

Lithostratigraphy and microfacies analysis of Middle-Late Eocene Pila Spi Formation in Sheikh Turab section, Kurdistan region of Iraq

Litoestratigrafía y análisis de microfacies de la Formación Pila Spi del Eoceno medio-tardío en la sección Sheikh Turab, Kurdistán de Irak

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ABSTRACT

The Middle-Late Eocene Pila Spi Formation in the Sheikh Turab section at the southern limb of the Safin Anticline in the northern Iraq (Kurdistan region) is studied to clarify the stratigraphy, realize the depositional environment using facies analyses, and offer insights into the sedimentological evolution of the Middle-Late Eocene succession. The formation has a total thickness of 92.5 m, was examined using section description and logging in addition to sample collection at one outcrop locality. The field descriptions of the formation revealed three lithostratigraphic units composed of marly limestone, dolomitic limestone, chalky limestone, and marl, with different bed sets and thicknesses. The petrographic analysis of the carbonate samples also identifies three main microfacies, namely mudstone, wackestone, and packstone, with their subdivisions. They are categorized into one facies association in accordance with their environmental interpretation. According to the facies analysis, the studied formation was deposited in a shallow marine, subtidal, semi-restricted lagoon setting. This environment indicated a vertical gradient from the underlying molasses facies of the Gercus formation to more marine carbonate facies in the subtidal setting. It is also deduced that transgression of the Tethys Sea covered the studied area since the middle Eocene until the Late Eocene, creating favorable accommodation for carbonate production and sedimentation.

Keywords: Eocene, microfacies, Lithostratigraphy, Pila Spi, Sheikh Turab.

RESUMEN

Se estudia la formación Pila Spi del Eoceno medio-tardío en la sección Sheikh Turab en el extremo sur del anticlinal Safin en el norte de Irak (región del Kurdistán) para aclarar la estratigrafía, determinar el entorno deposicional mediante análisis de facies y ofrecer información sobre la evolución sedimentológica de la sucesión del Eoceno Medio-Tardío. La formación tiene un espesor total de 92.5 m y se examinó utilizando la descripción de la sección y el registro, además de la recolección de muestras en una localidad de afloramiento. Las descripciones de campo de la formación revelaron tres unidades litoestratigráficas compuestas por calizas margosas, calizas dolomíticas, calizas calcáreas y margas, con diferentes estratos y espesores. El análisis petrográfico de las muestras de carbonato también identifica tres microfacies principales, mudstone, wackestone y packstone, con sus subdivisiones. Se clasifican en una asociación de facies de acuerdo con su interpretación ambiental. Según el análisis de facies, la formación estudiada se depositó en un entorno lagunar marino somero, submareal y semi-restringido. Este entorno indicó un gradiente vertical desde las facies de melaza subyacentes de la formación Gercus hasta facies de carbonato más marinos en el entorno submareal. También se deduce que la transgresión del Mar de Tetis cubrió el área estudiada desde el Eoceno medio hasta el Eoceno tardío, creando un alojamiento favorable para la producción y sedimentación de carbonatos.

Palabras clave: Eoceno, microfacies, Litoestratigrafía, Pila Spi, Sheikh Turab.

1. Introduction

The Pila Spi Formation is a well-known Eocene carbonate unit in northern Iraq (Kurdistan region), cropping out as a resistant ridge in the whole high folded zone, especially near the boundary with the low folded zone (Sissakian and Al-Jiburi, 2014). It was significant because of its petrophysical and geochemical properties, which act as reservoirs and aquifers for water and hydrocarbons (Al-Qayim and Othman, 2012; Al-Salim and Al-Ozeer, 2020), in addition to their use as industrial raw materials and construction materials (Sissakian *et al.*, 2020). Lees first identified and documented the formation in 1930 in Bellen *et al.* (1959) in the southern margin of the high folded zone of northern Iraq.

Posteriorly, Wetzel (1947) in Bellen *et al.* (1959) re-studied the formation around Darbandikhan town in the Kurdistan Region of Iraq. It is 85m thick and mainly consists of bedded white chalky limestone and bituminous limestone, which is porous in the lower part and crystalline and has green and white marl bands with chert nodules in the upper part. It is characterized by lagoonal facies and was deposited during the Middle to Late Eocene age (Buday, 1980).

The lateral age equivalent of the Pila Spi Formation in Iraq is partially associated with the Dammam, Jaddala, and Avanah formations (Jassim and Buday, 2006). Regionally, it is correlative with a part of the Midyat Group in Syria (Weber, 1963) and south Turkey (Altinli, 2023). In Iran, its equivalent unit is the Jahrum Formation (Jassim

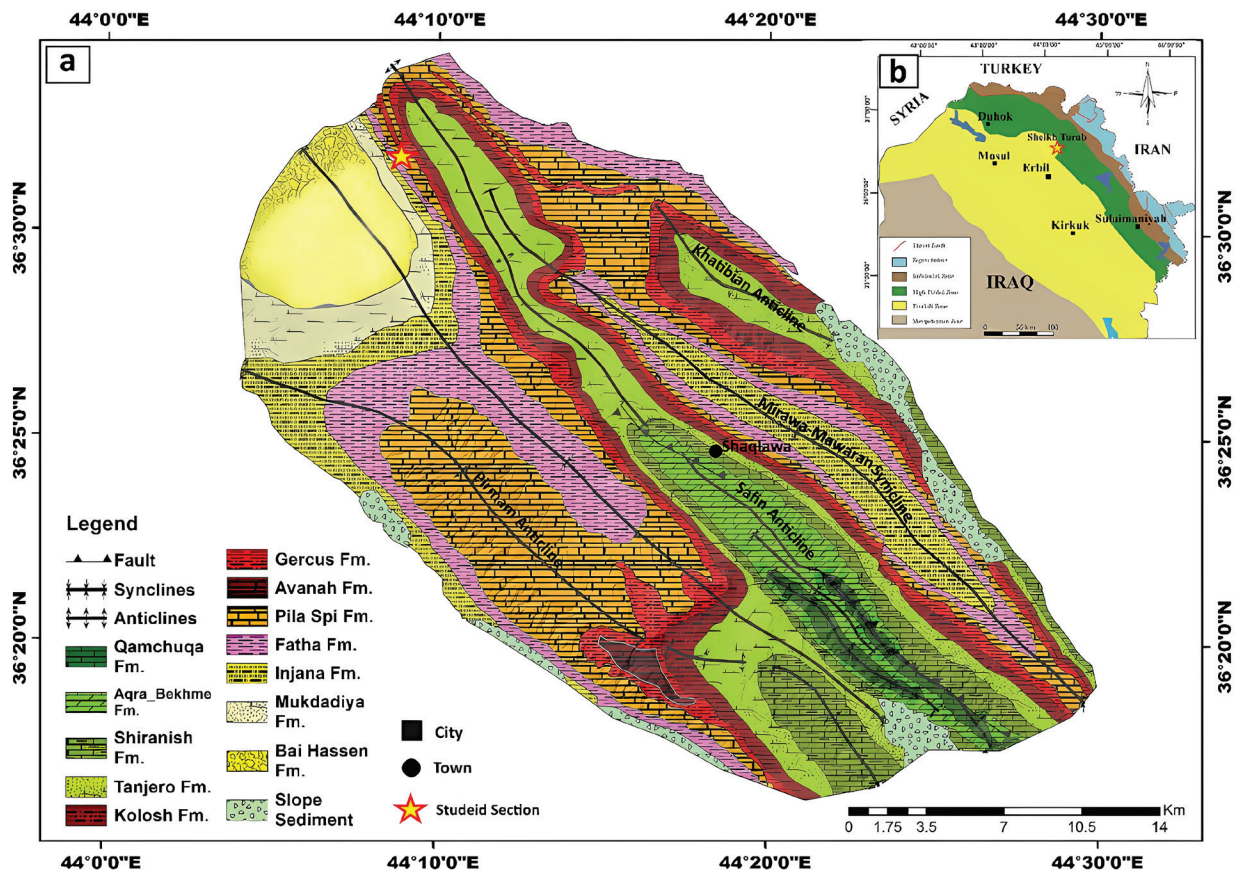


Figure 1 a) Geological map of Shaqlawa area include the studied section after (Abid *et al.*, 2022). b) Location and tectonic map of Kurdistan region (N-Iraq) revealing the studied location after (Jassim and Buday, 2006).

and Buday, 2006).

There are several studies dealing with the sedimentological and stratigraphical investigations of the Pila Spi Formation after the first description in Bellen *et al.* (1959), but no one studied the formation in the current studied outcrop. The most interested studies are Qadir (1989), Al-Qayim and Othman (2010, 2012), Khanaqa (2011), Sattam (2015), Hussien and Kadhim (2016), Mutar and Alsultan (2020), Balaky and Mahmud (2021), and Asaad (2022a).

The main objective of this research is to utilize petrographic examination, microfacies analysis, and field observation to define the lithostratigraphy and elucidate the depositional environment of the Pila Spi Formation at the Sheikh Turab outcrop.

2. Geologic setting

The Pila Spi Formation occupied the upper portion of the AP10 (Early Paleocene–Late Eocene) Arabian plate’s tectonostratigraphic megasequences, of Sharland *et al.* (2001). The deposition of the formation happened during the last phase of the Neo-Tethys closing, which was caused by the subduction of the Arabian and Eurasian plates in Paleocene-Eocene time (Jassim and Buday, 2006).

The Sheikh Turab studied area, which was not previously investigated through any works, is situated 1.5 km southeast of Sheikh Turab Village, at the Galley Garaw valley’s outlet on the southern limb of the Safin anticline, 38 km north east of Erbil city, roughly at Lat. 36° 31’ 49” N and Long. 44° 08’ 28” E (Figure 1a). From a structural per-



Figure 2 Panoramic view of the Pila Spi Formation in Sheikh Turab section: a) Field photograph of lower part of studied Formation. b) Field photograph of the upper part of investigated formation.

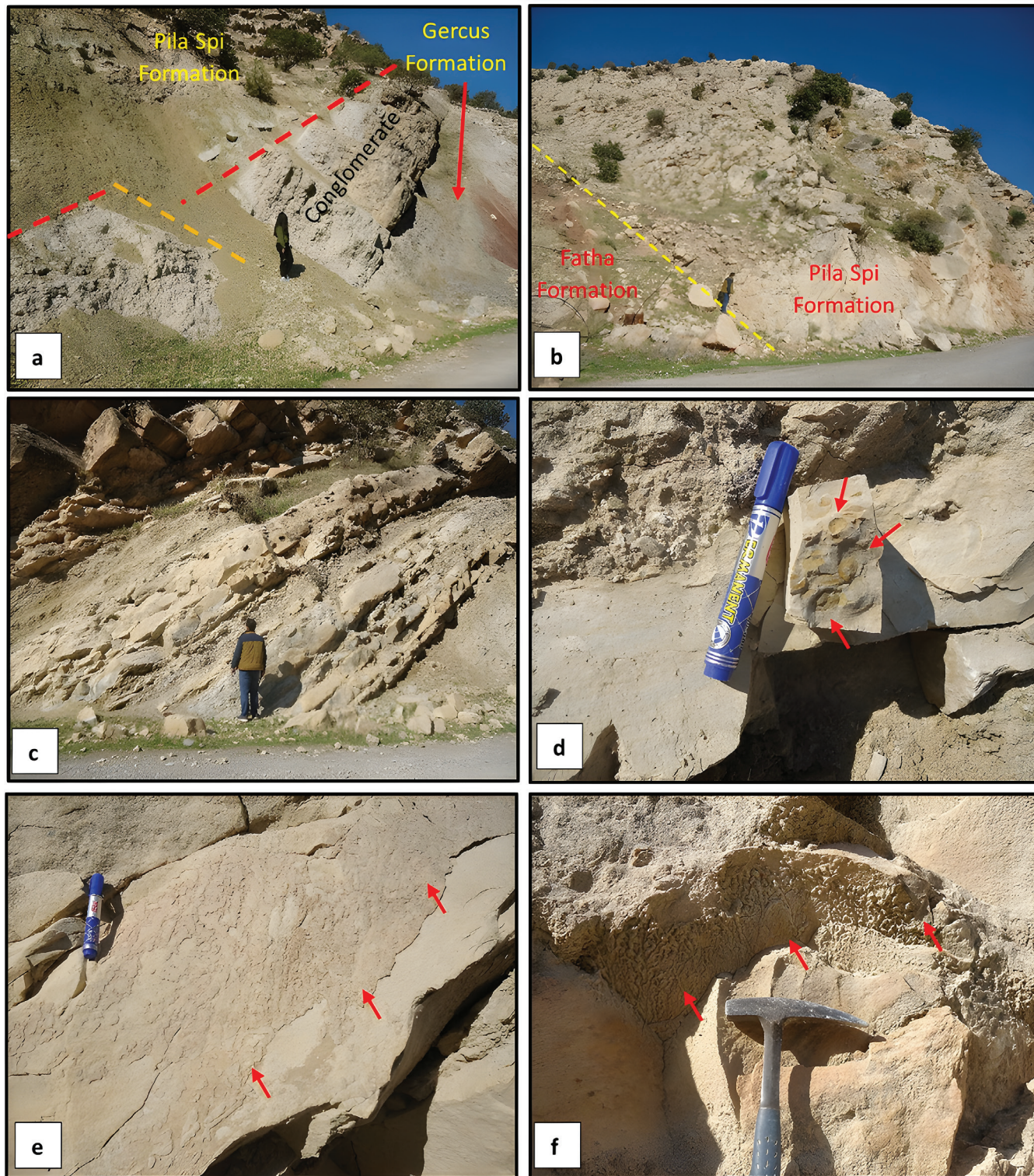


Figure 3 Field photographs of the Pila Spi Formation in the Sheikh Turab area display: a) lower boundary of the Pila Spi Formation with underlying red mudstone of the Gercus Formation, separated by white to yellow basal conglomerate. b) Upper boundary of the Pila Spi formation with the overlying Fatha Formation. c) Medium- to thick-bedded marly limestone intercalated with yellow marl. d) Pelecypods (red arrows) on the medium-bedded marly limestone of unit A. e) Wrinkle structure (red arrows) on the beds of limestone in the Pila Spi Formation. f) Bioturbation (red arrows) formed over the carbonate beds of unit A.

spective, the Sheikh Turab section is located in the southwestern limb of the Safin anticline, on the southern margin of the High Folded Zone (Figure 1b). This anticline is an asymmetrical, gently double plunging fold with south-westward vergency, trending NW-SE parallel to the Zagros Mountain Belt, and is regarded as one of the major anticlines in the High Folded Zone.

The Safin Anticline and the associated structures were formed as a result of regional horizontal compression stresses in the NE-SW direction during the Alpine Orogeny. They were affected by vertical stresses produced by the movement of basement blocks, which developed the Safin anticline (Doski, 2002).

The studied area is stratigraphically composed of a succession that begins with the Gercus and Pila Spi formations, which is overlain by Fatha (Lower Fars) and Injana (Upper Fars) formations, and far away Mukdadiya (Lower Bakhtiari) and Bai Hassan (Upper Bakhtiari) formations of Tertiary age (Figure 1a). The lower boundary of the formation is conformable with the underlying Gercus Formation, as indicated by its position above the last conglomerate beds of the Gercus Formation. On the other hand, the upper boundary is characterized by an unconformity, as it is found below the Fatha Formation, with an age gap present (Balaky and Mahmud, 2021).

3. Methods and materials

The fieldwork began by conducting a survey of the investigated area to choose the proper section for this study. Later, the Pila Spi Formation's succession is thoroughly measured and described, encompassing the logging of lithology and grain size in addition to the mineralogy. The major lithology observed in the studied section are dolomitic limestone, marly limestone, chalky limestone, and occasional thin beds of marl. The sum of 26 samples were collected from the Pila Spi carbonates. Furthermore, samples were collected in the lower and upper contacts with the Gercus and

Fatha formations, respectively. This was intended to clarify both boundaries' positions. Each sample was collected along a line perpendicular to the bedding plane, and they were obtained at random intervals when there was a change in lithology and/or color. They are also marked on both the lower and upper surfaces. Additionally, diluted HCl acid and a hand lens were used to perform a detailed description of the samples (a macroscopic study).

The overall of 26 thin sections (one thin section for each sample) were conducted in the laboratories of the Department of Earth Sciences and Petroleum, College of Science, Salahaddin University-Erbil. To distinguish between calcite and dolomite, the prepared thin sections were dyed with Alizarin Red Solution (ARS) using the Friedman (1959) procedure. An intensive petrographic investigation and microfacies analysis were carried out. The petrographic study was operated by utilizing a polarizing microscope for the identification of the components. Microfacies are described according to Dunham's (1962) classification.

4. Results

4.1. LITHOSTRATIGRAPHY

The entire thickness of the Pila Spi Formation in the Sheikh Turab area is around 92.5 m (Figure 2a, 2b). The formation is conformably underlain by the Gercus Formations and marked by 5.5 m of white to yellow conglomerate over the red mudstone of the Gercus Formation (Figure 3a). Whereas, the upper boundary is unconformable with the overlying Fatha Formation (which is the lower beds mostly covered in the studied section) (Figure 3b). Based on detailed field properties, the studied formation in the Sheikh Turab outcrop may be categorized into three lithostratigraphic units, arranged in ascending order:

Table 1. Microfacies description with proposed depositional environments of the Pila Spi Formation in Sheikh Turab Section.

Main microfacies Dunham (1962)	Subdivision of Dunham (1962)	Diagnostic features (main skeletal grain + common diagenetic process)	SMF Flügel (1982)	Environment of deposition
Lime Mudstone	Fenestral dolomitized lime mudstone	-Dissolution+ Dolomitization -Neomorphism	21	Subtidal (lagoon)
	Benthonic foraminifera dolomitized lime mudstone	- <i>Textularia</i> sp. -Dolomitization	8	Shelf lagoon with circulation
	Phosphatized bioclast lime mudstone	-Bioclasts -Phosphatization + Neomorphism	14	Subtidal (lagoon)
	Dolomitized lime mudstone	-Monocrystalline quartz -Dolomitization	23	Subtidal (lagoon)
	Peloidal dolomitized lime mudstone	-Peloids -Dolomitization+ Pyritization	9	Shallow lagoon with open circulation
Lime Wackestone	Ostracod-bioclasts lime dolomitized wackestone	-Ostracods+ Bioclasts. -Dolomitization+ Iron oxidization	9	Shelf lagoon with circulation
	Benthonic foraminifera- bioclasts dolomitized lime wackestone	-Miliolids+ Bioclasts -Dolomitization+ Iron oxidization	8	Shelf lagoon with circulation
	Gastropods-bioclasts dolomitized lime wackestone	-Gastropods+ Bioclasts -Dolomitization	9	Shallow lagoon with open circulation
	Dasycladacean lime wackestone	-Dasycladacean green algae -Neomorphism+ Dolomitization	8	Shelf lagoon with circulation
	Brecciated Molluscan- intraclasts dolomitized lime wackestone	-Mollusca+ intraclasts -Dolomitization+ Dissolution + Evaporites	14	Subtidal (lagoon)
Lime Packstone	Pelecypods- bioclast lime packstone	-Pelecypods + bioclasts -Cementation+ Neomorphism	9	Shallow lagoon with open circulation
	Bioclasts lime packstone.	-Bioclasts -Neomorphism+ Cementation	9	Shallow lagoon with open circulation

4.1.1 MEDIUM TO THICK BEDDED MARLY LIMESTONE INTERBEDDED WITH MARL UNIT (UNIT A)

This unit is overlying the 5.2 m of white to yellow conglomerate within the uppermost part of the older succession (Gercus Formation) and underlain the thick beds of dolomitic limestone interbedded with marl. The unit’s overall thickness is 17.5 m.

The first 6.5 m consist of calcareous yellow marl overlain by 4 m of thin (10–30 cm) grey to white marly limestone (Figure 3c) bearing pelecypods (Figure 3d) interbedded with thin yellow

marl. It was followed by 5m of medium-to-thick (30–50 cm) and thick (>50cm) bedded grey–yellow marly limestone intercalated with thin beds of marl. The rest 2 m composed of yellow calcareous marl. The unit exhibits several sedimentary structures, including horizontal planner lamination and wrinkle structure (Figure 3e), which are microbial-induced structures formed by cyanobacteria on the bedding planes of siliciclastic and carbonate beds (Choudhuri, 2020). The beds of this unit occasionally show different types of bioturbations (Figure 3f).



Figure 4 Field photographs of the Pila Spi Formation in the Sheikh Turab outcrop reveal: a) Thick bedded dolomitic limestone interbedded with marl (Blue line scale = 1.5 m). b) Brecciated orange to grey dolomitic limestone c) Honeycomb sedimentary structures (red arrows). d) Calcite geodes. e) Beds of medium- to thick fractured chalky limestone interbedded with thin beds of marl units. f) Macrostylolizations on the fractured limestone beds.

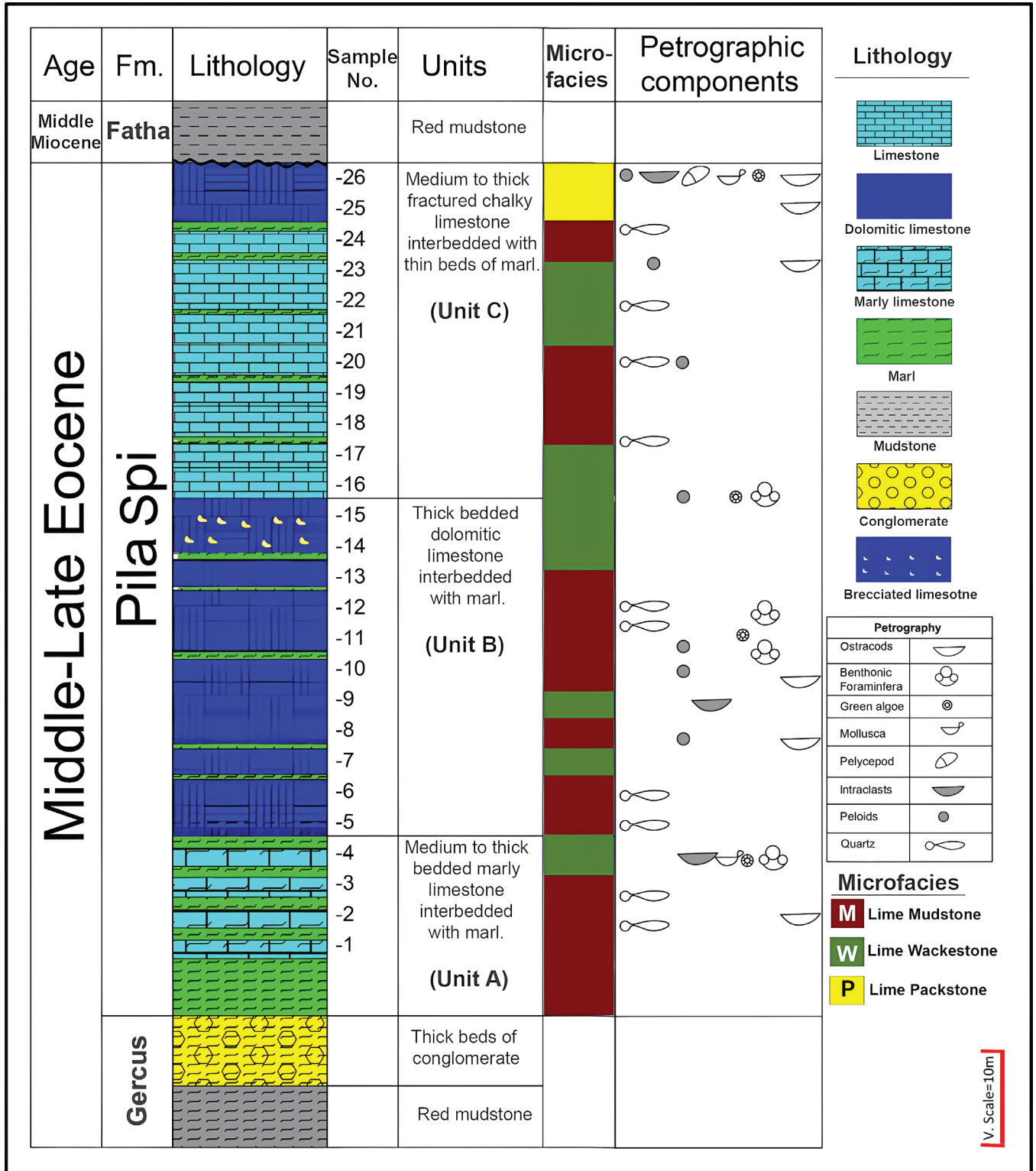


Figure 5 Columnar section of the Late Eocene Pila Spi Formation in the Sheikh Turab section with microfacies distribution.

4.1.2 THICK BEDDED DOLOMITIC LIMESTONE INTERBEDDED WITH MARL UNIT (UNIT B)

This unit is situated between the lower unit (A) and the upper unit (C) within the Pila Spi Formation. It is about 36 m in thickness. The lower 30.5 m is made up of thick (50–100 cm) bedded grey dolomitic limestone interbedded with very thin beds of yellow marl (Figure 4a) with 40 cm intervals of brecciated grey limestone in the lower part.

Following it, there was a 5.5 m alternation of thick (50–100 cm) bedded brecciated orange to grey dolomitic limestone and blue marl (Figure 4b). Horizontal planar lamination and honeycomb structures are the main sedimentary structures within these unit (Figure 4c). The upper carbonate beds of this unit are dominated by calcite geodes (Figure 4d).

4.1.3 MEDIUM TO THICK FRACTURED CHALKY LIMESTONE INTERBEDDED WITH THIN BEDS OF MARL UNIT (UNIT C)

This unit is located in the upper part of the Pila Spi Formation in the Sheikh Turab outcrop. It is positioned above the unit (B) and underlain red mudstone of the Fatha Formation. The unit consists of 38.5 m of medium-to-thick (30–50 cm) bedded with orange to red weathered color and white fresh color, fractured dolomitic limestone, and chalky limestone interbedded with thin beds of yellow and blue marl (Figure 4e). The layers of this unit display joints and macro-stylolization (Figure 4f).

4.1. MICROFACIES ANALYSIS

According to Dunham (1962) classification, the carbonates of the Pila Spi Formation show three primary microfacies types. Each one was further subdivided into several sub-microfacies, categorized according to essential fossil types and ratios. Subsequently, a comparison was made between these facies and the Facies Zones (FZ) described by Wilson (1975) and the Standard Microfacies (SMF) defined by Flügel (1982). The recognized

microfacies are the following (Figure 5; Table 1):

4.2.1 LIME MUDSTONE MICROFACIES

It is common in the studied section and dominant in the lower and middle portions of the Pila Spi Formation. Typically, it mostly comprises micrite with a rare fossil content (less than 10%) (Dunham, 1962). Different submicrofacies were recognized in it, including fenestral (Figure 6a), benthonic foraminifera (*Textularia*) (Figure 6b), phosphatized bioclast (Figure 6c) and dolomitized (Figure 6d), in addition to peloidal dolomitized mudstone submicrofacies (Figure 6e). The characteristic diagenetic process of this microfacies is dolomitization, in addition to neomorphism and pyritization.

4.2.2 LIME WACKESTONE MICROFACIES

It is characterized by the presence of grains that make up 10–50% within the micrite matrix, as described by Dunham (1962). The wackestone is found in the upper and middle units of the Sheikh Turab outcrop and undergoes several diagenetic processes, including dolomitization, cementation, and iron oxidation (Figure 7a). Based on the grain types, the wackestone facies can be subdivided into ostracod-bioclasts (Figure 6f), benthonic foraminifera (*miliolids*)-bioclasts (Figure 7a), gastropod-bioclasts (Figure 7b), dasycladacean (Figure 7c), and brecciated molluscan-intraclasts lime wackestone (Figure 7d) submicrofacies. The evaporate mineral is rarely observed within these microfacies (Figure 7d1).

4.2.3 LIME PACKSTONE MICROFACIES

It is relatively rare and primarily found in the upper part (Unit C) of the examined samples from the Pila Spi Formation. This facies type, as described by Dunham (1962), is characterized by a significant increase in skeletal grains, which account for up to 60% of the composition, with minor micrite present between the grains. The observed submicrofacies of this type consist of pelecypod-bioclast lime packstone (Figure 7e) and

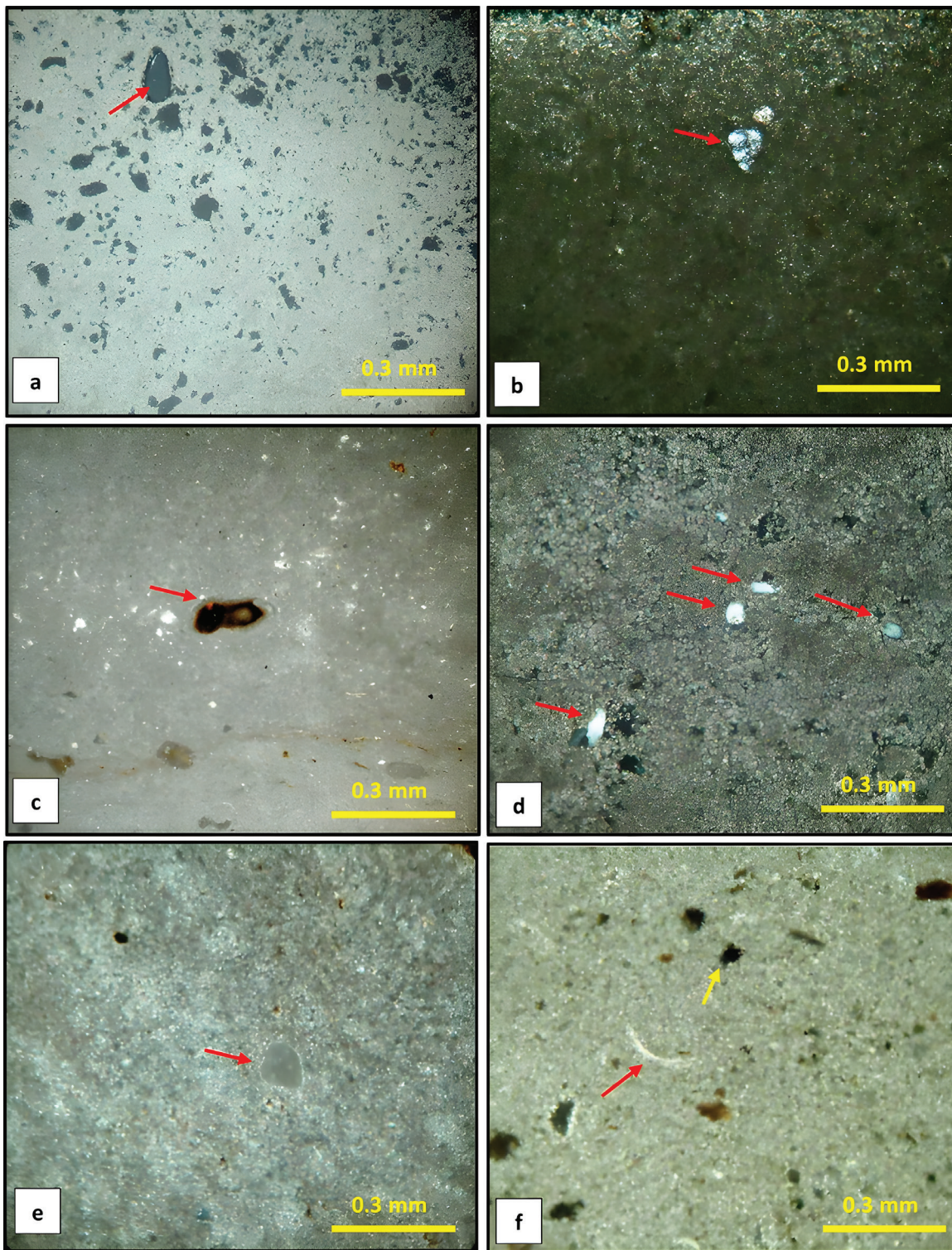


Figure 6 Photomicrographs of the Pila Spi Formation displaying: a) Fenestral dolomitized mudstone submicrofacies include molds of ostracods (red arrow). PS.10, X.N. b) Benthonic foraminifera lime mudstone submicrofacies include *Textularia* sp. (red arrow). PS.11., X.N. c) Phosphatized bioclast mudstone submicrofacies (red arrow). PS5., P.P. d) Dolomitized mudstone submicrofacies dominated by monocrystalline quartz (red arrows). PS24., X.N. e) Peloidal (red arrow) dolomitized lime mudstone PS8., P.P. f) Ostracods (red arrow)-bioclast dolomitized lime wackestone includes pyrite (yellow arrow). PS7., X.N. Key: PS: Pila Spi Sheikh Turab, P.P.: Plane polarized light; X.N.: Crossed Nicles.

bioclast lime packstone (Figure 7f) submicrofacies. Neomorphism and cementation are the primary diagenetic processes influencing these microfacies.

4.3. FACIES ASSOCIATION

Based on the depositional environment interpretation and the integration of field observation and microfacies types, one type of facies association (FA) was constructed in the carbonate rocks of the Pila Spi Formation in Sheikh Turab locality, which is the Subtidal semi-restricted lagoon Facies Association. It is identical to SMF 8, 9, 14, 21, and 23 of Flügel (1982) within FZ 8 of Wilson (1975). The FA covered the entirety of the Pila Spi succession in the studied section.

The lower part is 17.5m thick, consists of thin to medium bedded grey to white marly limestone rich lime mudstone, and medium to thick bedded grey to yellow marly limestone bearing lime mudstone, and wackestone interbedded with marl. The middle part is 36 m thick and is made up of thick beds of grey dolomitic limestone that contain lime mudstone and wackestone, as well as thick brecciated dolomitic limestone bearing lime wackestone with very thin beds of yellow and blue marl.

The upper part consists of 38.5 medium to thick bedded orange to red (weathering color) and white (fresh color) fractured dolomitic limestone bearing lime mudstone and lime wackestone, chalky limestone rich lime wackestone, and lime packstone interbedded with thin beds of yellow and blue marl. The sedimentary structures of this association include horizontal planar lamination and wrinkle structures. The bioturbation and chemical compaction of stylolitization are clear over the beds of this association. Pelecypod macrofossils were observed within the beds of the lower part.

The carbonates of Pila Spi Formation of this association are characterized by scarce microfossils, which include ostracods, benthonic foraminifera, dasycladacean green algae, pelecypods, gastropods, phosphatized bioclasts and bioclasts that

were significantly altered by diagenetic processes, including dolomitization, dissolution, and neomorphism. Fenestral texture is also abundant in this facies association. Non-skeletal grains involve principally peloids, monocrystalline quartz, and intraclasts. Evaporates are also observed within the middle beds of the association.

5. Discussion

The proposed Pila Spi Formation depositional environment in the Sheikh Turab outcrop is a subtidal, semi-restricted lagoonal setting. The microscopic examination of the carbonate rocks in the studied formation provides evidence of this. The identified microfacies had analogous litho and bio characterizations that show the congruency of the studied formation's facies and depositional environment. In this study, the dominant microfacies is mudstone, followed by wackestone. Both of them are characterized by the ascendancy of micritic groundmass with small grain proportions.

The dominance of micrite within these microfacies is evidence of the stagnation and calmness of the sea bottom sufficient to accumulate lime mud (Aqrabi *et al.*, 2023). The dolomitized lime mudstone, which is common in the studied formation, dominates in the restricted platforms (Flügel, 2010). Fenestral mudstone is formed by intense dolomitization and burrowing in the subtidal zone (Asaad, 2022a). The occurrence of benthonic foraminifera within micrite-dominated facies refers to shallow water settings (Bismuth and Bonnefous, 1981). *Textularia* sp. is found within the lagoonal environment with semi-restricted conditions (Asaad, 2022b). While porcelaneous wall miliolids are common within the hypersaline, restricted lagoon (Murray, 2006). On the other hand, dasycladacean green algae grow in a shallow marine environment, commonly at depths of 10–12 m below low tides (Kundal, 2010). Monocrystalline quartz is thought to be precipitated in low-energy, restricted subtidal, intertidal, and supratidal settings (Nowrouzi *et al.*, 2015).

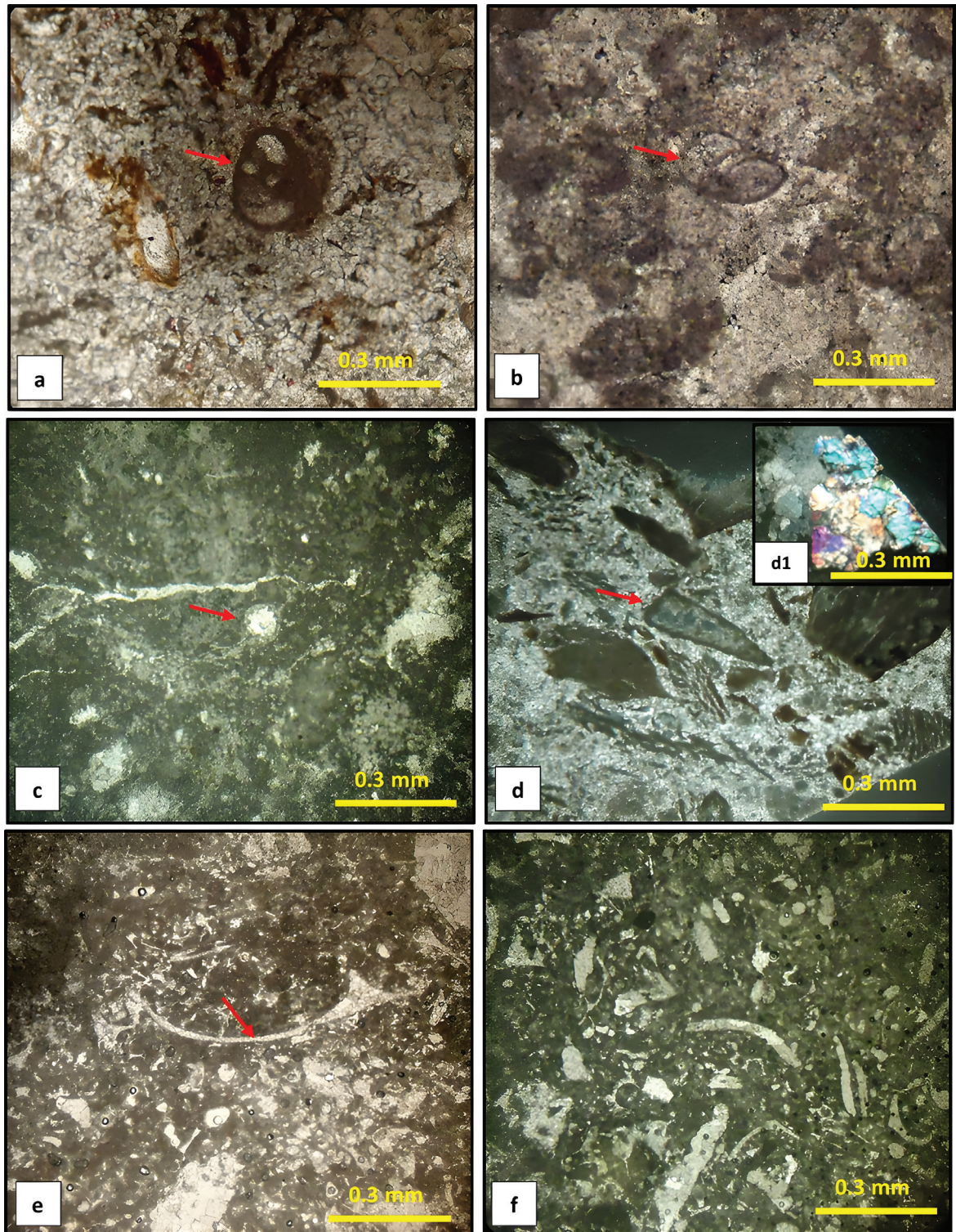


Figure 7 Photomicrographs of Pila Spi Formation displaying: (a) Miliolids (red arrow)-bioclasts dolomitized lime wackestone submicrofacies. PS6., P.P. (b) Gastropods (red arrow)-bioclasts dolomitized lime wackestone.PS16., P.P. (c) Dasycladacean (red arrow) lime wackestone. PS 15., P.P. (d) Molluscan- intraclasts dolomitized lime wackestone, (d1) evaporites within the submicrofacies. PS4., X.N. (e) Pelecypods- bioclast lime packstone PS25. P.P., A.S. (f) Bioclasts lime packstone.PS26. X.N. Key: PS: Pila Spi -Sheikh Turab, P.P: Plane polarized light, X.N: Crossed Nicoles. A.S: Alizarine Solution.

It is occurring with benthic foraminifera, which indicates a subtidal lagoon environment (Ameen *et al.*, 2020). Pelecypods are found in several habitats ranging from coastal to deep basins (Clarkson, 1998), and coexisting with gastropods is frequent in shallow lagoon environments (Flügel, 2010). Peloids, bioclasts, and intraclasts in wackestone and packstone microfacies are prevalent in the lagoonal setting (Wadood *et al.*, 2021). Phosphatized bioclast lime mudstone, derived from the phosphatic-walled organism remains, is found in the lower part of the Sheikh Turab outcrop and is a feature of lag deposits, which are created in the time of reduced conditions of sedimentation or non-deposition in a regime of deposition (Flügel, 2010) and occur in the subtidal lagoonal environment (Asaad *et al.*, 2021).

Wrinkle sedimentary structure is common in an intertidal environment, and there are two assumptions for its formation: first, that it analogizes the truly crinkled upper surface of living mats (Hagadorn and Bottjer, 1999), or second, that it is created as a result of post-burial deformation of the mat by overlying bed pressure (Noffke, 2000).

Its occurrence in shallow subtidal zones contributes to a decrease in benthonic biodiversity in addition to suppressed grazing in shallow marine settings (Peterffy *et al.*, 2016). On the other hand, the presence of the evaporates within the beds of the formation indicated stressful conditions arising from notable salinity variations or a confined basin setting (Asaad *et al.*, 2021). The origin of the brecciated limestone-bearing intraclastic wackestone, which has recrystallized groundmass supposed to

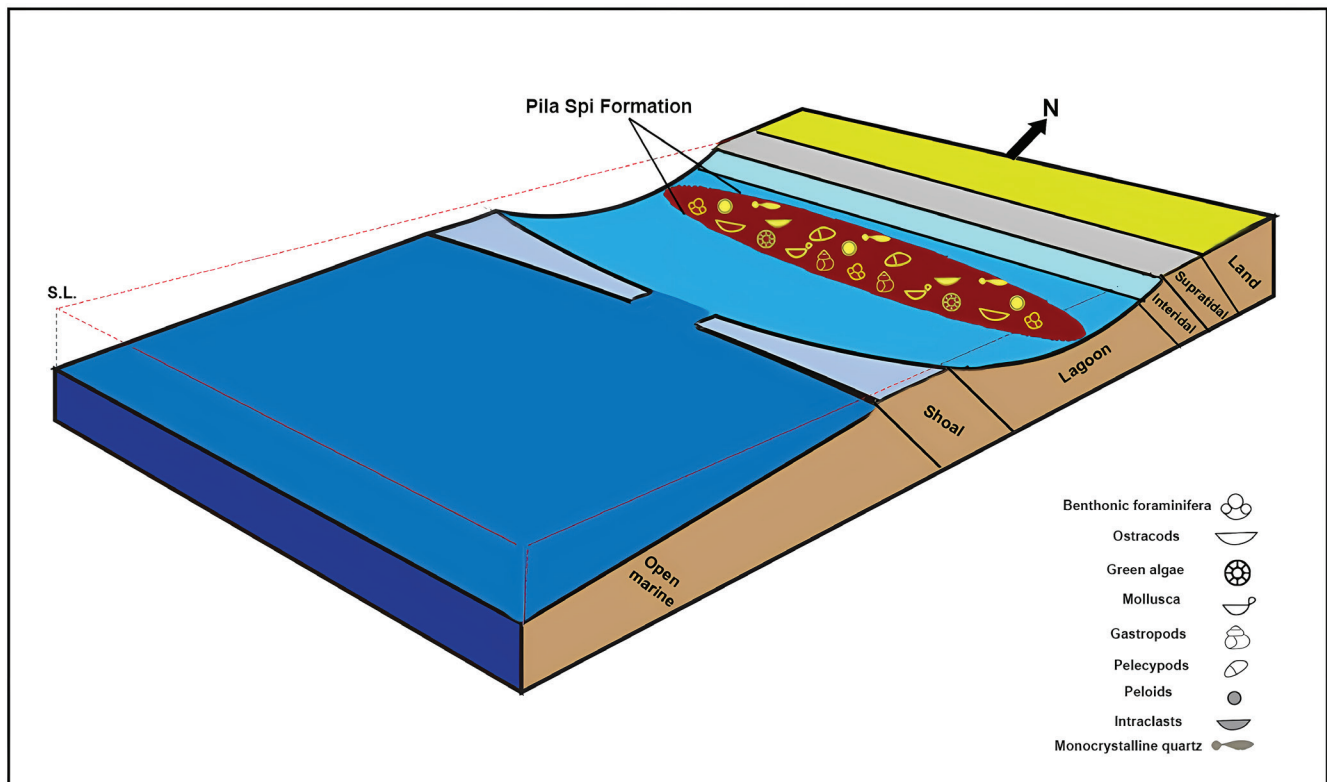


Figure 8 Depositional model of Middle-Late Eocene Pila Spi Formation in Sheikh Turab section, Safin anticline, High Folded Zone, Kurdistan region, Iraq.

be evaporite-solution collapses and is evident by patches of evaporites present within its thin section, refers to restriction circulation in the lagoonal environment (Balaky *et al.*, 2020). Furthermore, pyrites within the studied formation in the Sheikh Turab section suggest euxinic and restriction conditions of the lagoonal environment (Kauffman and Sageman, 1990).

So, based on the above analysis and interpretation, it is believed that the depositional setting of the Pila Spi Formation in the Sheikh Turab section can be determined as a subtidal, semi-restricted lagoonal environment (Figure 8). This environment indicated a vertical gradient from the underlying molasses facies of the Gercus formation to more marine carbonate facies in the subtidal environment. It is also deduced that transgression of the Tethys Sea covered the Sheik Turab area from the middle Eocene until the Late Eocene, creating favorable accommodation for carbonate production and sedimentation.

The above findings are relatively comparable with some previous works that was done on the Pila Spi Formation in the surrounding areas of the current study. Balaky and Mahmud (2021) studied the formation in Gomaspan and Bekhma sections, 33 km southeast and 16 km northwest of the studied section respectively. They mentioned that the formation was composed of dolomitic limestone, marly limestone, chalky limestone and cherty limestone lithofacies and deposited in the semi-restricted and open lagoon environments. Mutar and Alsultan (2020) studied the formation in Shaqlawa section, 20 km southeast of Sheikh Turab section and they concluded that the dominance microfacies types are lime mudstone, fossiliferous, bioclastic, peloidal and intraclastic lime wackestone, packstone and floatstone, that was deposited in the back reef/lagoonal and intertidal environment. The more recent study conducted by Asaad (2022a), showed that the formation in Nerwa section 18 km northeast of the current studied area consist of medium to thick bedded limestone interbedded with marl, thick bedded dolomitic limestone and cherty limestone bear-

ing lime mudstone, wackestone and packstone. He concluded that the Pila Spi Formation was deposited in a subtidal semi-restricted lagoon in the lower part and open lagoon setting in its upper part.

In the Middle-Late Eocene time a shallow marine carbonate platform prevailed in the north and northeastern Iraq, led to rocks of Pila Spi Formation deposited in the intertidal to lagoonal/back shoal environments. This setting was laterally changed to an open marine and basinal environments toward the south and southwestern part indicated by dominance of pelagic facies of Jaddala Formation in the central part of country (Alsultan, 2018). The Pila Spi basin in the northern Iraq separated by a ridge which intervalley made a shoal between shallow marine of Pila Spi Formation and open marine Jaddala Formation.

Toward, the southern and southwestern Iraq, the facies changed to shallower than those of middle part (Jaddala Formation) consists of grey to white porous, dolomitized and chalky limestone interbedded with some green-grey shales belong to Dammam Formation and mainly deposited in a shallow, neritic conditions (Alshahran and Nairn, 2003).

Regional correlation of Pila Spi Formation with surrounding territories, shows that the Jahrum Formation in Iran mainly consist of carbonate rocks that its lower part pervasively dolomitized, whereas, the middle and upper parts are mainly limestone bearing larger benthic foraminifera. As well as, there are intervals of breccias within the formation (James and Wynd, 1965). The facies analysis and paleontological evidences of the Jahrum Formation shows that it was deposited in a distally steepened ramp environment in the lowermost part. while it was changed to homoclinal ramp and proximal inner ramp setting towards the upper part and changed laterally to deep marine Pebdeh shale Formation towards the coastal Fars (Zohdi *et al.*, 2013). In southeast Turkey and northeast Syria (Northern margin of Arabian Plate), it is correlative with the Hoya Formation (Lower part of Midyat Group) which mainly consist of

thick-bedded to massive limestones and dolomites, deposited in a restricted, semi-restricted to shallow open marine platform (Perinçek *et al.*, 1992).

6. Conclusions

The carbonate rocks of the Middle-Late Eocene Pila Spi Formation in the Sheikh Turab section comprise 92.5 m of thin to medium and medium to thick bedded grey marly limestone, thick bedded grey dolomitic limestone, and medium to thick bedded fractured white chalky limestone, all intercalated with yellow and grey marl with partly brecciation in the middle part. The Lower contact is conformable with the underlying siliciclastic rocks of the Gercus Formation, while the upper contact is unconformable with the overlying siliciclastic-carbonate successions of the Fatha Formation.

Lithostratigraphically, the studied formation is divided into three litho units, which are: medium-to thick-bedded marly limestone interbedded with marl; thick-bedded dolomitic limestone interbedded with marl; and medium- to thick-fractured chalky limestone interbedded with thin beds of marl. The matrix of microfacies is basically composed of micrite with recrystallized microspar.

Skeletal grains represent shallow marine fossils and include benthonic foraminifera, dasycladacean green algae, ostracods, pelecypods, mollusca, gastropods, and bioclasts. While non-skeletal grains consist of peloids, intraclasts, and monocrystalline quartz. According to Dunham's (1962) classification, three basic microfacies and 12 submicrofacies were recognized in the carbonate rocks of the studied formation. These microfacies were integrated into one facies association depending on their environmental interpretation, which is a subtidal, semi-restricted lagoon.

This environment indicated a vertical gradient from the underlying molasses facies of the Gercus formation to more marine carbonate facies in the subtidal environment.

It also referred to the transgression of the

Tethys Sea submerged Sheik Turab area from the middle Eocene until the Late Eocene, generating favorable accommodation for carbonate production and sedimentation. This setting laterally changed to an open marine and basinal environment toward the south and southwestern part of the country, indicated by the dominance of the pelagic facies of Jaddala Formation.

Contributions of authors

ISA: conceptualization, field work, analysis, methodologic/technical development, writing of the original manuscript and interpretation; AMAhmed: graphic design and analysis; SMB: writing of the corrected and edited manuscript.

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Conflicts of interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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