sangaw area Northeastern Iraq, and finally, Qader (2020) argued stratigraphy, microfacies, and paleoenvironment of the Oligocene–Early Miocene successions in Sagrma and Aj-Dagh structures, Kurdistan Region, Northeastern Iraq.

Materials and methods

Surveying the area and collecting data from the field is the first step for this study (Fig. 4a, b). Forty samples are taken from both carbonate and marl layers. One hundred thin-sections are prepared in the laboratory; from each sample, more than one thin section is prepared in different directions in order to get clear of large benthic foraminifera (LBF). The thin sections are examined by using a polarized and stereomicroscopes for foraminiferal identification. All thin sections were preserved at the Department of Geology, College of Science, University of Sulaimani. The taxonomic determination of the large benthic foraminifers (LBF) is based on the foraminiferal classifications by previous authors such as Seyrafian and Mojikhalifeh (2005); Sirel et al. (2013); Gedik (2014); Serra-Kiel et al. (2016); Roozpeykar and Moghaddam (2016); Ferrandez-Canadell and Bover-Arnal (2017);

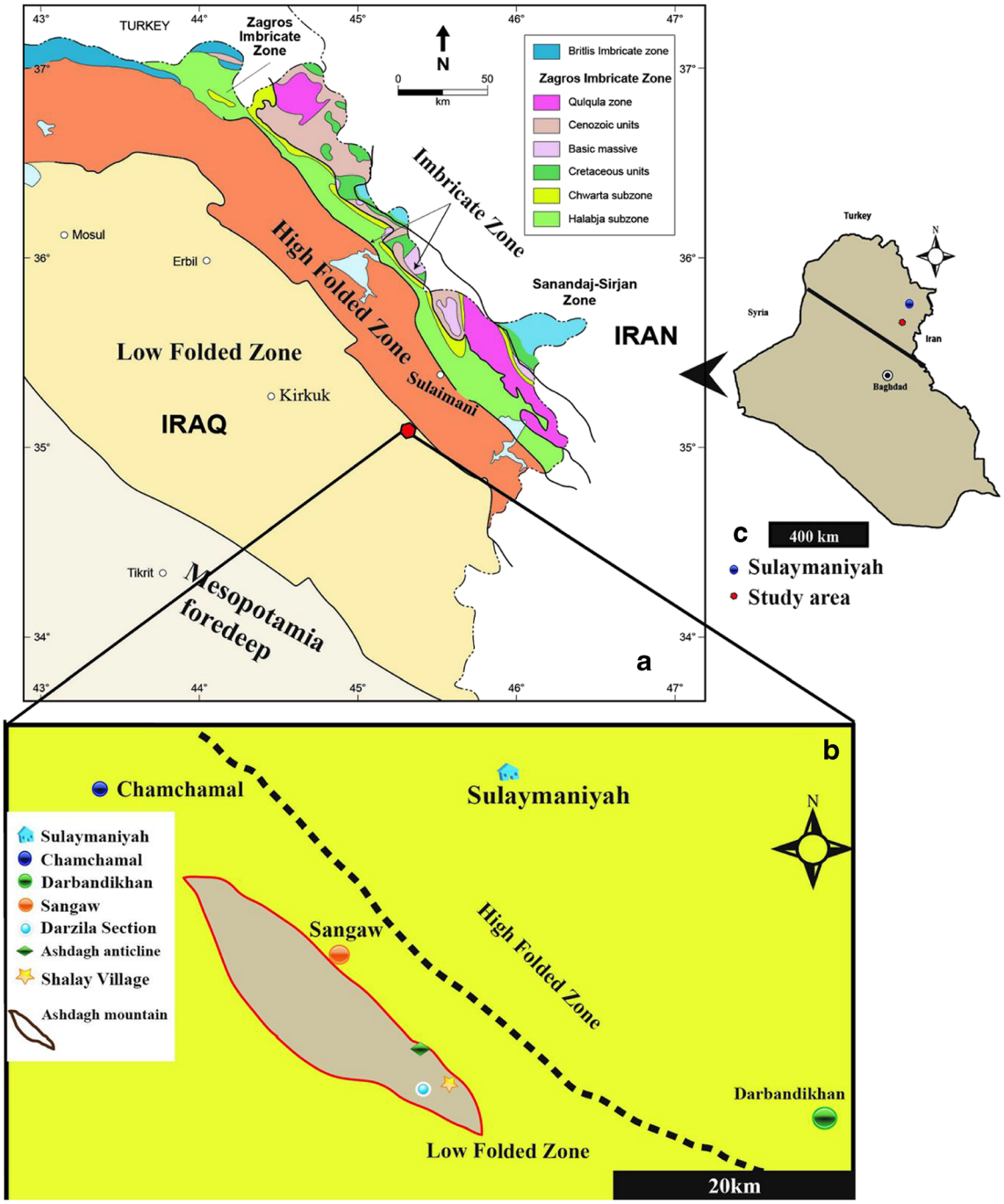

Fig. 2 Location map of the studied section. **a** Tectonic map of Iraq after (Al-Kadhimi et al. 1996). **b** Location map of the study area. **c** Location map of the studied area

Boudagher-Fadel (2018); Joudaki and Baghbani (2018); and Moghaddam et al. (2019).

Results

The outcrops of the Darzila section consist of thin to thick-bedded and massive limestones, highly jointed, fractured and are dominated by benthic foraminifera and non-foraminifera. The existing benthic foraminifera correspond to large benthic foraminifera (LBF), and non-foraminifera are dominated by echinoid fragments, bryozoan, red algae, green algae, bivalve, and coral. In the studied area, the Oligocene–Miocene successions of the studied section were subdivided into six lithostratigraphic units, which are (from old to young), Sheikh Alas, Baba, Bajawan, Anah, Jeribe, and Fatha

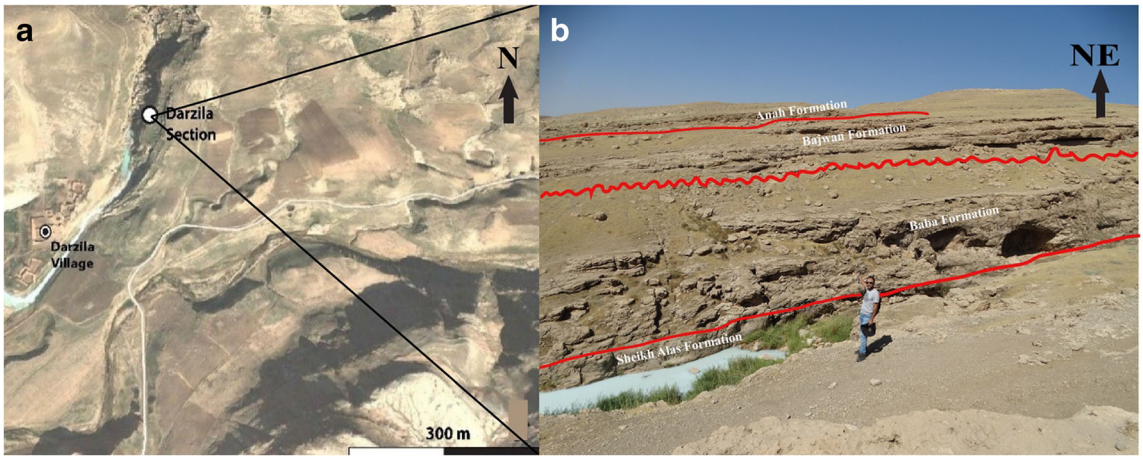

Fig. 3 **a** Satellite map of the Darzila section, Ashdagh anticline. **b** Field photograph of the exposed lithostratigraphic units at the Darzila section

formations from which six biozones of large benthic foraminifera (LBF) are identified from the lower to the upper part of the section.

Lithostratigraphic units

The Oligocene and Miocene sequence is deposited on a carbonate platform at the Arabian northeastern margin, as a part of an inter-orogenic sag-interior basin during the evolution history of the Zagros Foreland basin (Al-Qayim 2006, 2012). The outcrop of the Darzila section is subdivided into six formations; based on the lithology, and stratigraphic position, these units are (Sheikh Alas; Baba; Bajwan; Anah; Jeribe and Fatha) formations (Fig. Fig. 5), which are arranged from older to younger as seen below.

Sheikh Alas Formation

The type section of this formation is located about (732 m) of the Sheikh Alas village on the northern dome of the Qarah Chauqh- Dagh, north Iraq, and it is described for the first time by Van Bellen (1956). It has a thickness about 26 m which composed of dolomitic and recrystallized porous limestone, generally porous and occasionally rubbly; the lower boundary is unconformable with Eocene shoal limestone while the upper limit is conformable with the Shurau Formation. The lower part of this formation was deposited in a fore slope environment, whereas the upper part represents a lagoonal environment, without any explanation while these two different facies occur next to each other (Majid and Veizer 1986). According to Bellen et al. (1959), the formation identified by only rare, poorly preserved fauna of foraminifera like *Nummulites intermedius-fichteli,* and it is considered to be of "lower" Oligocene age. Sheikh Alas Formation of the studied section is composed of white, massive fossiliferous, highly jointed, fractured, and cavernous Nummulitic limestone (Fig. 6a), also contains chert bed of about 10 cm thick, with many microfossils and thickness of this formation is about five meters, the lower boundary is not indicated, but it is overlain by Baba Formation conformably.

Fig. 4 **a**, **b** Field photograph showing sampling and labeling at the Darzila section, Ashdagh anticline, Sangaw area, in different time and days

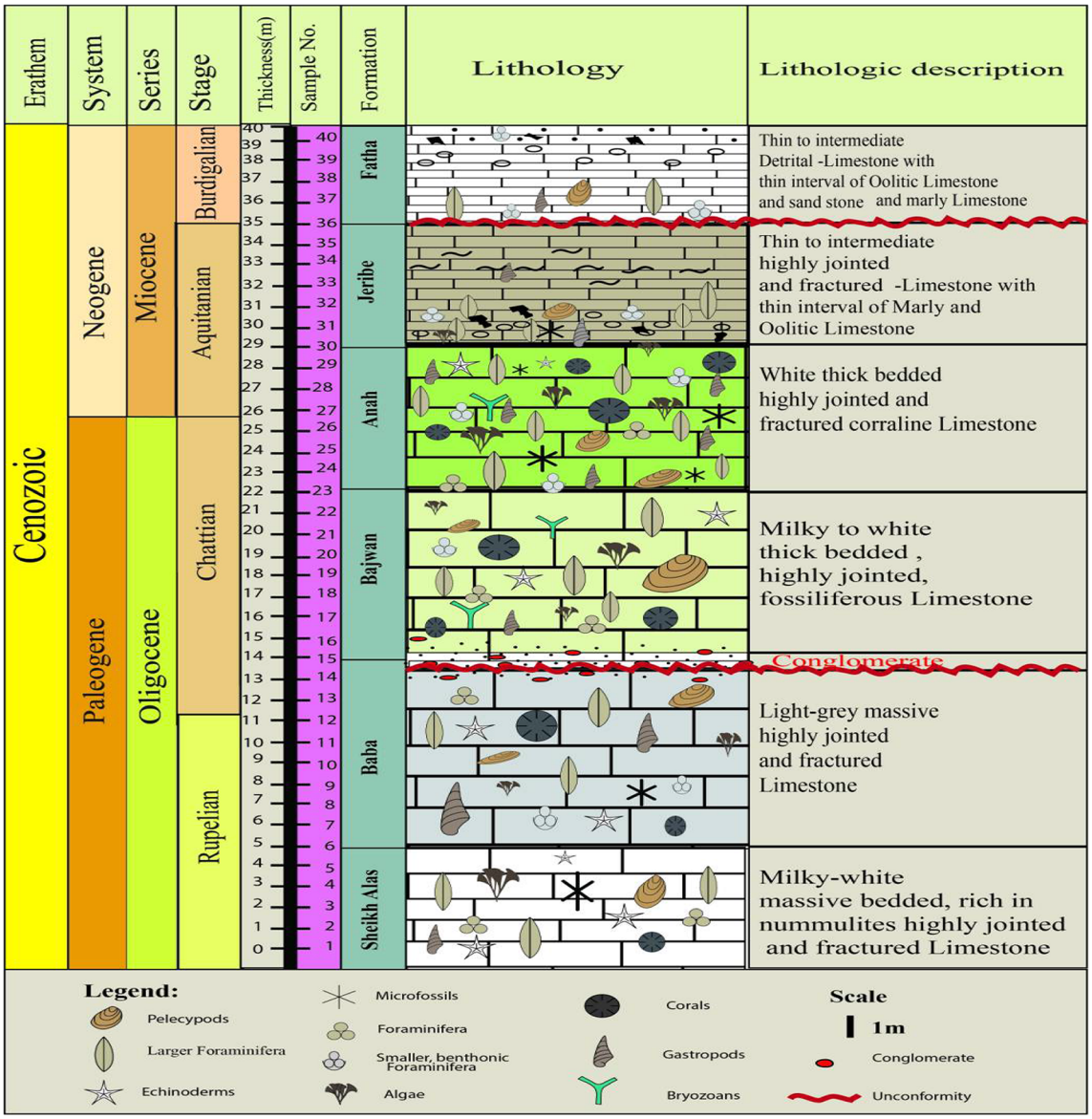

Fig. 5 Lithostratigraphic column of the Oligocene-Early Miocene rock units at the Darzila section, Ashdagh anticline, Sangaw area

Baba Formation

Baba Formation was described for the first time by Van Bellen (1956), from Kirkuk well − 10, on the Baba dome of the Kirkuk structure, which is about 20 m thick and composed of porous dolomitized limestone of fore-reef environment of lagoonal Bajwan Formation and changes seawards into Tarjil Formation, that is from the second reef cycle of the Middle Oligocene age. This formation is covered conformably by Bajwan Formation and underlies unconformably by Shurau Formation; he found different types of fossils in this formation such as rare bryozoa, rare *Lepidocyclina* s.l. spp., *Nummulites intermedius-fichteli*, and Haime, *Operculina* sp.; occasionally, *Rotalia viennoti* and *Heterostegina* cf. *assilinoides* also occur; a "middle" Oligocene age has been adopted for this formation (Bellen et al. 1959). Baba Formation in the Darzila is generally composed of 8 m thick of light grey, highly fractured, and cavernous massive, fossiliferous limestone containing large gastropods; the formation overlies Sheikh Alas Formation conformably and underlain by Bajwan Formation unconformably which represents by one-meter-thick of conglomerate located between these two formations (Fig. 6b).

Bajwan Formation

Van Bellen (1956) defined the Bajwan Formation from well Kirkuk-109 and it consists of the alternation of tight miliolid limestone with more porous, dolomitized coralline algal reef limestone, with relatively abundant coral fragments and thin argillaceous limestone beds; the total thickness is about 39 m,

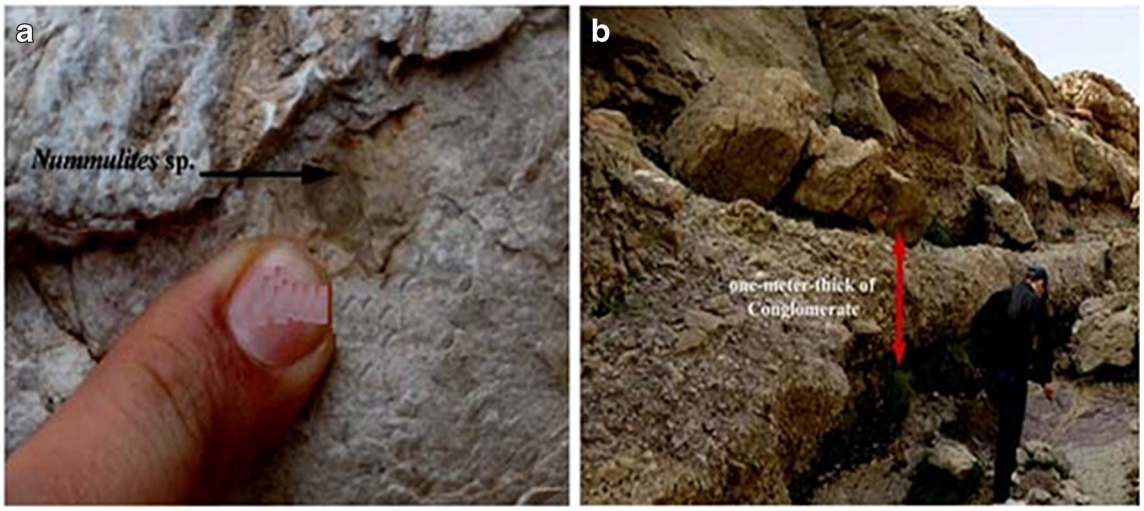

Fig. 6 **a** Image showing *Nummulites*, in the sheikh Alas Formation, Darzila section, Ashdagh anticline, Sangaw area. **b** Field photograph showing conglomerate bed located between Baba and Bajwan formations at the Darzila section, Ashdagh anticline, Sangaw area

and it is conformably underlain by the Baba Formation and overlain by the Lower Fars Formation unconformably, rich in fossils such as *Actinacis* sp., Anthozoa spp. indet., Bryozoa spp. indet., Corallinacaea spp. indet., and the following foraminifera: *Archaias kirkukensis*, *Austrotrillina howchini*, *Peneroplis evolutus*, *Peneroplis thomasi*, *Praerhapidionina delicata*, occasionally *Borelis pymaea*, *Meandropsina anahensis*, and *Rotalia viennoti* (Bellen et al. 1959). Bajwan Formation of the studied section consists of milky thick-bedded fossiliferous limestone, with tight, cream-colored, backreef miliolid limestones, alternating with more porous, partly dolomitized, rotalid algal reef limestones with fairly abundant coral fragments; the thickness is about 8 m thick, rich in large benthic foraminifera (LBF). Anah Formation overlies the Bajwan Formation conformably, and the later formation overlies the Baba Formation unconformably (Fig. 7).

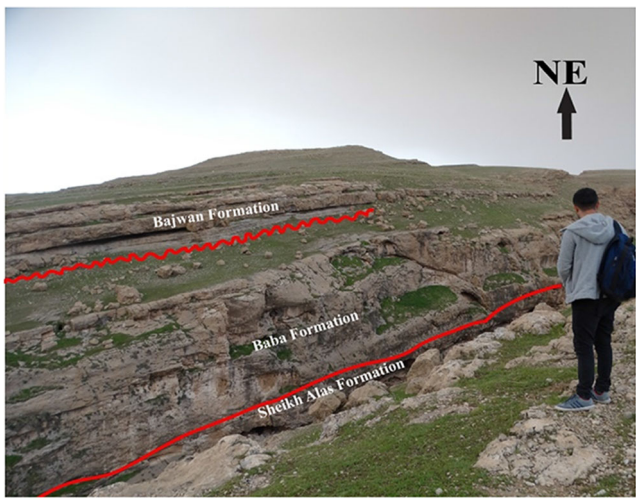

Fig. 7 Field photographs showing lower and upper boundary of the Baba Formation at the Darzila section, Ashdag anticline, Sangaw area

Anah Formation

This formation was studied by Van Bellen (1956) for the first time, which is located on the Euphrates river, about 15 km east of Nahiyah village close to Anah, composed of limestone, grey, breccious, recrystallized, detrital and coralline, and its thickness in the type section is about 45 m thick. The common fossils include algae, anthozoa, bryozoa, echinoidea, mollusca, and abundant foraminifera: *Archaias* sp., *Austrotrillina howchini* (Schlumberger), *Borelis pygmaea*, *Heterostegina* cf. *assilinoides*, *Miogypsinoides complanata Rotalia viennoti*, and numerous undetermined miliolids (Bellen et al. 1959). The lower contact of this formation is conformable with the Azkand Formation, while the upper contact is unconformable with the Euphrates Formation. The stratigraphic position of this formation is considered to be a back-reef, and the fore-reef equivalent of this unit is the Azkand limestone, and probably of the Late Oligocene age (Abid 1983). The Anah Formation of the Darzila section is about 7 m thick and composed of white, thick-bedded highly jointed and fractured coralline limestone (Fig. 8a), which is overlain by Jeribe Formation conformably, and underlain by Bajwan Formation conformably.

Jeribe Formation

The first definition of the Jeribe Formation was showed by Van Bellen (1956), near Jaddala Village, Jebel Sinjar, which represents by 73 m of massive, recrystallized, dolomitized limestone, rich in fossils such as *Amphistegina* sp., *Borelis melo* var. *curdica*, *Elphidium* sp., *Nonion* sp., *Rotalia beccarii* (chilostomellids, dendritinids, miliolids, ostracods, lithophyllid, fragmentary gastropods, lamellibranchs, and echinoids), and *Clausinella* sp. (Bellen et al. 1959).

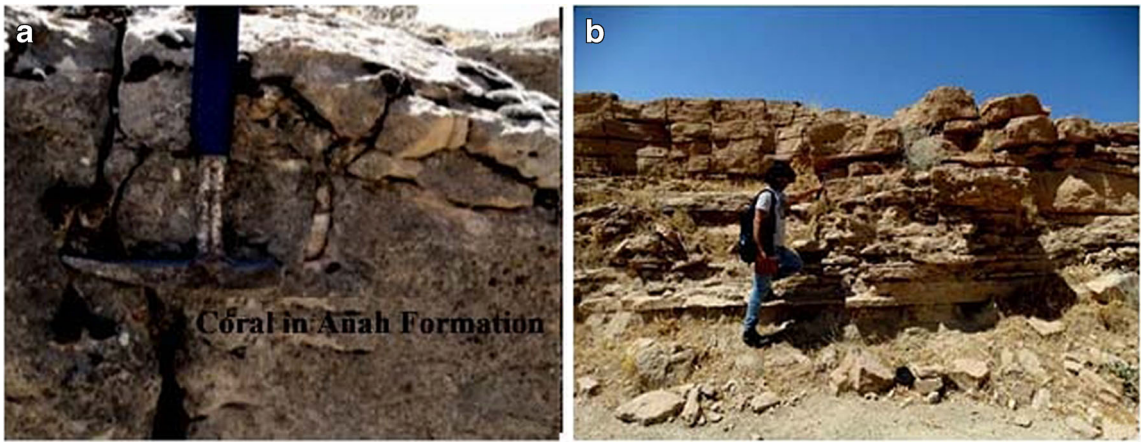

Fig. 8 **a** Field photograph showing coral, within the Anah Formation at the studied section. **b** Field photograph showing highly jointed and fractured limestone beds of Jeribe Formation, at the Darzila section

Serikagni Formation underlies the Jeribe Formation unconformably, and it is overlain by Fatha Formation unconformably, which indicated by basal conglomerate. The Jeribe Formation belongs to lower Miocene age (Bellen et al. 1959). The Jeribe Formation is recognized in the studied section, which is composed of 6 m of thin to intermediate highly jointed and fractured limestone with a thin interval of marly and oolitic limestone; this unit is overlain unconformably by the Fatha Formation, which is indicated by the gap (missing age) in the upper part of the unit, and underlies conformably by Anah Formation (Fig. 8b).

Fatha Formation

The Lower Fars Formation was originally described from Masjd Suliman area in the Fars Province of Iran by Busk (1918), in Bellen et al. 1959), and Elder (1958) indicate the type section of this formation near Makhul mountain that is about 445 m thick. The name of Lower Fars was replaced by Fatha in Iraq by Al-Rawi et al. (1992). The common fossils in the type locality are *Clausinella lamidei Elphidium* sp., *Rotalia beccarii*, miliolids, ostracods, etc. The index fossils are *Clausinella* spp. and *Ostrea latimarginata*, which probably indicate the age of middle Miocene (Bellen et al. 1959). Fatha Formation consists of thin to intermediate detrital limestone with a thin interval of oolitic limestone, marly limestone with few beds of gypsum and marlstone. In the studied section, the thickness of the unit is about 5–6 m, which refers to the lower most part of the formation. The formation is overlain Jeribe Formation conformably.

Biostratigraphy

About 40 m thick of Oligocene-Miocene succession have been studied biostratigraphically with recognition of forty-three species from twenty-nine genera of large benthic foraminifera (LBF), echinoid fragments, bryozoan, red algae, green algae, bivalve fragments, coral, gastropods, and pelecypods (Plates 1, 2, 3, 4, and 5). The biozones are arranged from old to young (Fig. 9), and each biozone represents a specific rock unit and the biostratigraphic zones were correlated with the other biozones (Table 2).

Nummulites vascus-Nummulites fichteli assemblage zone (Rupelian)

This zone was characterized by the assemblage of the nominate taxa (*Nummulites vascus* and *Nummulites fichteli*), which consists of large benthic foraminifera (LBF) taxa (*Nummulites vascus* and *Nummulites fichteli*). This biozone has 5 m thickness of fore-reef Sheikh Alas Formation from sample number 1–6, and the most diagnostic species include large benthic foraminifera (*Nummulites fichteli, Nummulites vascus, Austrotrillina paucialveolata,Austrotrillina* sp., *Hetrohestigerina asillinoides, Operculina complanata, Pyrgo* sp., *Rotalia viennoti, Sphaerogypsina* sp., *Spiroloculina cylindracea, Discorbis* sp., *Textularia* sp., *Valvulina* sp.); also, it is associated with the green algae and echinoid fragments. This biozone is time equivalent to *Nummulites vascus- Nummulites fichteli* assemblage zone of (Bellen et al. 1959) and Laursen et al. (2009) also correlate with biozones SBZ21 of Cahuzac and Poignant (1997) in the mediterean region, and equivalent to biozone *Nummulites fichteli-Nummulites intermedius* assemblage zone (BZ1) of Al-Banna et al. (2010), Moghaddam et al. (2019), and *Nummulites fitchteli* (NF), biozone of Lawa and Gafur (2015) which indicates Rupelian age.

Eulepidina dilatata-Nephrolepidina marginata concurrent-range zone (Rupelian-Early Chattian)

Biostratigraphic interval of this zone was characterized by the concurrent-range of the nominate taxa (*Eulepidina dilatata*,

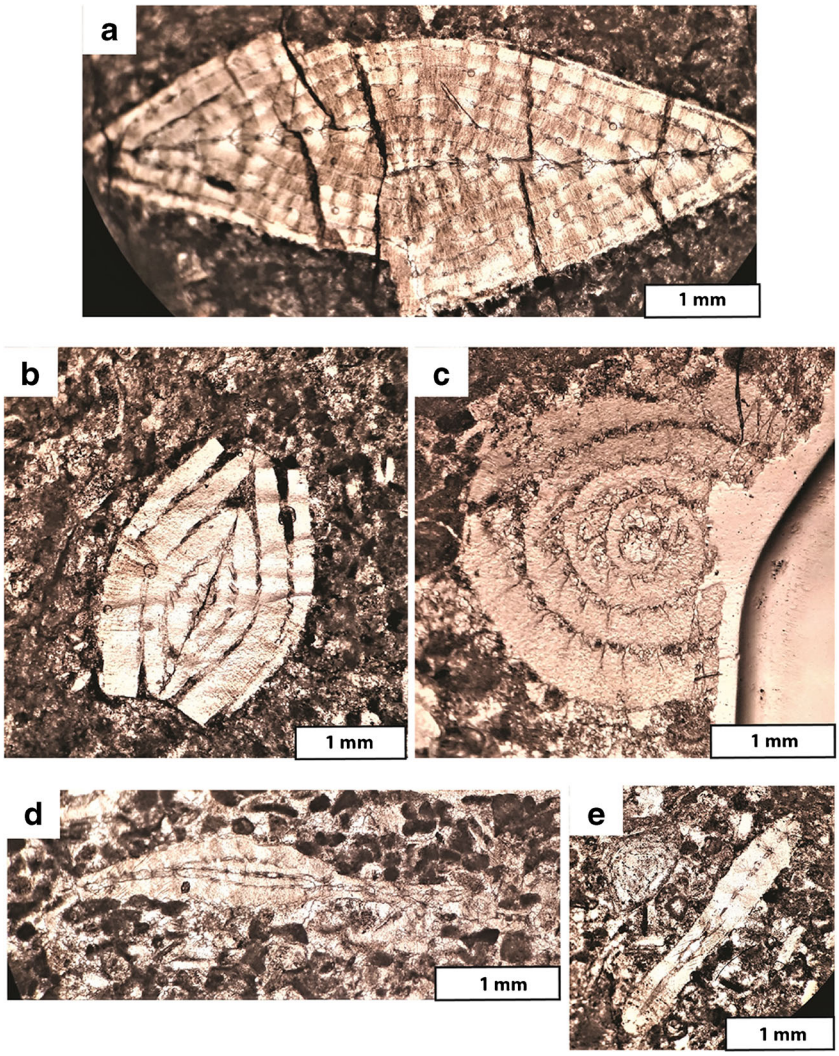

Plate 1 Large benthonic foraminifera (LBF) from the Sheikh Alas Formation, Darzila section. **a** *Nummulites fichteli* Michelotti, 1841, subaxial section sample no. (2); **b** and **c** *Nummulites vascus* Joly and Leymerie (1848); **b** subaxial section, **c** equatorial section, samples no. (2, and 4); **d** *Heterostegina assilinoides* Blanckenhorn, 1890, subaxial section, sample no. (1); **e** *Operculina complanata* (Defrance in de Blainville, 1822), axial section, sample no. (4)

and *Nephrolepidina marginata*). This biozone started by the First Appearance Datum (FAD) of *Eulepidina dilatata*, in sample number 6, and ended by the Last Appearance Datum (LAD) of *Nephrolepidina marginata*, in sample number 15. The zone is about 9 m thickness which started from the sample number 6–15, and refers to the fore-reef Baba Formation and the most diagnostic species include *Austrotrillina* sp., *Bigenerina* sp., *Discocyclina* sp., *Discocyclina* sp.1, *Eulepidina dilatata, Hetrohestigerina asillinoides*, *Miogypsinoides* sp., *Neorotalia viennoti*, *Operculina complanata*, *Pyrgo* sp., *Praerhapydionina delicata, Planorbulina* sp., *Nephrolepidina marginata*, *Nephrolepidina praemarginata*, *Nephrolepidina* sp., *Miogypsinoides formosensis*, *Amphistegina bohdanowiczi*, *Rotalia viennoti*, *Sphaerogypsina* sp., *Spiroclypeus* sp., *Spiroloculina cylindracea*, *Triloculin tricarinata*, *Textularia* sp., *Valvulina* sp., *Triloculina trigonula*, *Lepidocyclina* sp., and some species of non-foraminifera are recognized: (*Titanoderma pustulatum*, *Lithothamnion* cf. *giammarinoi*, *Lithoporella melobesioides*, *Ditrupa* sp., *Tubucellaria* sp., green algae, corals, echinoid fragments, gastropoda, pelecypoda, and bryozoa). This zone is correlated with biozones *Lapidocyclina Lapidocyclina*/ *Nummulites* of Bellen (1956) and SBZ22A of Cahuzac and Poignant (1997), and *Lepidocyclina-Operculina-Ditrupa* assemblage zone of Moghaddam et al. (2019).

Praerhapydionina delicata-Peneroplis evolutus—-concurrent range zone (Chattian)

Biostratigraphic interval of this zone was characterized by the concurrent range of the nominate taxa (*Peneroplis evolutus*,

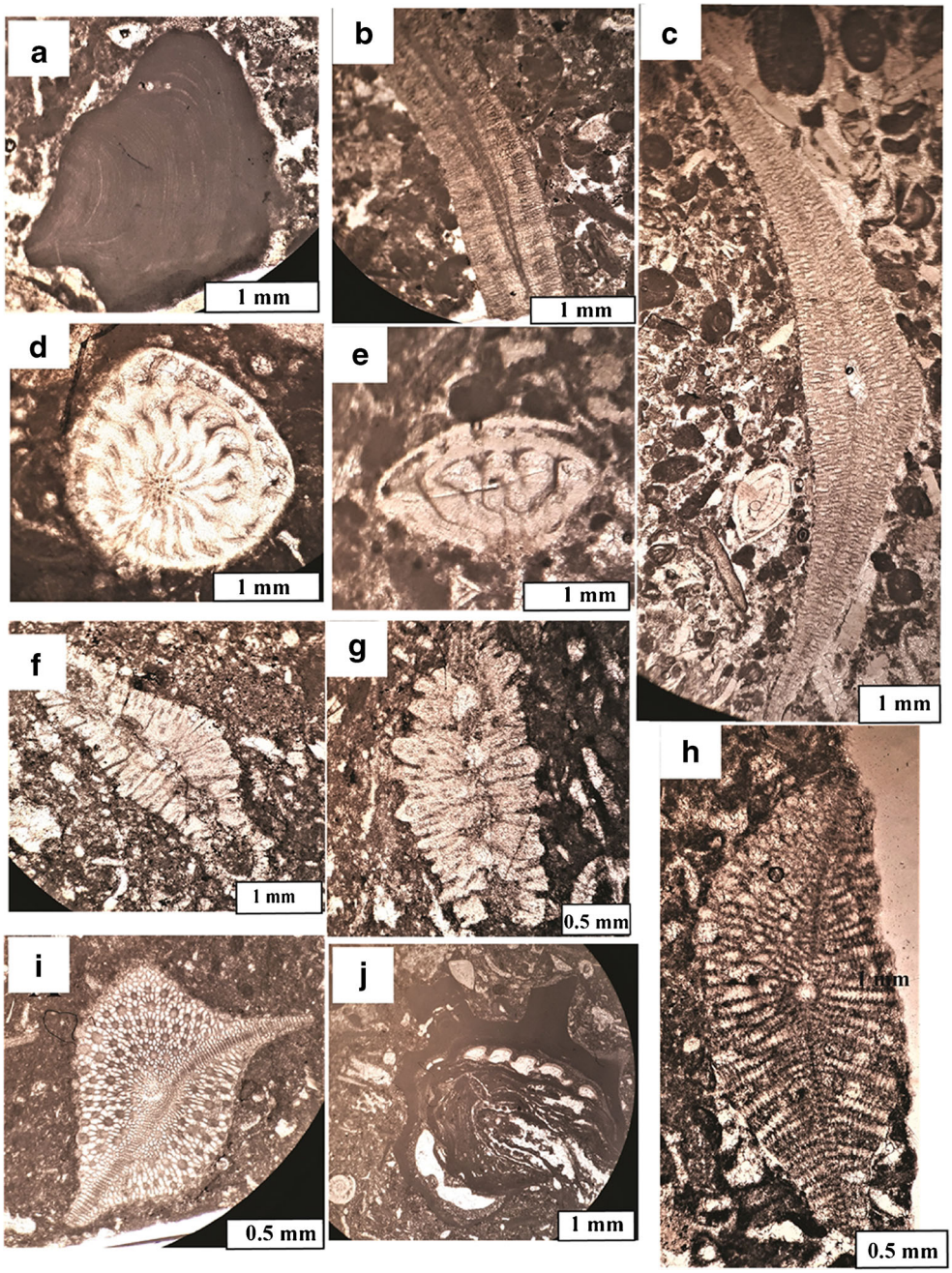

Plate 2 Large benthonic foraminifera (LBF), and coralline algae from the Baba Formation, Darzila section. **a** *Lithothamnion* cf. *giammarinoi* Fravega, Piazza & Vannucci, 1993, sample no. (13); **b**, **c** *Eulepidina dilatata* (Michelotti, 1841), **b** sub–axial section, **c** axial section, sample no. (6, and 7); **d**, **e** *Amphistegina bohdanowiczi* Bieda, 1936, **d** oblique section, **e** subaxial section, sample no. (12, and 13); **f**, **g** *Miogypsinoides* sp., axial section, sample no. (13, and 14); **h** *Nephrolepidina praemarginata*, axial section, sample no. (13); **i** *Nephrolepidina* sp., subaxial section, sample no. (14); **j** *Lithoporella melobesioides* Foslie, D. Basso, et al., 2019, sample no. (13)

and *Praerhapydionina delicata*). This zone includes of about 8 m thick of reef/back reef Bajwan Formation from the samples 15–23, which starts by the First Appearance Datum (FAD) of *Peneroplis evolutus*, in the sample number 15, and ended by the Last Appearance Datum (LAD) of *Praerhapydionina delicate*, in the sample number 23. This zone contains many species such as *Praerhapydionina delicata*, *Austrotrillina striata*, *Austrotrillina asmariensis*, *Peneroplis evolutus*, *Peneroplis thomasi*, *Triloculina trigonula*, *Pyrgo* sp., *Spiroloculina* sp., *Textularia* sp., and the non- foraminifera assemblages include coral, echinoid fragments, gastropoda, pelecypoda, and bryozoa. This biozone is time equivalent to biozones *Eulepidina fomosoides*, and *Nummulites vascus- Nummulites fichteli- Eulepidina (*SBZ22a SBZ22b) of Cahuzac and Poignant (1997), recorded as Late Rupelian-Early Chattian, and it is correlated with the biozone *Praerhapydionina delicata-Austrotrillina howchini-Peneroplis evolutus* assemblage zone (BZ3) of Al-Banna et al. (2010) and equivalent to *Praerhaypidionina delicata* (PD), biozone of Lawa and Ghafur (2015); also, it is corresponding to biozone *Lepidocyclina–Operculina–Ditrupa* assemblage zone of Joudaki and Baghbani (2018).

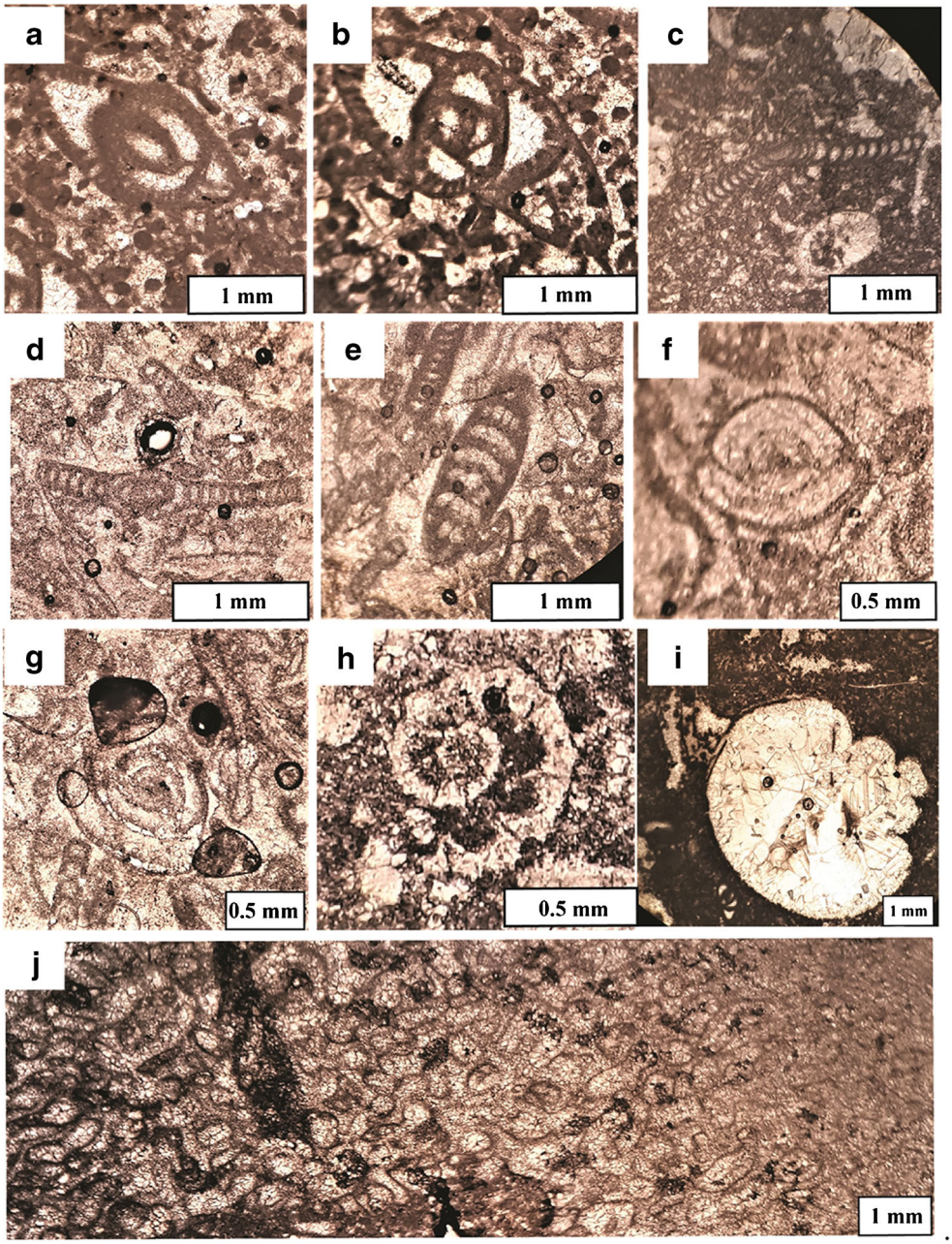

Plate 3 Larger benthonic foraminifera (LBF), and non-foraminifera from the Bajwan Formation, Darzila section. **a** *Austrotrillina asmariensis* Adams, 1968, equatorial section, sample no. (18); **b** *Austrotrillina striata* Todd & Post, 1954, **b** equatorial section, l-subequatorial section, sample no. (18); **c**, **d** *Peneroplis* cf. *evolutus* Henson 1950, **c** axial section, **d** subaxial section, sample no. (19, and 21); **e** *Praerhapidionina delicata* Henson 1950, Oblique longitudinal sections, sample no. (21); **f** *Pyrgo* sp., equatorial section, sample no. (22); **g** *Triloculina trigonula* Lamarck, 1804, equatorial section, sample no. (22); **h** *Rotalia viennoti* Greig, 1935, equatorial section, sample no. (22); **i** Gastropoda, sample no. (18); **j** Coral, sample no. (20)

Meandrospina anahensis-Austrotrillina asmariensis interval zone (Chattian-Early Aquitanian)

Biostratigraphic interval of this zone was characterized by the concurrent range of the nominate taxa (*Meandrospina anahensis*, and *Austrotrillina asmariensis*). This zone consists of 7 m thick of reef/back reef Anah Formation from the samples 23–30, which starts by the First Appearance Datum (FAD) of *Meandrospina anahensis*, in the sample number 23, and ended by the Last Appearance Datum (LAD) of *Austrotrillina asmariensis*, in the sample number 30. The most diagnostic species include *Austrotrillina howchini*, *Austrotrillina asmariensis*, *Austrotrillina* sp., *Bigenerina* sp., *Dendritina rangi*, *Meandrospina anahensis*, *Pyrgo* sp., *Peneroplis evolutus*, *Peneroplis thomasi, Quinloculina* sp., *Triloculina trigonula, Textularia* sp., and *Valvulina* sp., and includes some non-foraminifera species like *Ditrupa* sp., coral, and gastropoda. This zone is correlated with biozones *Miogypsinoides, Miogypsinoides/Lapidocyclina* zone of Bellen (1953) and biozones SBZ23 and SBZ24 of Cahuzac and Poignant (1997), and this zone is time equivalent to the Upper Oligocene-Lower Miocene (Chattian-Aquitanian, P22-N4, equivalent to Te1-4-Te5) assemblage of Sharaf et al. (2005) and correlated with *Austrotrillina howchini*, (SBZ 24), biozone of Lawa and Gafur, (2015), also corresponding with biozone *Miogypsinoides–Lepidocyclina– Nummulites bouille* of Nouradini et al. (2019).

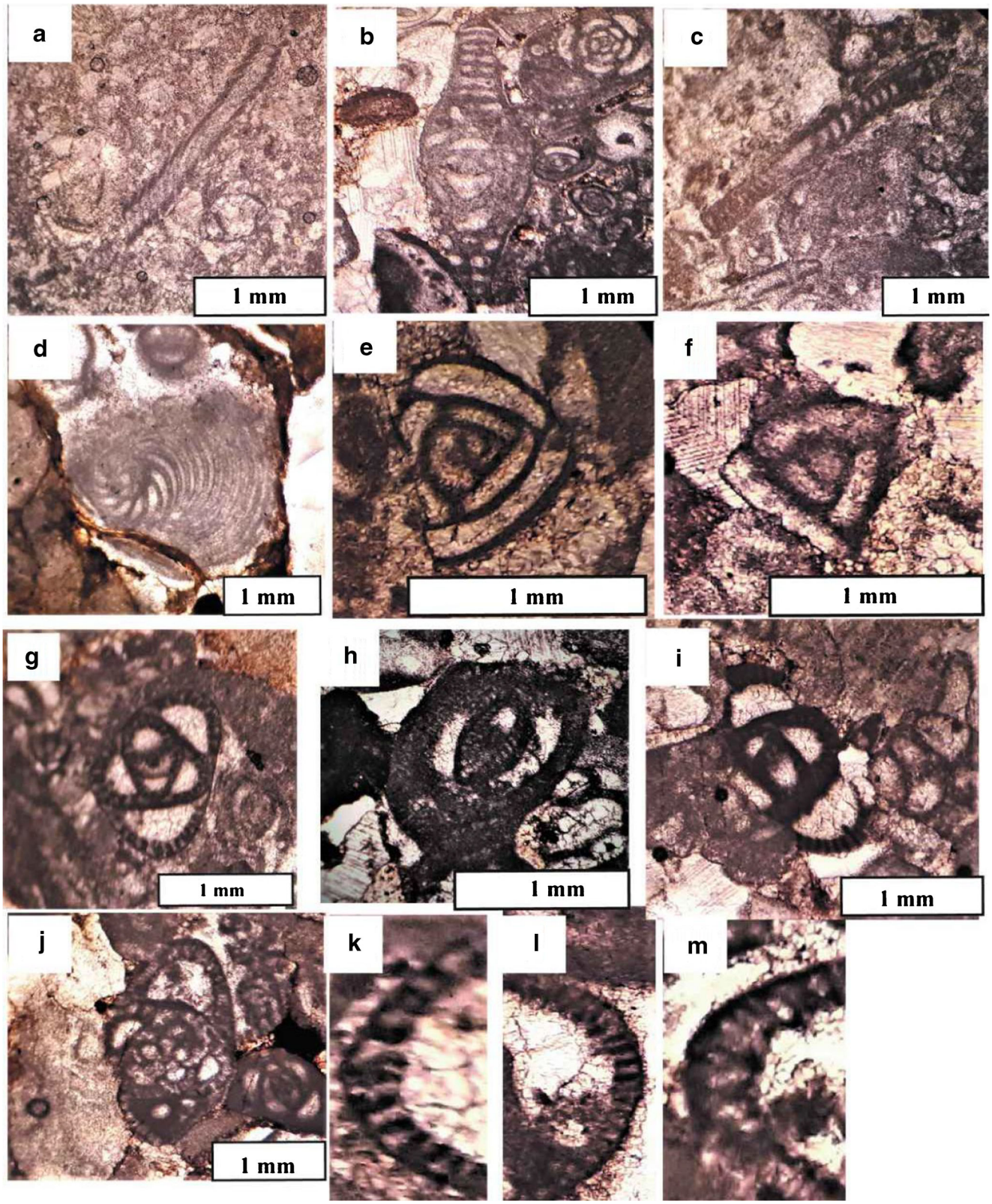

Plate 4 Larger benthonic foraminifera (LBF) from the Anah Formation, Darzila section. **a** *Meandropsina anahensis* Henson, 1950, axial section, sample no. (25); **b** *Archaias hensoni* Smout and Eames, 1958, sample no. (28); **c**, **d** *Peneroplis evolutus* Henson, 1950, **c** axial section, **d** equatorial section, sample no. (26); **e** *Triloculina trigonula* Lamarck, 1804, equatorial section, sample no. (28); **f** *Triloculina tricarinata* (d'Orbigny, 1826), equatorial section, sample no. (28); **g–k** *Austrotrillina striata* Todd & Post, 1954, equatorial section, sample no. (28); **h-i-l** *Austrotrillina asmariensis* Adams, 1968, equatorial section, sample no. (28); **j-m** *Austrotrillina howchini* (Schlumberger, 1893), equatorial section, sample no. (28)

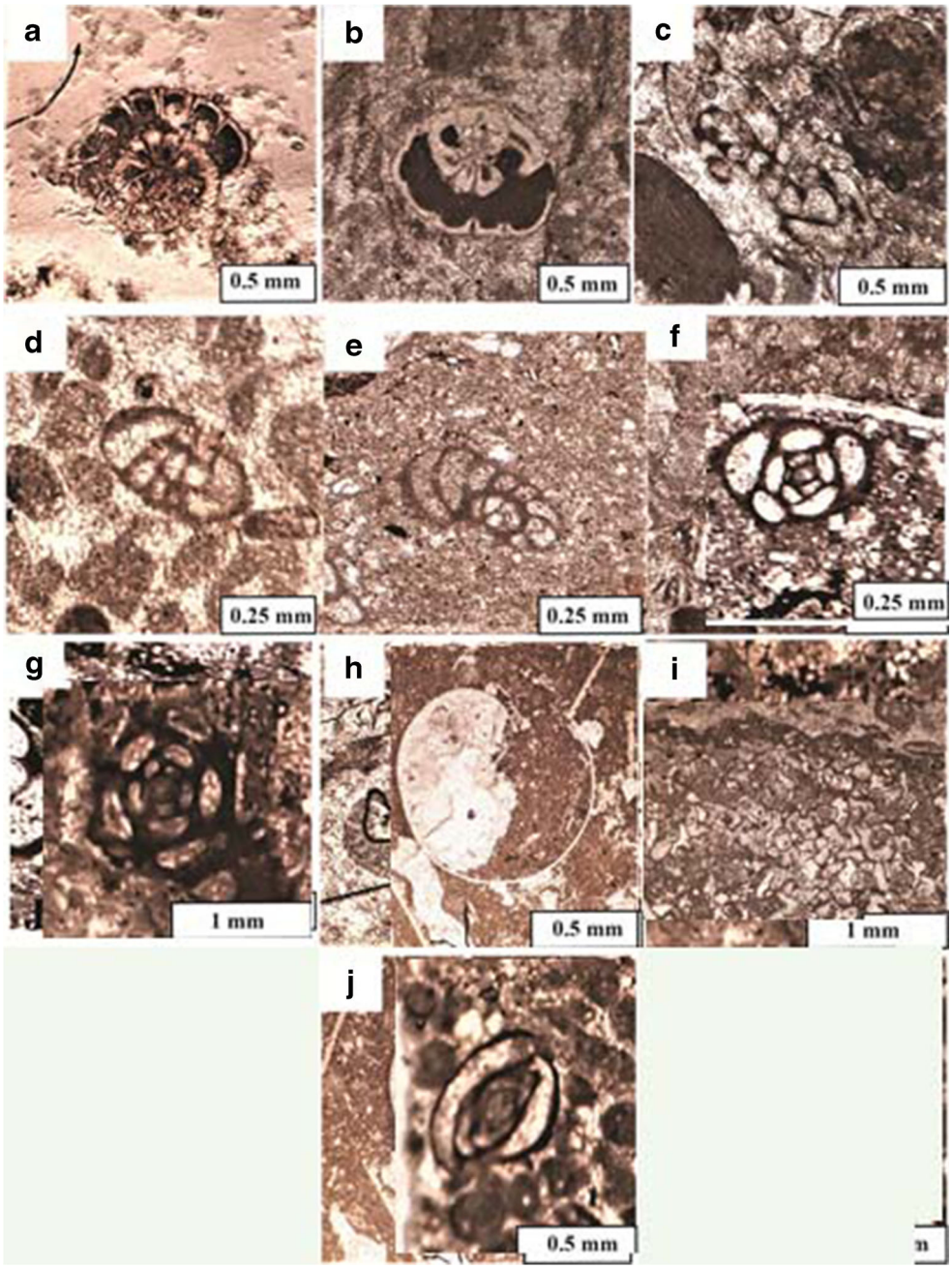

Plate 5 Non- Foraminifera, and Larger Benthonic Foraminifera (LBF) from the Jeribe and Fatha Formation, Darzila section. **a, b** *Ammonia beccarii* (Linne, 1758), **a** equatorial section, **b** axial section, sample no. (31); **c, d, e** *Dendritina rangi* d'Orbigny emend. Fornasini, 1904, axial section, sample no. (31); **f, g**. *Quinqueloculina* sp., equatorial section, sample no. (32, and 37); **h** *Gastropoda*, sample no. (30); **i** Coral, sample no. (30); **j**. Miliolids sp., equatorial section, sample no. (31)

Ammonia beccarii-Austrotrillina howchini assemblage zone (Aquitanian)

Biostratigraphic interval of this zone was characterized by the assemblage of the nominate taxa (*Ammonia beccarii* and *Austrotrillina howchini*). This assemblage consists of 6 m thick from sample number 30 to sample number 36 of lagoonal Jeribe Formation. The most important fauna are *Ammonia beccarii*, *Dendritina rangi*, *Austrotrillina howchini*, *Austrotrillina* sp., *Pyrgo* sp., *Quinloculina* sp., *Discorbis* sp., and non-foraminifera species which are *Ditrupa* sp., echinoid fragments, and gastropods. According to Cahuzac and Poignant (1997), this zone was recorded as SBZ24 and SBZ25 (Aquitanian-Burdigalian) age, and equivalent to *Ammonia beccarii* zone, *Ammonia beccarii-Borelis melo curdica* zone of Al-Ghreri (2015) and correlated with and correlated with *Borelis melo curdica* (BMK), Biozone of Lawa and Ghafur (2015) also this zone is equivalent to *Ammonia beccarii Miogypsina globulina* assemblage zone, of Al-khaykanee and Al-Dulaimi (2019), which returns to lower Miocene.

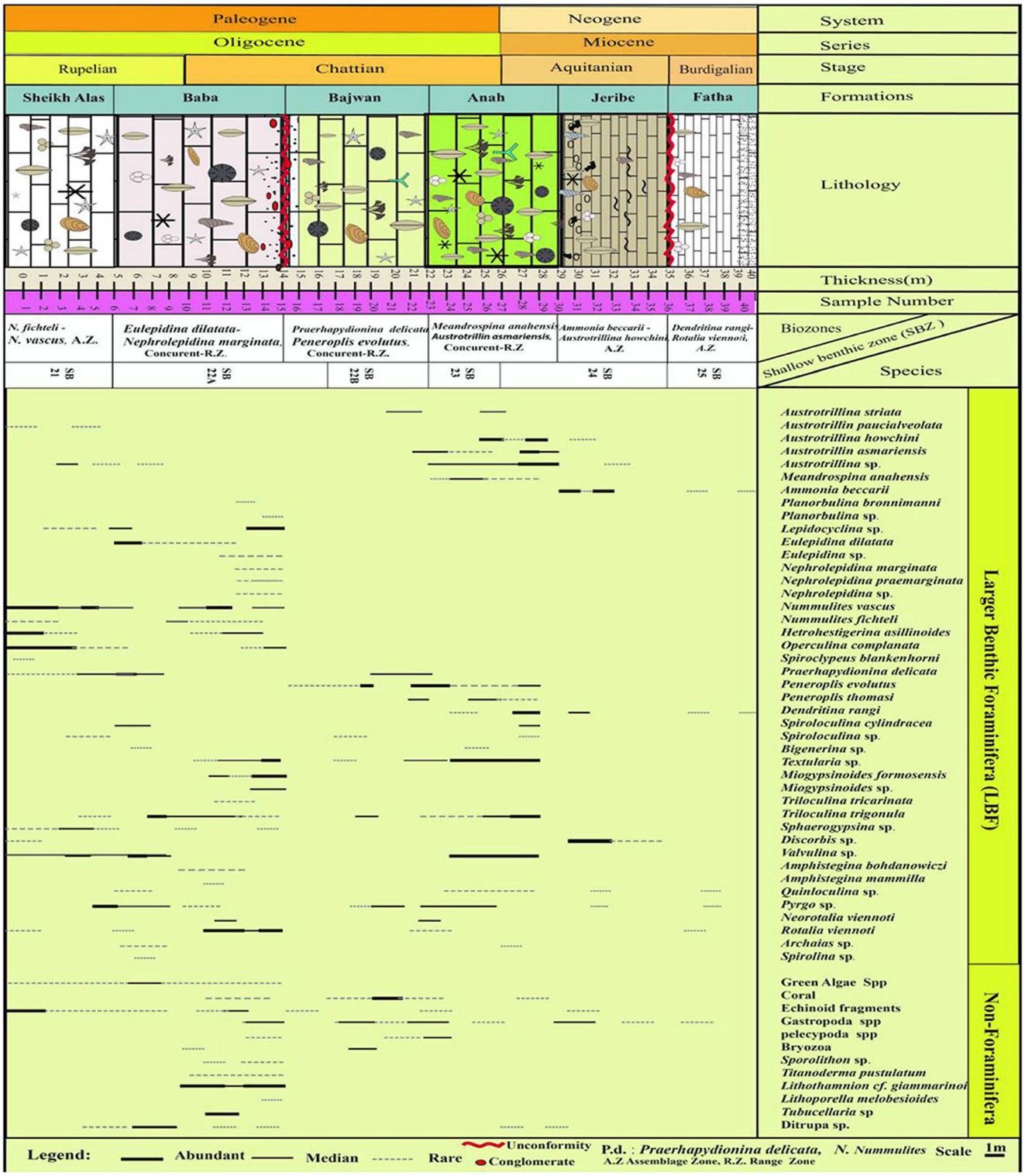

Fig. 9 Biostratigraphic range chart of large benthic foraminifera (LBF), and non-foraminifera at the Darzila section

Dendritina rangi-Rotalia viennoti assemblage zone (Burdigalian)

Biostratigraphic interval of this zone was characterized by the assemblage of the nominate taxon (*Dendritina rangi*, and *Rotalia viennoti*). This biozone represents 5 m thick from sample (36–41) of the lower part of the lacustrine Fatha Formation. The zone contains some species including *Ammonia beccarii*, *Dendritina rangi*, *Pyrgo* sp., *binloculina* sp., *Rotalia viennoti*, and gastropoda. This biozone correlated

Table 2 Correlation chart showing the biostratigraphic zones of this study with the other studies

Eratheme	System	Series	Stage	Biozones	Laursen et al. (2009) Zagros Basin	Sirel, Özgen-Erdem, & Kangal, (2013), Central Turkey	Serra-Kiel et al., (2016), Yemen	Joudaki & Baghbani, (2018), SW of Iran	Saraswati, Khanolkar, & Banerjee (2018) Kutch, India	Moghaddam et al. (2019), Lorestan Zone, SW Iran.	This Study: Darzila section
Cenozoic	Neogene	Miocene	Burdigalian	SB 24	*Borelis melo curdica, Borelis melo melo.*	*Miogypsinid species and others*			Not Studied	*Borelis melo curdica, Borelis melo melo*	*Dendritina rangi - Rotalia viennoti ,* Assemblage Zone.
			Aquitanian	SB 24	*Miogypsina, Peneroplis farsenesis, Elphidium* sp.		*Miogypsinoides bantamensis*	*Borelis melo curdica, Borelis melo melo*		*Elphidium* sp.-14 *Miogypsina* sp.	*Ammonia beccarii - Austrotrillina howchini* Assemblage Zone.
	Paleogene	Oligocene	Chattian	SB 23	*Archaias asmaricus, Archaias hensoni, Miogypsinoides complanatus.*	*Miogypsinoides borodinensis, Miogypsinoidescomplanata Marasella* sp. *Postmiogypsiniella* sp. *Miolepidocyclina* sp.	*Miogypsinoides complanatus*	*Archaias asmaricus, Archaias hensoni, Miogypsinoides complanatus.*	*Miogypsinoides complanatus – formosoides and Spiroclypeus margaritatus that*	*Archaias asmaricus, Archaias hensoni, Miogypsinoides complanatus.*	*Meandrospina anahensis Austrotrillin asmariensis* Assemblage Zone. *Praerhapydionina delicata, Peneroplis evolutus,* Concurrent-R.Zone
				SB 22B		*Sivasina egribucakensis Archaias asmaricus Peneroplis flabelliformis Archaias kirkukensis*	*Nummulites fichteli, Nummulites vascus, Spiroclypeus carpathicus, Eulepidina formosoides, Austrotrillina brunni, Austrotrillina asmariensis, Austrotrillina striata, and Austrotrillina paucialveolata*	*Lepidocyclina, Operculina, Ditrupa.*	*Nummulites bormidiensis, Nummulites kecskemetii,* and *Heterostegina assilinoides*	*Lepidocyclina Operculina Ditrupa*	*Eulepidina dilatata Nephrolepidina marginata* Concurrent-R.Zone
			Rupelian	SB 22 A	*Nummulites fichteli, Nummulites vascus*	*Coscinospira sivasensis Coscinospiraelongata Austrotrillina brunni, Praearchaias minimus, Praearchaias diyarbakirensis Praebullalveolina minuta n.* sp. *Praebullalveolina oligocenica n.* sp..		*Globigerina, Turborotalia cerroazulensis, Hantkenina.*	Hiatus	*Nummulites vascus and Nummulites fichteli*	
				SB 21							*Nummulites fichteli, Nummulites vascus* Assemblage Zone.

with biozone SBZ25 of Cahuzac and Poignant (1997), and it is equivalent in time with assemblage II of Roozpeykar and Moghaddam (2016), also equivalent to *Operculina. marginata*, biozone of Lawa and Ghafur (2015) and *Borelis melo curdica- Borelis melo melo* assemblage zone of Moghaddam et al. (2019), which indicate Burdigalian age.

Discussion

Generally, the Oligocene-Early Miocene show progressive shallowing upwards with a major depression mainly within Kirkuk embayments. Previously, the Oligocene cycle consists of the Palani, Sheikh Alas, and Shurau Formations extending through a variety of depositional environments (Van Bellen et al. 1959-2005). Ditmar et al. (1971) considered the Palani and part of the Tarjil and Sheikh Alas formations as forming one cycle in the Late Eocene. This was based on the premise that *Nummulites* in the absence of *Lepidocyclina* indicated a Rupelian age using the Geologic Time Scale of Gradstein et al. (2004). Al-Banna et al.(2008) shows that the Oligocene first cycle (Rupelian) in the Sinjar basin consists of the Palani, Sheikh Alas, and Shurau formations, and the lower part of the Tarjil Formation, and the second cycle (Late Rupelian to Early Chattian) consist of Bajwan and Baba Formation and upper part of the Tarjil Formation, while the Miocene cycles subdivided into Anah, Azkand and Ibrahim formations (Aquitanian) and Euphrates, Serikagni and Dhiban formations and the lower part of the Jeribe Formation (Burdigalian) (Fig. 1). Kharajiany (2008) subdivided the Oligocene strata in Ashdagh Mountain into Sheikh Alas and Shurau Formations (Lower Oligocene), Baba, Bajwan and possible Tarjil Formations (Middle Oligocene), and Anah Formation (Late Oligocene), and according to Kharajiany et al. (2014), the Oligocene–Miocene in the Mamlaha anticline is divided into the Middle Oligocene to Middle Miocene period of time; they identified these formations of the anticline which are Bajwan Formation (Middle Oligocene), Anah and Ibrahim formations (Late Oligocene), Serikagni, Euphrates and Dhiban formations (Early Miocene), and Jeribe Formation (Middle Miocene) respectively. Lawa and Ghafur (2015) studied the sequence stratigraphy of Late Eocene-Oligocene–Early Miocene sequences of the Kurdistan foreland basin, and subdivided the Oligocene sequence into the lower sequence, Sheikh Alas and Shurau formations (Rupelian) and Upper sequence, Baba, Bajwan, Azkand and Anah formations (Chattian Early Aquitanian), and Miocene sequence into Late Aquitanian–Burdigalian sequence

(Serikagni, Euphrates, Jeribe and Dhiban formations). Kakemem et al. (2016) subdivided the Asmari Formation in Zagros basin, southwest Iran into Lower Asmari (Rupelian-Chattian), Middle Asmari (Aquitanian), and Upper Asmari (Burdigalian). The present interpretation in the Darzila section shows that the Oligocene (Rupelian) consists of the Sheikh Alas Formation and the lower part of the Baba Formation and the Oligocene (Chattian) consists of the upper part of the Baba Formation, Bajwan Formation, and the lower part of the Anah Formation, while the Early Miocene (Aquitanian-Burdigalian) consists of the upper part of the Anah Formation, Jerebi, and Fatha formations (Figs. Fig. 5 and 9).

Conclusions

This study revealed the following conclusions: the Oligocene–Early Miocene rock units in the Darzila section were studied in detail and based on the 43 species from 29 genera of identified large benthic foraminifera (LBF) assemblages, the studied section was subdivided into six biostratigraphic zones, from old to young (*Nummulites vascus* - *Nummulites fichteli* Assemblage Zone, *Eulepidina dilatata* - *Nephrolepidina marginata* Concurrent-Range Zone, *Praerhapydionina delicata* - *Peneroplis evolutus*-Concurrent Range Zone, *Meandrospina anahensis* - *Austrotrillina asmariensis* Interval Zone, *Ammonia beccarii* -*Austrotrillina howchini* Assemblage Zone and *Dendritina rangi* Assemblage Zone. The Oligocene–Early Miocene rock units in the Darzila section were subdivided into the following rock units, from old to young (Sheikh Alas, Baba, Bajwan, Anah, Jeribe, and Fatha) formations. In addition to large benthonic foraminifera (LBF) assemblages, twelve fossils of non-foraminifera are identified such as coral, algae, pelecypods, gastropods, bryozoa, and fragment and spine of echinoids. The six Biozones that reognized in this study were correlated with the other studies.

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Declarations

Conflict of interest The author(s) declare that they have no competing interests.

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