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The palaeoshoreline of Early Miocene formations (Euphrates and Jeribe) at the periphery of the Zagros Foreland Basin, Sulaimani Governorate, Kurdistan Region, NE Iraq

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Abstract

A sedimentological investigation of the Early Miocene deposits at the periphery of the Zagros Foreland Basin, Kurdistan Region, around Qishlagh-Sargrma and Darbandikhan, reveals the presence of the Euphrates and Jeribe Formations in this area. A carbonate-dominated unit, comprising four regressive carbonate cycles, at the base of the Fatha Formation, has been investigated to characterize the depositional environments and stratigraphic context of these Early Miocene deposits. Outcrop and thin-section analyses of the carbonate succession reveal a gently inclined, carbonate-dominated ramp based on the depositional lithofacies and microfacies. Eight carbonate microfacies were identified and interpreted to have been deposited in a shallow marine environment. The Euphrates Formation passes up from deposits of restricted lagoon to shoal depositional environments, while the Jeribe Formation was deposited in a hypersaline lagoon to a restricted lagoon. The Early Miocene index fossil *Borelis melo melo* was identified in the deposits of the Euphrates Formation. Stratigraphic correlation of the studied sections allows the development of a revised palaeogeography for the Early Miocene deposits in the Kurdistan Region.

Keywords Euphrates · Jeribe · Early Miocene · Palaeoshoreline · Carbonate

Introduction

The Zagros Foreland Basin occupies much of northern Iraq along a NW-SE trend and extends into NE Syria and SW Iran. The basin includes the succession deposited during the Zagros collision (Upper Eocene to Holocene). The Early Miocene units in Iraq represent deepwater facies of the Serikagni Formation (basinal) and shallow carbonate and evaporite facies of the Euphrates, Dhiban, and Jeribe Formations (Aqrawi et al. 2010). These facies are time-equivalent to the shallow water carbonate of the Asmari Formation in Iran of approximately Oligocene-Early Miocene age (James and Wynd 1965). The Asmari Formation was regionally developed across what is now the Zagros Mountain range and is the main hydrocarbon reservoir in Iran (Amirshahkarami et al. 2007; Amirshahkarami 2013). Regionally, the Early Miocene palaeofacies covered most of the northeastern margin of the Zagros Basin (Ziegler 2001). These Early Miocene facies are significant as a carbonate reservoir in the Zagros Foreland Basin (Beydoun et al. 1992), and they have recently been a main focus of study in the Kurdistan Region of Iraq.

The Early Miocene units have been studied by numerous authors in many parts of Iraq, including the central and western areas (Abawi and Hani 2005; Al-MutwaIi and Al-Banna 2005; Al-Youzbaki et al. 2005; Al-Juboury et al. 2007; Aghwan and Abdulrahman 2009; Al-Ghreri et al. 2010; Al-Juboury et al. 2010; Al-Ameri et al. 2011; Al-Dabbas et al. 2013; Al-Ghreri et al. 2013). However, the Early Miocene shoreline was not previously defined in the Kurdistan Region of Iraq. According to a previous palaeogeographic map of Iraq by Aqrawi et al. (2010), the Early Miocene deposits did not reach the Kurdistan Region, and the palaeoshoreline was

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interpreted to run through Kirkuk city. Recently, Kharajiany (2014) and Kharajiany et al. (2014) studied the Oligocene and Miocene units in the Azh Dagh and Mamlaha areas, in the southwest of the Kurdistan Region (Fig. 1), and identified the Euphrates, Dhiban, and Jeribe Formations. These studies defined the Early Miocene shoreline in the Kurdistan Region for the first time. Hussein et al. (2017) then studied the reservoir properties and stratigraphic equivalence of the outcrops of the Euphrates and Jeribe Formations in the Azh Dagh and Mamlaha areas.

The presence of a carbonate unit at the base of the Fatha Formation, in the Qishlagh-Sargrma Mountain and Darbandikhan area, has been reported in previous studies. In most of the studies, it was defined as the lower part of the Fatha Formation (van Bellen et al. 1959; Buday 1980). However, Khanaqa et al. (2009) stated that the age of the identified fauna indicates a Late Oligocene to Lower Miocene age, and suggested the carbonates might be of the Anah/Ebrahim and Serikagni/Euphrates Formations, or probably a new geological unit, equivalent to the Oligocene Asmari Formation in Iran. The occurrence of Early Miocene units in other parts of the Kurdistan Region, especially in the Qishlagh-Sargrma and Darbandikhan areas, as well as the palaeoshoreline of the basin, were still questionable and further studies were necessary.

This research studied the carbonate units at the base of the Fatha Formation and investigated a new palaeoshoreline of the basin in the Kurdistan Region, in the Qishlagh-Sargrma Mountain and Darbandikhan area. This paper summarizes field observations and microfacies studies of three stratigraphic sections along the mountain and one section in Darbandikhan town (Fig. 1). These data were correlated with the Early Miocene Euphrates and Jeribe Formations in the Hazar Kani and Mamlaha sections in the Garmyan area, along the Azh Dagh-Qara Wais anticline.
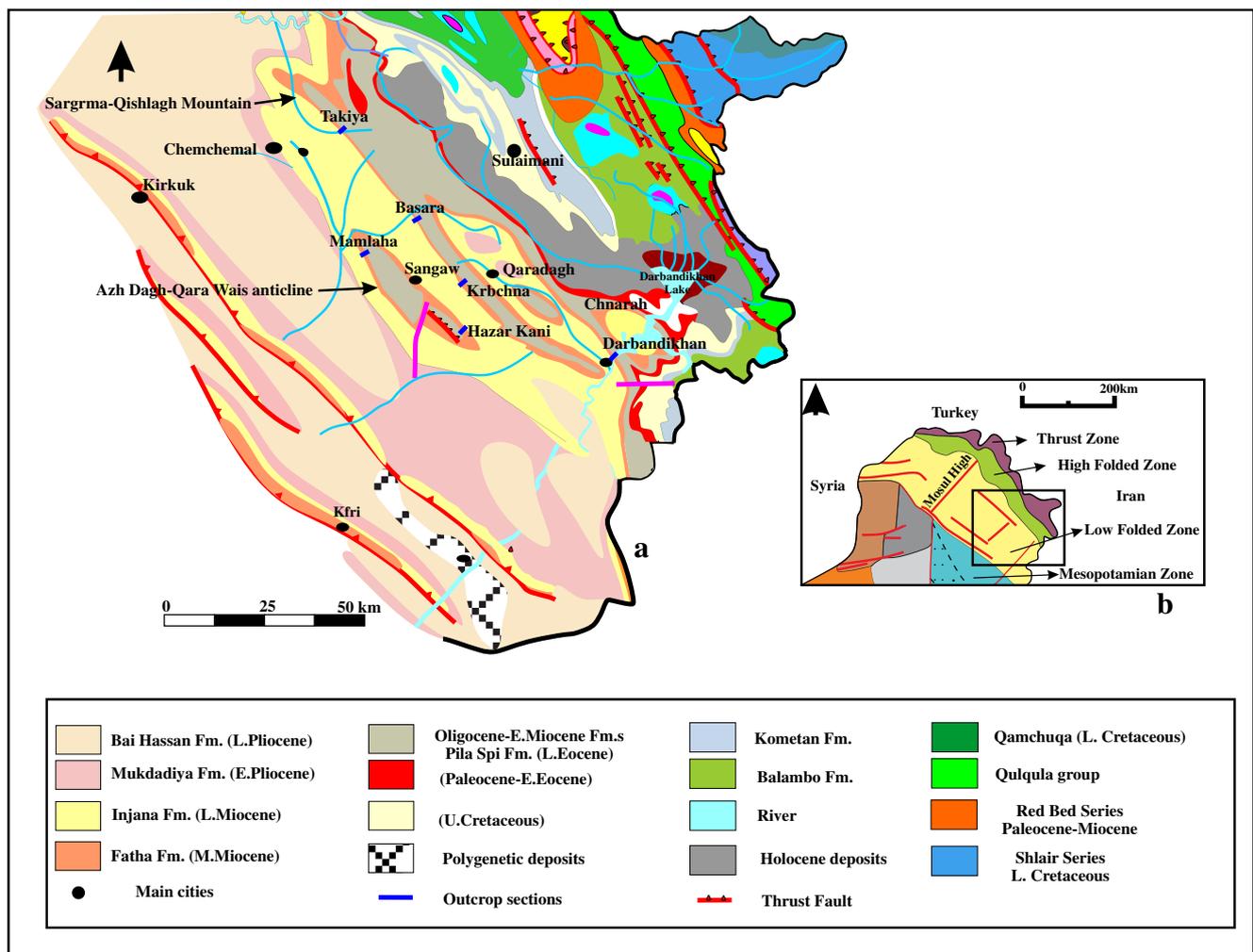
Fig. 1 Geological maps of the study area. a Geological map illustrating the study area and the studied sections. b Structural map of northern Iraq including Kurdistan structural elements and the study area (Aqrawi et al. 2010)

Geological setting

A thick Miocene succession is preserved in the Zagros Foreland Basin, which covers most parts of central and NE Iraq and SW Iran. The Miocene succession in Iraq is represented by the Ghar, Serikagni, Euphrates, Dhiban, and Jeribe Formations in the Early (Lower) Miocene (Fig. 2), and the Fatha, Injana, Mukdadiya, and Bai Hassan Formations of Middle-Upper Miocene times (Buday 1980; Aqrawi et al. 2010). The Euphrates Formation is separated from the underlying Oligocene Anah Formation by a siliciclastic conglomeratic unit, while the Oligocene unit becomes thin or absent toward the Qishlagh-Sargrma and Darbandikhan areas. The upper boundary of the Euphrates Formation is determined by a change from carbonate to evaporite or evaporitic-carbonate of the Dhiban Formation (Fig. 3). The Jeribe Formation is characterized by highly fractured and jointed limestone alternating with evaporitic-limestone and sits upon the Dhiban Formation. The upper boundary of the Jeribe Formation is determined by the first occurrence of red claystone of the Fatha Formation.

The Euphrates Formation is mainly composed of carbonate and contains beds of yellowish marl, breccia, marly sand, and conglomerate (Buday 1980). It is characterized by chalky, shelly, well-bedded recrystallized limestones, with siliceous, oolitic, corraline, and coquina materials (van Bellen et al. 1959). Based on these variations in lithological composition, the formation was divided into three members: a basal cavernous and conglomeratic limestone, a shelly carbonate, and a marly and chalky carbonate (van Bellen et al. 1959). The formation was deposited in shallow marine lagoons and reef settings (Buday 1980). Hussein et al. (2017) characterized the Euphrates Formation in outcrop around the Azh Dagh anticline as including restricted lagoon and shoal environments of a carbonate ramp. The lower stratigraphic boundary is usually unconformable with the underlying Oligocene and Late Eocene formations, whereas in some areas, where the underlying unit is the Serikagni Formation, it is conformable (Buday 1980). The upper boundary is conformable with the overlying Dhiban Formation. The Dhiban Formation is composed of thick beds of gypsum that are interbedded with thin beds of marls, recrystallized limestone, and dolomite (Buday 1980). It is approximately 100 to 150 m thick in the subsurface. Fossils are lacking in the formation, and its age is determined based on its stratigraphic position, being underlain by the Serikagni or Euphrates Formations (Al-Juboury et al. 2007). The Jeribe Formation is composed of recrystallized and dolomitized carbonates that are interbedded with evaporite and dolomite. The lower boundary is conformable with the Dhiban Formation, whereas it is unconformable with the Serikagni Formation in the type area with evidence of a conglomeratic bed at the base of the formation (Buday 1980). The upper boundary is conformable with the Fatha Formation. The formation was deposited in lagoon and reef environments (van Bellen et al. 1959). Hussein et al. (2017) describe inner to outer carbonate ramp environments being represented at outcrop, in the Azh Dagh area. The study area is located in the Kurdistan Region, north-eastern Iraq, in the Qishlagh-Sargrma Mountain, and Darbandikhan area, where four stratigraphic sections were logged. The Sargrma Mountain is an asymmetrical double-plunging anticline, of which the north-eastern limb is steeper than the south-western limb (Ghafur 2012). This structure extends to the south-east toward the Golan structure and to the north-west toward the Bazian structure. As a whole, the Qishlagh-Sargrma structure extends in length for more than 80 km and is 2 to 3 km in width. Three sections were logged along this structure: the Takiya, Basara, and Krbchna sections from NW to SE (Fig. 1). The fourth section is logged around Darbandikhan town, next to the Darbandikhan Dam, along the NE limb of the Qaradagh anticline (Table 1).

The stratigraphic sections were correlated with the Euphrates and Jeribe Formations in the Azh Dagh-Qara Wais anticlines of the Garmyan area. These anticlines are asymmetrical with a NW-SE trending, double-plunging fold, and en-echelon fold geometries (Kharajiany 2008). They are parallel to the Qishlagh-Sargrma Mountain. The Azh Dagh anticline is located at the SE end of the structure, whereas
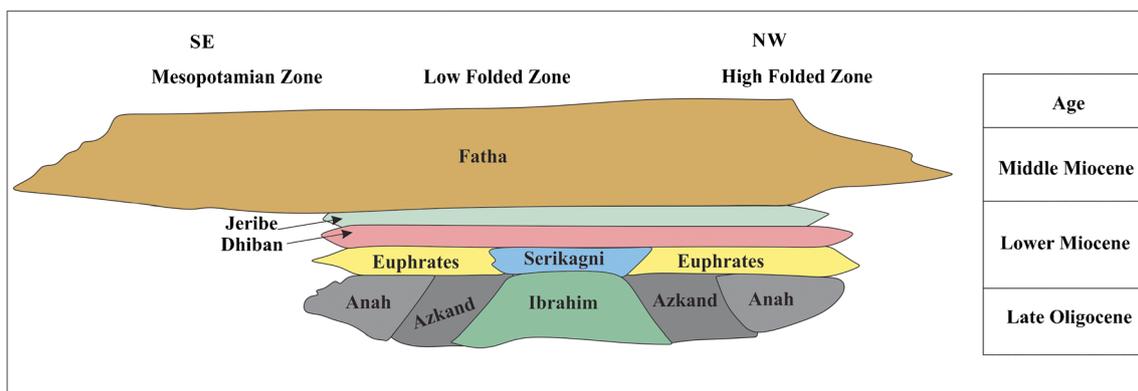
Fig. 2 Chronostratigraphic chart of Iraq (after van Bellen et al. (1959) and modified by Aqrawi et al. (2010))

Age	Fm.	Lithology	Thickness (m) This study	Thickness (m) Type section	Equivalent units Iran	Types of their boundaries
Middle Miocene	Fatha		50-300 m	445 m	Gachsaran	First appearance of the red claystone of the Fatha Formation.
Lower Miocene	Jeribe		6-12 m	73 m	Asmari Formation	The lower contact changes from the evaporitic facies of the Dhiban Formation to the highly-jointed carbonate of the Jeribe Formation. However, in areas where the Dhiban Formation is not available, the boundary changes from the ooilitic carbonate of the Euphrates Formation to the highly-jointed carbonate of the Jeribe Formation. The upper boundary is defined by the first appearance of the red claystone of the Fatha Formation. The lower and upper contacts of the Dhiban Formation (1m) are abrupt with the Euphrates and Jeribe formations, respectively. However, the formation become thin toward the margin of the basin, where only 10-20 cm thick yellowish evaporitic deposi was documented.
	Dhiban		0.2-1 m	72 m		
	Euphrates		4-5 m	8 m		The lower contact is defined by an erosional and unconformable surface with the siliciclastic conglomeritic unit, while the upper contact is gradational with Dhiban Formation, if it is availbale. However, it is unconformable, if it is underlain by the Jeribe Formation.
	Siliciclastic Conglomeritic unit		3-10 m	1 m		The lower and upper boundary of this unit is sharp and erosional. The upper boundary marks as marine transgression.
	Oligocene Anah Fm. or Eocene Pila Spi Fm.					The Oligocene unit was recorded in Azh Dagh - Qara Wais anticlines, while in Qishlagh-Sargrma area, was not widely deposited, instead the Late Eocene Pila Spi Formation was documented. The nature of the upper boundary is erosional.

Fig. 3 Stratigraphic column of the lower Miocene deposits in the Kurdistan Region, illustrating lateral and vertical changes, as well as the nature of their boundaries

the Qara-Wais anticline is at the NW end of the structure. The Hazar Kani section was logged along the Azh Dagh anticline, whereas the Mamlaha section was logged along the Qara-Wais anticline.

Data collection

The data used for this study were collected from the Kurdistan region, specifically the Qishlagh-Sargrma and Azh Dagh-Qara Wais mountains, and the area around Darbandikhan. This study focused on the carbonate unit below the Fatha Formation along the Qishlagh-Sargrma Mountain and Darbandikhan area, and correlated these with the carbonates of the Euphrates and Jeribe Formations along the Azh Dagh-Qara Wais anticlines. For this purpose, four outcrop sections were measured along the Qishlagh-Sargrma and Darbandikhan areas, while two sections were logged along the Azh Dagh-Qara Wais anticlines. Overall, 80 samples were collected from the carbonate unit and 60 thin sections were made for microfacies analysis (Table 2). Six stratigraphic columns were logged and correlated, using Corel Draw software. Carbonate microfacies were analyzed based on standard

carbonate description schemes and methods (Dunham 1962; Embry and Klovan 1971; Tucker and Wright 1990; Geel 2000; Flugel 2004; Flugel and Munnecke 2010).

Results

Stratigraphy

Oligocene formations

The Oligocene rocks are not widely recorded in the Qishlagh-Sargrma area, while a thin carbonate unit (4 m) that is rich in corals is documented, near Krbchna village, which is determined on this basis to be the Anah Formation. The Oligocene formations become thicker toward the Azh Dagh and Qara Wais anticlines. Both underlying and overlying units are unconformably separated from the Oligocene strata.

Siliciclastic conglomeritic unit

This unit was first defined by van Bellen et al. (1959) at the base of the Fatha Formation (previously Lower Fars) as the

Table 1 Geographic coordinates of the studied sections

Sections	Latitude N	Longitude E	Structure	Description
Takiya	35° 39′ 07.38″	44° 57′ 28.90″	Qishlagh	45 km NW of Sulaimani
Basara	35° 26′ 40.30″	45° 09′ 25.84″	Qishlagh	26 km SW of Sulaimani
Krbchna	35° 17′ 53.65″	45° 16′ 22.31″	Sargrma	32 km SW of Sulaimani
Darbandikhan	35° 06′ 43.01″	45° 42′ 12.07″	Qaradagh	53 km SE of Sulaimani
Hazar Kani	35° 09′ 31.87″	45° 17′ 50.98″	Azh Dagh	18 km SE of Sangaw
Mamlaha	35° 22′ 06.84″	45° 00′ 27.72″	Qara Wais	19 km NW of Sangaw

Basal Fars Conglomerate. In the studied areas, this unit is composed of thick siliciclastic deposits that comprise conglomerate, sandstone, siltstone, and claystone, as well as carbonate conglomerates that are channelized within palaeosols (Fig. 4). It contains carbonate fragments of the underlying Oligocene Anah Formation and Eocene Pila Spi Formation. It is about 10 m thick in the studied sections (Fig. 4a, c, d), occurring below the Euphrates and Jeribe Formations. This unit tends to thin toward the SW of the studied area, around the Azh Dagh-Qara Wais anticlines, to 3–4 m thick (Fig. 4b).

Euphrates Formation

In this study, a carbonate unit was documented that overlies the siliciclastic conglomeritic unit and underlies the Fatha Formation. The carbonate unit consists of four main cycles of carbonate and yellowish-grey marl. These carbonate cycles outcrop extensively along Qishlagh-Sargrma Mountain for approximately 90 km distance in all the studied sections. The first carbonate cycle is correlated as representing the Euphrates Formation, while the other three carbonate cycles represent the Jeribe Formation.

The Euphrates Formation (first carbonate cycle) is characterized by a thick well-bedded limestone, approximately 4.5 to 5.0 m thick (Fig. 5a–c). The lower contact is determined by the occurrence of the siliciclastic conglomeritic unit, which overlies the Eocene Pila Spi Formation or the carbonate of the Oligocene Anah Formation. The upper boundary is indicated by yellowish-grey marl of the second carbonate cycle (Jeribe Formation). The Euphrates Formation comprises two main depositional units; a basal brecciated limestone and an upper shelly limestone. The basal brecciated limestone unit, between 0.5 and 1.0 m thick (Fig. 5a, b), is characterized by the presence of horizontal burrows and vertical *Skolithos* bioturbation. The shelly-limestone unit is characterized by the presence of shell fragments (Fig. 5d) and is approximately 3.5 to 4.0 m thick. The upper most part of this unit is distinguished by a dark-grey limestone with wavy-laminations, ripple marks (Fig. 5e), and cross laminations (Fig. 5f). These two depositional units were similarly observed in all the studied sections. The upper boundary is indicated by the occurrence of the yellowish-grey marl or yellowish evaporitic-marl of the second cycle, Jeribe Formation, while, in some places, it is interrupted by a yellowish evaporitic-carbonate, which may belong to the Dhiban Formation (Fig. 6a).

Dhiban Formation

In the studied areas, the formation was recorded in the Azh Dagh-Qara Wais Mountain where it is only 1.0 m thick (Fig. 6b). It is underlain and overlain by the Euphrates and Jeribe Formations, respectively. It is characterized by yellowish evaporitic-carbonate, degraded at outcrop. However, the formation is locally recognized for the first time in this study along the Qishlagh-Sargrma Mountain at the boundary of the Euphrates and Jeribe Formations, while only approximately 10 cm thick (Fig. 6a).

Jeribe Formation

The Jeribe Formation in the study area consists of three carbonate-yellowish marl cycles. Each cycle starts with yellowish-marl at the base to well-bedded carbonate at the top. The first carbonate cycle of the formation comprises yellowish-grey marl and well-bedded and highly-jointed limestone, about 3.0 to 4.0 m thick (Fig. 6c, d). The limestone unit is characterized by white well-bedded, fractured, and highly jointed limestone that is rich with shell fragments and oysters. Moreover, it is distinguished by being highly bioturbated with vertical *Skolithos* and horizontal *Planolites* burrows (Fig. 6e). The upper contact of this cycle is determined by the occurrence of the yellowish-grey marl of the second cycle.

The second carbonate cycle of the Jeribe Formation comprises yellowish-grey marl and highly jointed and well-bedded limestone, approximately 3.0 to 4.0 m thick. The limestone is characterized by being highly fossiliferous and oyster-rich (Fig. 6f), as well as highly bioturbated and containing *Skolithos*. The upper boundary is recognized by the occurrence of the yellowish-grey marl of the last cycle.

The third cycle includes the basal yellowish-grey marl and upper well-bedded limestone, about 3.0 to 5.0 m thick. The limestone is highly bioturbated and fossiliferous, including large oysters and bivalves. The upper boundary is indicated

Table 2 Thickness and the number of collected samples of the Lower Miocene formations

Sections	Euphrates (m)	Jeribe (m)	Samples	Elevation (m)
Takiya	5	12	25	954
Basara	5	11.5	23	673
Krbchna	4.5	11	20	1078
Darbandikhan	4	6	15	511
Hazar Kani	4.5	12	24	774
Mamlaha	5	12	26	582

by the first occurrence of the red claystone of the Fatha Formation.

These three cycles of the Jeribe Formation were also documented in the Azh Dagh-Qara Wais area.

Microfacies analysis

Eight different microfacies have been recognized in the studied carbonate cycles, E1, E2, E3, and E4 from the Euphrates Formation and J1, J2, J3, and J4 from the Jeribe Formation. These microfacies have been investigated based on their stratigraphic positions, composition, fossil content, and presence of sedimentary structures. The descriptions and interpretations of the studied microfacies are given as the following and summarized in Table 3.

Reworked-bioclastic grainstone (E1)

This microfacies belongs to the brecciated-limestone unit at the base of the Euphrates Formation, which is composed of reworked bioclasts and carbonate fragments of the underlying Oligocene and Eocene rocks. The major bioclasts include different forms of the Miliolina suborder such as *Triloculina*, *Quinloculina*, *Dentritina*, and *Peneroplis* and quartz grains. The bioclasts and quartz grains are characterized by being poorly sorted and angular shapes, scattered in a sand-grade matrix (Fig. 7a). Bioturbation, including both vertical *Skolithos* and horizontal burrow ichnofacies, are very common in this unit (Table 3). This microfacies was recorded in all the studied sections.

This microfacies is located above the siliciclastic conglomeritic unit, which is considered as representing a near-hiatus in sedimentation below the base of the Euphrates Formation. The microfacies records initial deposition above a transgressive surface of the Early Miocene. The presence of reworked fossils from the underlying units, including
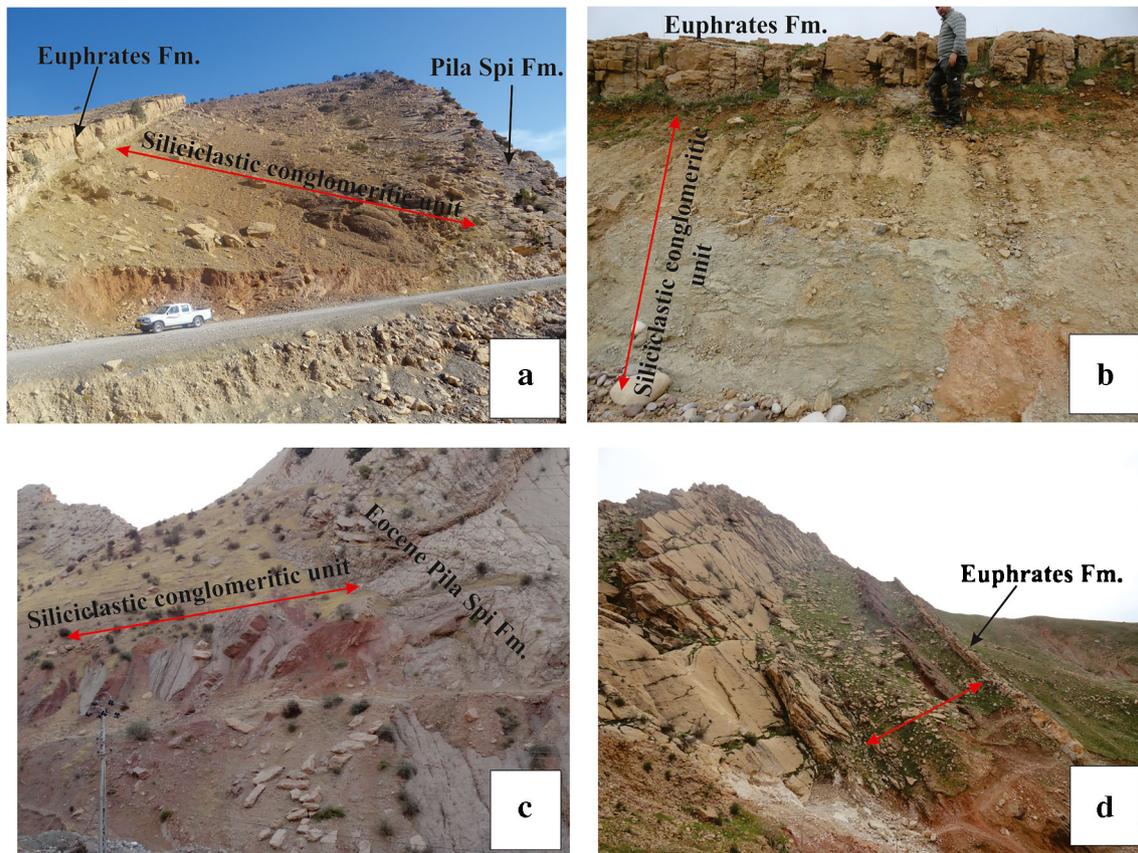
Fig. 4 Representative outcrop photographs of the siliciclastic conglomeritic unit. **a** Basara section. **b** Hazar Kani section. **c** Darbandikhan section. **d** Takiya section. This unit is overlain by the carbonate of the Euphrates Formation

Fig. 5 Representative outcrop photographs of the Euphrates Formation. **a–c** Outcrop of the carbonate of the Euphrates Formation, showing both a brecciated carbonate unit, at the base, and a shelly carbonate unit, at the top, from the Basara, Hazar Kani, and Darbandikhan sections, respectively. **d** Shelly carbonate unit of the formation, showing shell bioclasts in the Takiya section. **e** Ripple marks at the top of the formation within the E4 bioclastic-ooidal grainstone microfacies in the Mamlaha section. **f** Planar to low-angle cross-laminations in the Hazar Kani section

Oligocene and Late Eocene units (Kharajiany 2008), may represent transgressive lag deposits which resulted from a rapid transgression. This transgressive lag deposit may be laterally equivalent to the deep facies of the Lower Miocene Serikagni Formation in the basin center. Cattaneo and Steel (2003) stated that lag deposits reflect periods of erosion of the underlying deposits with accumulation of older reworked and broken fossils. Furthermore, the presence of *Skolithos* typifies shallow marine deposition in a high-energy, well-oxygenated environment with a sandy substrate (Seilacher 1967).

Bioclastic-miliolid packstone to grainstone (E2)

This microfacies is recognized by well-bedded chalky limestone, which is rich with shell fragments. This microfacies corresponds to the shelly-limestone unit of the Euphrates

Fig. 6 Representative outcrop photographs of the Dhiban and Jeribe Formations. **a** Yellowish evaporitic carbonate of the Dhiban Formation between the Euphrates and Jeribe Formations in the Takiya section, which is only 10 cm thick and overlain by the carbonate of the Jeribe Formation. **b** Evaporitic carbonate of the Dhiban Formation between the Euphrates and Jeribe Formations, approximately 1 m thick, Hazar Kani section. **c**, **d** Highly jointed carbonate unit of the Jeribe Formation in the Takiya and Basara sections, respectively. **e** Highly bioturbated *Skolithos* ichnofacies, in the carbonate of the Jeribe Formation, Takiya section. **f** Oyster-rich carbonate of the Jeribe Formation in the Krbchna section

Formation and overlies the brecciated-limestone unit. The major bioclasts include different forms of miliolina such as *Triloculina*, *Quinloculina*, *Dentritina*, *Borelis*, and *Peneroplis (*Fig. 7b). *Borelis melo melo* as an index fossil of the Early (Lower) Miocene was identified in this microfacies (Fig. 7c). The minor bioclasts include shell fragments of molluscs, rotaliids, pelecypods, and gastropods. Quartz grains are also present. This microfacies is characterized by planar laminations and was recorded in all the studied sections.

The occurrence of miliolina foraminifera is generally used as an indicator of restricted lagoon and hypersaline environments (Geel 2000). Where they are abundant, miliolina indicate a connection to open ocean (Chassefiere et al. 1969), fore-reefs, and shallow lagoons (Schlanger 1963). Thus, this microfacies represents a very shallow hypersaline lagoon in

the inner ramp, and bioturbation and muddy matrix indicate low energy and high nutrition environments. The presence of pelecypods, gastropods, and quartz grains indicate that the depositional environment was relatively close to the shoreline.

Bioclastic-peloidal grainstone (E3)

The bioclastic-peloidal grainstone overlies the bioclastic-miliolid grainstone and is characterized by dark-grey well-bedded limestone with planar-laminations. The microfacies is composed of poorly sorted ellipsoidal to angular shaped peloids, approximately 100–400 μm in size. Moreover, it consists of sub-rounded ooids, pellets, miliolids, and bivalve shells, as well as micro-borings, quartz, intraclasts, and cementation being very common. The nuclei of the ooids are replaced by micritic cements.

The occurrence of the associated bioclasts and dominance of peloids are interpreted to represent deposition in a low energy, shallow lagoonal environment with poor connection with the open marine. The abundance of bioturbation and micro-borings, as well as the restricted biota and lack of wave-generated sedimentary structures, suggest that the microfacies was deposited in a restricted, relatively quiet and protected environment, with low sedimentation rate (Tucker and Wright 1990; Geel 2000; Flugel and Munnecke 2010).

Bioclastic-ooidal to ooidal grainstone (E4)

The bioclastic-ooidal grainstone corresponds to the uppermost part of the Euphrates Formation and overlies the bioclastic-peloidal grainstone microfacies (Fig. 7d). This microfacies is composed of dark-grey, well-bedded limestone with wavy-laminations, ripple marks (Fig. 5e), and cross-laminations (Fig. 5f) as the preserved sedimentary structures. The ooids are poorly sorted, concentric, and sub-rounded in shape, approximately 200–500 μm in diameter. The nuclei of the ooids are filled with micritic cements. The associated bioclasts

include Miliolid foraminifera, bivalve shells, and peloids, and a lithic component is represented by quartz grains.

The occurrences of ooids with wavy-lamination sedimentary structures indicate shallow marine and high energy conditions, in which the ooids were influenced by wave and current action (Flugel and Munnecke 2010). The association of the ooids with peloids and benthic foraminifera, and the observed sedimentary structures are indicators that the bioclastic-ooidal to ooidal grainstone microfacies accumulated along a sand shoal (Table 3).

Calcareous mudstone (J1)

The calcareous mudstone microfacies describes the yellowish-marl at the base of the cycles of the Jeribe Formation (Fig. 7e). The facies contains only very few rotaliids and miliolids, which are scattered at a muddy matrix. The rotaliids and miliolids are approximately 200 to 500 μm and 300 to 500 μm in sizes, respectively.

The presence of benthic foraminifera, including miliolina and rotaliid forms, is indicative of a hypersaline lagoon (Debenay et al. 2001). These benthic foraminifera were recorded in a modern hypersaline lagoon by the authors. In contrast, Hariri (2008) stated that the rotaliids live in a deeper hypersaline lagoon (2–14 m depth) than miliolids (2 m depth). The presence of a mud matrix indicates a quiet environment and low sedimentation rate (Flugel and Munnecke 2010).

Bioclastic-peloidal grainstone (J2)

The bioclastic-peloidal grainstone corresponds to the first carbonate cycle of the Jeribe Formation. It comprises poorly sorted, oval to rod-shaped peloids, constituting approximately 90 % of the facies and are 100–400 μm in size (Fig. 7f). Shell fragments, miliolina, rotaliids, quartz, and pellets are associated with this microfacies. Large oysters, which have elongated, irregularly shaped shells, and mollusks, approximately 2 to 3 cm in size, were

Table 3 Summary of descriptions and interpretations of the studied microfacies in the Lower Miocene formations

Formation	Microfacies	Descriptions	Interpretation
Euphrates	Reworked-bioclastic grainstone E1	Coarse brecciated-carbonate. Bioclastic. Horizontal burrows and vertical *Skolithos*.	Transgressive lag deposits.
	Bioclastic-miliolid packstone-grainstone E2	Well-bedded limestone, planar laminations.	Restricted lagoon, inner ramp.
	Bioclastic-peloidal grainstone E3	Well-bedded limestone, planar laminations.	
	Bioclastic-ooidal to ooidal grainstone E4	Well-bedded limestone, dark-grey, wavy laminations.	Shoal depositional environment, inner ramp.
Jeribe	Calcareous mudstone J1	Yellowish-grey marl, structureless.	Hypersaline lagoon, inner ramp.
	Bioclastic-peloidal grainstone J2	Dark-grey well-bedded planar lamination.	Restricted lagoon, inner ramp.
	Miliolid packstone-grainstone J3	Well-bedded, *Skolithos*, oyster, and bivalves.	
	Miliolid-rotaliids packstone J4	Well-bedded, *Skolithos*, oyster, and bivalves.	

Fig. 7 Representative photomicrographs of the Euphrates and Jeribe Formations. **a** Reworked-bioclastic grainstone microfacies E1, which belongs to the brecciated carbonate unit of the Euphrates Formation in the Darbandikhan section, showing reworked fossils in an arenitic ground mass. **b** Bioclastic miliolid packstone microfacies E2 of the Euphrates Formation, Basara section. **c** Bioclastic miliolid packstone to grainstone microfacies E2 of the Euphrates Formation in the Basara section, showing the Early (Lower) Miocene index fossil, *Borelis melo melo*. **d** Ooidal grainstone microfacies E4 of the top of the Euphrates Formation, Basara section. **e** Calcareous mudstone microfacies J1 of the yellowish-marl of the Jeribe Formation in the Takiya section. **f** Bioclastic-peloidal grainstone microfacies J2 of the Jeribe Formation. **g** Miliolid packstone microfacies J3 of the Jeribe Formation, Mamlaha section. **h** Miliolid-rotaliids packstone microfacies J4 of the Jeribe Formation in the Basara section
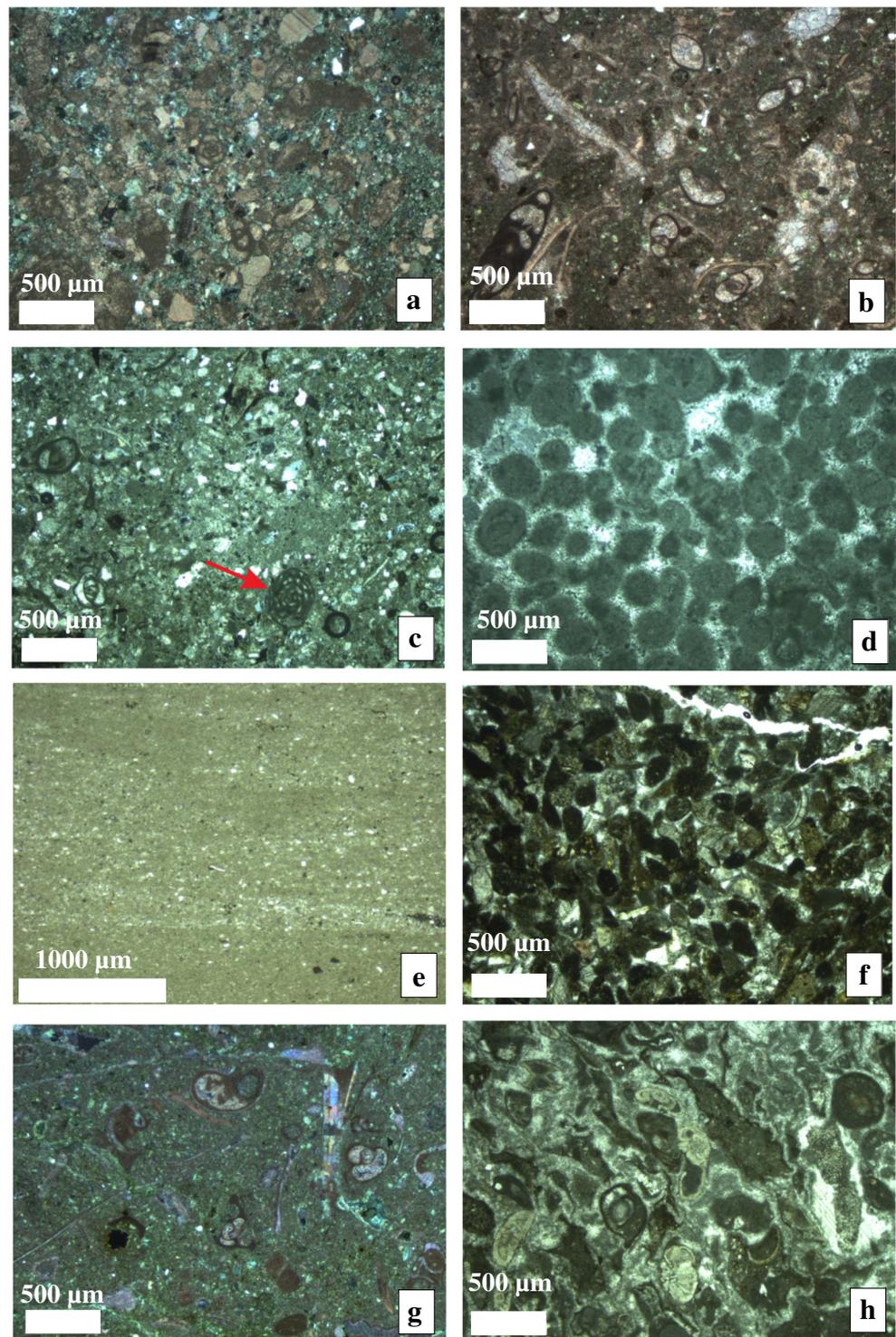
collected from this unit. Moreover, bioturbation, including vertical *Skolithos* and horizontal *Planolites*, is very abundant.

The occurrence of peloids with the associated benthic foraminifera indicates a low-energy shallow lagoon (Flugel and Munnecke 2010). The presence of oysters indicates a nearshore setting in shallow, low-energy marine environments (El-Hedeny 2005). Modern oysters live in brackish water (5 ppt salinity) to normal marine water (35 ppt salinity) (El-Hedeny 2005). The *Skolithos* ichnofacies is common in very

shallow coastal environments (Seilacher 1967) and also occurs in brackish water settings (Curran 1985).

Miliolid packstone to grainstone (J3)

The miliolid packstone-grainstone microfacies belongs to the second carbonate cycle of the Jeribe Formation. The miliolina foraminifera observed included different genera, such as *Triloculina*, *Quinloculina*, *Dentritina*, *Peneroplis*, and *Borelis* (Fig. 7g), which were scattered in a muddy matrix. Some of the miliolids are partially or totally micritized, so that their original structures are not recognized. This microfacies was very common and recorded in all the studied sections.

The miliolid packstone-grainstone microfacies in a muddy matrix is interpreted to have been deposited in a low-energy restricted lagoon environment (Chassefiere et al. 1969).

Miliolid-rotaliids packstone (J4)

The miliolid-rotaliids packstone microfacies belongs to the third carbonate cycle and is characterized by associations of miliolina and rotaliid foraminifera. The Miliolina group is represented by different forms of *Triloculina*, *Quinloculina*, *Dentritina*, *Peneroplis*, and *Borelis*, while identified rotaliids consist of the genera *Ammonia*, *Neorotalia*, *Pararotalia*, and *Rotalia* (Fig. 7h). The minor associated bioclasts include bryozoans and gastropods.

The associations of miliolina and rotaliids are interpreted to represent a shallow hypersaline lagoon, which is supported by a published investigation of a modern hypersaline lagoon in Brazil by Debenay et al. (2001).

Depositional model

Facies patterns and sedimentary environments of Early Miocene carbonate cycles in the study area within the Kurdistan Region reveal deposition at the periphery of a shallow carbonate ramp depositional environment (Fig. 8). The discovery of the depositional settings was based on microfacies analysis, sedimentary structure, rock texture, benthic foraminifera, and lateral and vertical variations of the facies. The recognized microfacies have allowed identification of a ramp model and its different depositional environments, including shallow lagoon, hypersaline lagoon, restricted and protected lagoon, sand shoal, and low-energy lagoon. The depositional microfacies of the Euphrates Formation suggest shallow marine, inner ramp depositional environments. The base of the formation was marked by a rapid transgression over the underlying siliciclastic conglomeritic unit (Fig. 4a–d). The presence of the E4 bioclastic-ooidal grainstone microfacies represents a high-energy sand shoal that would have separated the open-marine waters from the restricted lagoon. The occurrence of wavy-laminations, ripple marks,

and cross laminations in the E4 bioclastic-ooidal grainstone suggests a high-energy depositional environment. The recorded associated bioclasts with ooids indicate reworking of bioclasts from the adjacent restricted lagoon. In the restricted lagoonal depositional environment, the E2 bioclastic-miliolid grainstone microfacies was deposited with a restricted fauna, including miliolids and rotaliids. The E3 bioclastic-peloidal grainstone microfacies is interpreted to have been deposited in a low-energy shallow restricted lagoon. The occurrence of quartz grains, generally in most of the microfacies, indicates that the deposition was close to the shoreline. The high abundance of micro-borings and micritization indicates a low-energy, restricted setting.

In the Jeribe Formation of the study area, the sedimentary microfacies are also interpreted to have been deposited in a shallow marine, restricted lagoon setting. The J1 calcareous mudstone facies suggests a low-energy hypersaline lagoon. The high abundance of mud and low diversity of fauna in this facies suggest quiet conditions and a relatively low sedimentation rate (Flugel and Munnecke 2010). The occurrence of the J2 bioclastic-peloidal grainstone indicates a restricted shallow lagoon. The high abundance of miliolids in the J3 bioclastic-miliolids packstone-grainstone allows inference of the presence of a restricted hypersaline depositional environment. Moreover, the association of miliolids and rotaliids in the J4 miliolid-rotaliids packstone implies hypersalinity in the depositional environment. The high abundance of bioturbation, including *Skolithos* and *Plantolites*, suggests well-oxygenated conditions and deposition close to the shoreline.

Palaeogeography

According to all the previous studies, much of the Kurdistan Region was uplifted during the Early Miocene, and the palaeoshoreline of the basin lay to the southwest, through Kirkuk city, approximately 30 km away from the Garmyan area (Buday 1980; Aqrawi et al. 2010). During latest Chattian-early Aquitanian (Fig. 9a), the carbonates of the Euphrates and Serikagni Formations covered most of the central part of Iraq, while the red bed clastics of the Ghar Formation were deposited to the southwest of the shoreline (Goff et al. 1995; Aqrawi et al. 2010). During the Middle Aquitanian, the basin was restricted into two small depocenters which accommodated deposition of the anhydrite and halite of the Dhiban Formation. Then, during Late Aquitanian to early Burdigalian times (Fig. 9b), deposition of the carbonates of the Jeribe Formation covered most of the central part of Iraq (Aqrawi et al. 2010). However, the field observations and sedimentary analysis presented in this study have shown the presence of the Early Miocene basin extending into the Kurdistan Region. In this study, a new palaeoshoreline has been determined, which ran through what is now the position of Darbandikhan town to the end of the Qishlagh-Sargrma

Mountain, for approximately 80 km (Fig. 9). This investigation thus modifies the geological map and palaeoshoreline of Iraqi Kurdistan.

Stratigraphic correlation

Stratigraphic correlation is the technique of linking up information from separated identical sedimentary facies in order to create a stratigraphic panel for interpreting depositional environment. This stratigraphic correlation was carried out based on the presence of matching sedimentary facies and their stratigraphic locations.

In the studied sections, the Early Miocene formations comprise four main carbonate cycles, approximately 15 to 17 m thick. These carbonate cycles can be easily correlated along the Qishlagh-Sargrma Mountain for approximately 80 km distance (Fig. 10). In order to accomplish the correlation, the depositional units, i.e., carbonate cycles, have been used as marker beds. For example, the siliciclastic conglomeratic unit at the base of the Early Miocene formations has been used as a marker bed and traced along all the studied outcrops. Above this unit, the transgressive lag deposits of the brecciated carbonate unit of the Euphrates Formation were documented in all the studied areas and traced along the correlation panel. The second depositional unit of the formation, the shelly carbonate unit, is also correlated along the area. The evaporitic-

carbonate of the Dhiban Formation tends to pinch-out toward the Qishlagh-Sargrma Mountain where it is only about 10 cm thick. Finally, the three carbonate cycles of the Jeribe Formation were correlated. The stratigraphic correlated panel is illustrated in Fig 10.

Discussion

The cyclical nature is one of the most characteristic features of the Miocene deposits of the Zagros Foreland Basin (Gill and Ala 1972). The cyclicity commenced with the deposition of the Euphrates Formation, then the Jeribe and Fatha Formations, and continued in the Late Miocene Injana, Mukdadiya, and Bai Hassan Formations. In the studied area, the siliciclastic conglomeratic unit was recorded in all the studied area and tends to thin, to approximately 1.0 to 3.0 m thick, toward the Garmyan area, in the SW of the Kurdistan Region. These deposits and their basal unconformity record a gap in marine sedimentation at the top of the Oligocene deposits. The deposition of the Euphrates Formation records a relatively rapid transgression after deposition of the conglomerates. The formation implies an overall transgressive to regressive trend, from transgressive lag deposit (0.5 to 1.0 m thick), at the base, to restricted lagoonal facies and shoal deposits at the top. The evaporitic-carbonate facies of the Dhiban

Fig. 8 Schematic diagram of the depositional ramp model of the Early (Lower) Miocene formations in the Kurdistan Region. FWWB, fair weather wave base; SWB, storm wave base
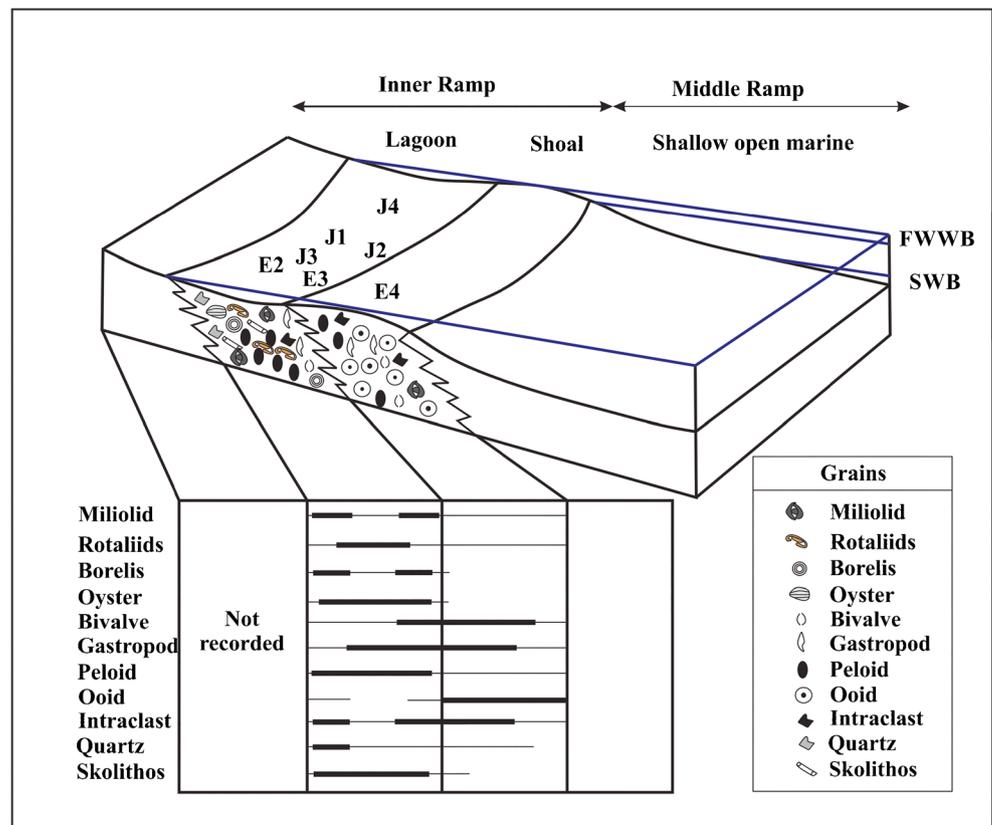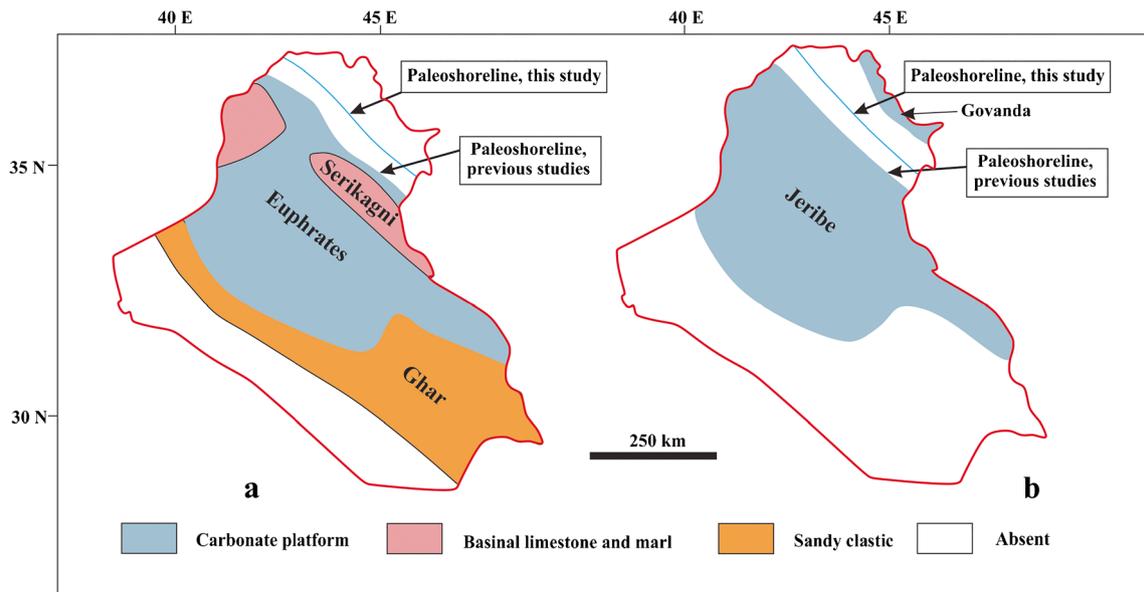
Fig. 9 Palaeogeography of Iraq. **a** During latest Chattian to early Aquitanian, showing the deposition of the Euphrates and Serikagni Formations after Aqrawi et al. (2010), and the new palaeoshoreline in this study. **b** During late Aquitanian to early Burdigalian, showing the deposition of the carbonate of the Jeribe Formation after Aqrawi et al. (2010), and the new palaeoshoreline inferred from this study

Formation, nearly 1.0 m thick, was recorded in the Azh Dagh and Qara Wais areas, whereas it thins toward the Qishlagh-Sargrma area. There is a discontinuity surface between the Euphrates and Jeribe Formations toward the Qishlagh-
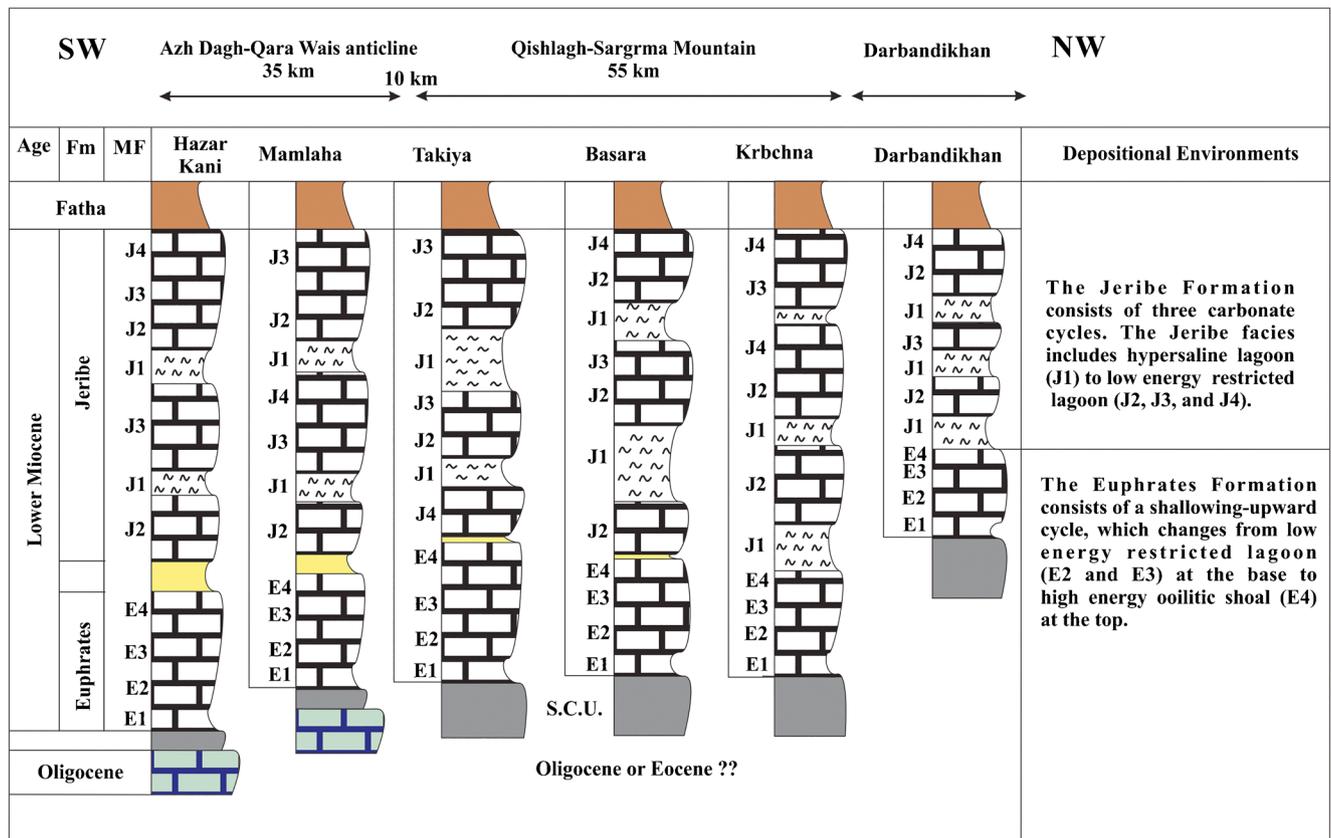
Fig. 10 Lithostratigraphic correlations of the Lower (Early) Miocene formations in the studied areas, Qishlagh-Sargrma, Darbandikhan, and Azh Dagh-Qara Wais, illustrating the facies distributions and depositional environments (refer to Fig. 1 and Table 1 for locations of logged sections). S.C.U., siliciclastic conglomeratic unit

Sargrma Mountain. The Jeribe Formation consists of three shallowing-upward cycles, passing up from hypersaline lagoon of the calcareous mudstone to restricted hypersaline lagoon of the miliolid packstone-grainstone and bioclastic-peloids grainstone microfacies, at the top. The upper boundary of the formation marks a short discontinuity surface toward the margin of the basin. The Early Miocene succession is thus interpreted to record a cyclical, regressive shallowing-upward trend, with the first regression of the shoreline through the area being recorded with the initial appearance of the red claystone of the Fatha Formation (Abdullah 2016). Overall, the Euphrates and Jeribe Formations were deposited in variable shallow marine environments in a gently-dipping inner ramp setting.

Conclusions

The Lower Miocene Euphrates and Jeribe Formations have been identified for the first time as the most proximal part of the marine Zagros Foreland Basin, in the Qishlagh-Sargrma Mountain and Darbandikhan study area, within the Kurdistan Region. The Early Miocene succession consists of an approximately 15 to 17 m thick carbonate-dominated package, which includes four main regressive carbonate cycles. The Euphrates Formation consists of two main sedimentary units; brecciated carbonate and shelly-carbonate, while the Jeribe Formation includes three main regressive cycles. Eight carbonate microfacies have been identified from the succession, E1, E2, E3, and E4 from the Euphrates Formation and J1, J2, J3, and J4 from the Jeribe Formation. The identification of the Early Miocene index fossil *Borelis melo melo* specifically confirms the occurrence and correlation of the Euphrates Formation. The microfacies analysis reveals that the Early Miocene formations in the studied areas accumulated at the margin of the basin on a very gently dipping carbonate ramp, comprising a variety of detailed environmental settings. The Euphrates Formation was deposited in restricted lagoon to shoal environments, while hypersaline and restricted lagoons are suggested for the deposition of the Jeribe Formation within the study area. The palaeoshoreline of the Early Miocene basin passed through what is now the location of Darbandikhan town and along Qishlagh-Sargrma Mountain, approximately 30 km away from the previously mapped position of the shoreline.

The stratigraphic correlation and revised palaeogeography imply that deposition occurred of all the Early Micoene depositional units, including Euphrates and Jeribe Formations, throughout the studied areas. The study also demonstrates the value of detailed outcrop mapping and microfacies and biostratigraphic analyses in the delineation of accurate palaeogeographies.

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