INTERPRETATION OF NEW FACIES IN THE PILA SPI FORMATION (MIDDLE – LATE EOCENE), IN SULAIMANIYAH, NE IRAQ

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ABSTRACT

The Pila Spi Formation (Middle – Late Eocene) was previously assigned as lagoonal crystallized limestone and poorly fossiliferous, including gastropods, miliolids and algae. Conversely, during fieldwork new facies and lithologies were observed in outcrop sections. These sections contain intervals (10 – 40 m thick) that are characterized by massiveness and high fossils content; such as: algae, corals and bryozoans and their bioclasts. These constituents can be identified only in polished slab, while in thin section they are hardly identifiable due to diagenetic processes. These constituents form several facies such as: floatstone, bindstone, framestone, bafflestone and rudstone.

The discovery of these facies revealed new environmental and paleogeographic setting for the Middle – Late Eocene in the northeastern part of Iraq. The depositional environment is a carbonate ramp with low topographic patchy reef, back reef and lagoon. The evidences for ramp are gradual changes of the facies and absence of high energy facies. The new facies of the Pila Spi Formation and Avanah Formation are deposited on back reef and reef environments, respectively. The ramp is bordered from south and southwest by open marine basin where Jaddala Formation was deposited, while it is limited from the north by paleohigh, which separates the ramp from Walash – Naopurdan Group.

تفسير سحنات جديدة في تكوين البيلا سپي (الأيوسين الأوسط – المتأخر)، في محافظة السليمانية، شمال شرق العراق

پولا آزاد خانقاه

المستخلص

إن تكوين البيلا سپي قد عرف سابقاً بأنه يتكون من صخور جيرية متبلورة لاغونية وفقيرة بالمستحاثات (يحتوي على بعض بطنية القدم، المليوليد والطحالب). في هذه الدراسة تم تسجيل سحنات وصخور جديدة في التكوين، حيث أن مقاطع تكوين البيلا سپي تحتوي تجمعات صخرية كتلية ومتبلورة بسمك (10 – 40) م تتميز بكثرة احتوائها على مستحاثات مثل الطحالب، المرجان، البرايوزوا أو الفتات الحياتي. وتظهر هذه المكونات من خلال الألواح المصقولة فقط، أما في الشرائح الرقيقة فلا يمكن التعرف عليها بسهولة بسبب العمليات التحويرية. هذه المكونات يمكن أن تمثل مجموعة من سحنات مثل Floatstone، Bindstone، Framestone، Bafflestone وRudstone. إن اكتشاف هذه السحنات يطرح فكرة جديدة عن البيئة الترسيبية والجغرافية القديمة لعصر (Middle – Late Eocene) في شمال شرق العراق. دلت هذه السحنات على أن البيئة الترسيبية كانت عبارة عن منحدر (ramp) جيري مع وجود كتل مرجانية منخفضة وبيئة خلف الشعاب واللاغون. إن دلائل المنحدر هو التغير التدريجي للسحنات وعدم وجود سحنات ذات طاقة عالية. إن السحنات المكتشفة في تكوين البيلا سپي وتكوين آفانة قد ترسبت في بيئة خلف الشعاب وبيئة شعابية، على التوالي. إن المنحدر (ramp) قد أحيط من الجنوب والجنوب الغربي ببحر مفتوح والذي ترسب فيه تكوين الجدالة، أما من الشمال أحيطت بارتفاع قديم (Paleohigh) والذي فصل المنحدر من مجموعة ولاش – ناوبردان.

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INTRODUCTION

The studied area is located in the Sulaimaniyah Governorate at the boundary between High and Low Folded Zones, where extensive outcrops of the formation could be found (Figs.1 and 2). According to Bellen *et al.* (1959), Pila Spi Formation was first described by Lees in 1930 from the Pila Spi area of the High Folded Zone. They added that the original type section was submerged under the reservoir of the Darbandi Khan Dam during the sixtieth of the last century. A supplementary type section was thus described at Kashti, on the Barand Dagh, about 10 Km to the north of Darbandi Khan town. The resistant Pila Spi Formation forms a conspicuous ridges between the less resistive Gercus and Fatha formations throughout the High Folded Zone.

The Pila Spi Formation (Middle – Late Eocene) is about (100 – 200) m thick. The upper part of the formation comprises of well bedded, bituminous, chalky and crystalline limestone, with bands of white, chalky marl, with chert nodules towards the top. The lower part comprises well bedded, hard, porous or vitreous, bituminous, white, poorly fossiliferous limestones, with algal or shell sections. In the supplementary type section, it consists of dolomitic and chalky limestone with chert nodules (Bellen *et al*., 1959 and Jassim and Goff, 2006). According to the former authors, the formation consists generally of lagoonal sediment, with probable primary (chemical) dolomite. The fauna are stunted (dwarf), which include miliolids, gastropods and algae.

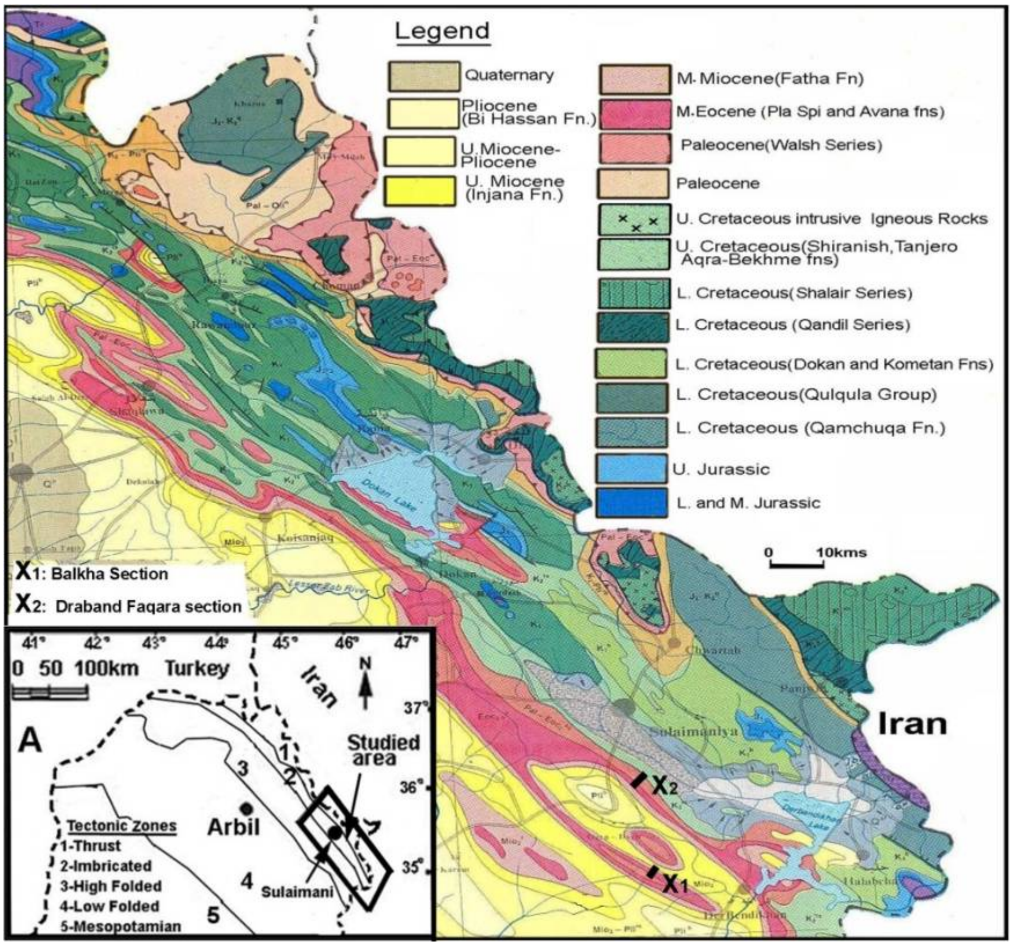

Fig.1: location and geological map of the studied area (after Sissakian, 2000) the location of the two sections are indicated as X1 and X2.

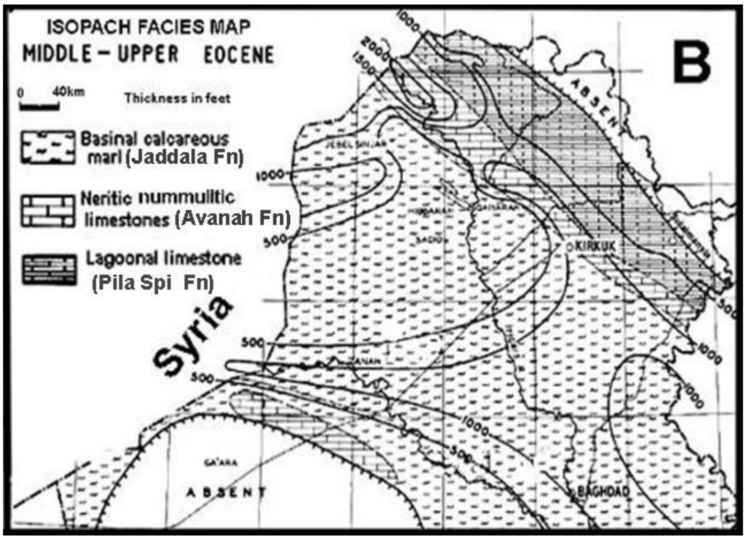

Fig.2: Isopach facies map of the Middle-Upper Eocene showing distribution of Basinal marl (Jaddala Formation), limestone (Avanah Formation) and lagoonal limestone (Pila Spi Formation) (after Bellen *et al*., 1959)

NEW RECORDED LITHOLOGIES

During fieldwork at the south and southwest of Sulaimaniyah city (at the boundary between High and Low Folded Zones) new lithologies were observed in the outcrop sections of the Pila Spi Formation. These sections contain intervals (10 – 40 m thick) that are characterized as massive and high content of fossils, such as coral, bryozoans and green algae. The occurrence of these fossils in the Pila Spi Formation is abnormal and not recorded previously. These intervals consist of very thick to massive beds (1 – 4 m thick) and form cliffs about 20 m high at the top of Baranan and Qara Dagh (Sagrma) Mountains (Fig.3A and B). Now these beds are quarried for decoration stones (sedimentary marble as called commercially), which have white to milky color. Several quarries are now in use along the Baranan (Glazarda) Mountain, south of Sulaimaniyah city.

The fossils appear neither clearly in hand specimens nor in thin sections, but they could be observed in polished slabs. In slabs, many fossils, with relatively clear detail sculptures become visible. The fossils appear in fresh samples as large or small, light grey spots and when observed by hand lens, the spots appear porous (with diameters 0.4 – 2 mm). Under the microscope, the fossils cannot be distinguished, either due to large size or due to defused and gradational boundary between the fossils and matrix because of crystallization. The skeleton of the fossils are replaced by dark grey or black spary calcite (as seen in polished slabs) with white background (dolomitized micrite). There are more or less reworked bioclast (debris) beds of the skeletons, which are badly sorted and angular. However, some of the reworked beds show crude laminations. Qadir (1989) recorded unusual lithologies (as compared to original description of the type section) in Pila Spi Formation including nummulitic limestone with red algae (*Lithophylum* sp.) in the middle part of the formation in Darbandi Bazian Section. The recorded nummulites were found in the interval of (105 – 120) m (Fig.4). The species of the nummulites that are recorded by the author are: *Assilina exponens*, *Discorbinus, Perforatus*, *Millecuput* and *Gizehensis*. These nummulites are not recorded previously by Bellen *et al*. (1959) and Buday (1980) and they are not found in the present study too, although great effort has been spent for inspection of that mentioned interval in Darbandi Bazian section.

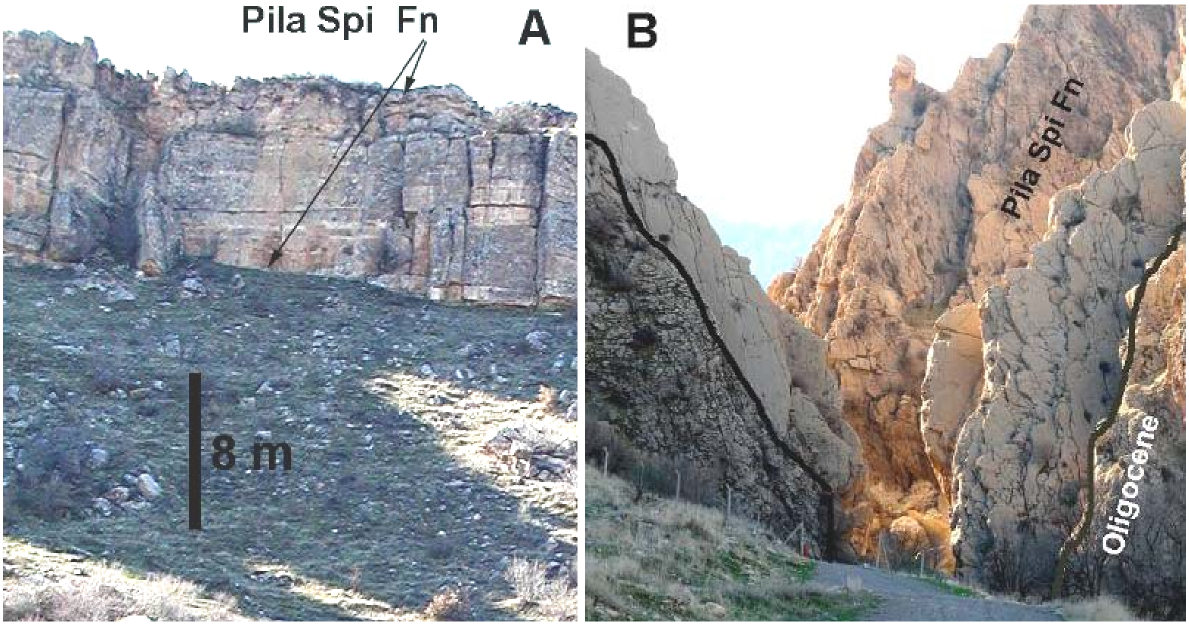

Fig.3: **A)** Massive section of the Pila Spi Formation at the Peak of Baranan Mountain, south of Sulaimaniyah city, 2 Km east of Glazarda village. It contains algae, coral and bryozoa colonies
B) Darband Balkha (at the lower part of the southwestern limb of Sagrma anticline) 10 Km south of Qara Dagh town shows Oligocene rocks above Pila Spi Formation

LITHOFACIES ANALYSIS

New lithofacies are found in the Pila Spi Formation, which have environmental and paleogeographic importance. These facies can be recognized in polished slabs clearly. The problems that stand against accurate identification of the facies are the fact that the rocks of the formation have suffered from different degrees of recrystallization. Therefore, the photos of the facies might not be so clear and not easily recognizable. However, the following five facies are identified.

▪ Floatstone Facies

Floatstone is matrix supported carbonate rocks that contain more than 10 % grains larger than 2 mm. The matrix of floatstone does not necessarily correspond to micrite, but often exhibits fine-grained textures that must be described separately (Flugel, 2004). This facies is very common in the studied succession of Pila Spi Formation, which consists of grains larger than sand size and floated or embedded in white fine matrix of dolomitized lime mudstone (Fig.5). The grains are generally derived from the fragmentation of reef builder skeletons, such as: coral, green algae and bryozoans. In most cases, the grains are very angular and the delicate sculptures are clear, which are denoting very short distance of transportation and relatively calm environment (Fig.6). In case of increase and grouping of elongated grains, this facies may grade to bafflestone.

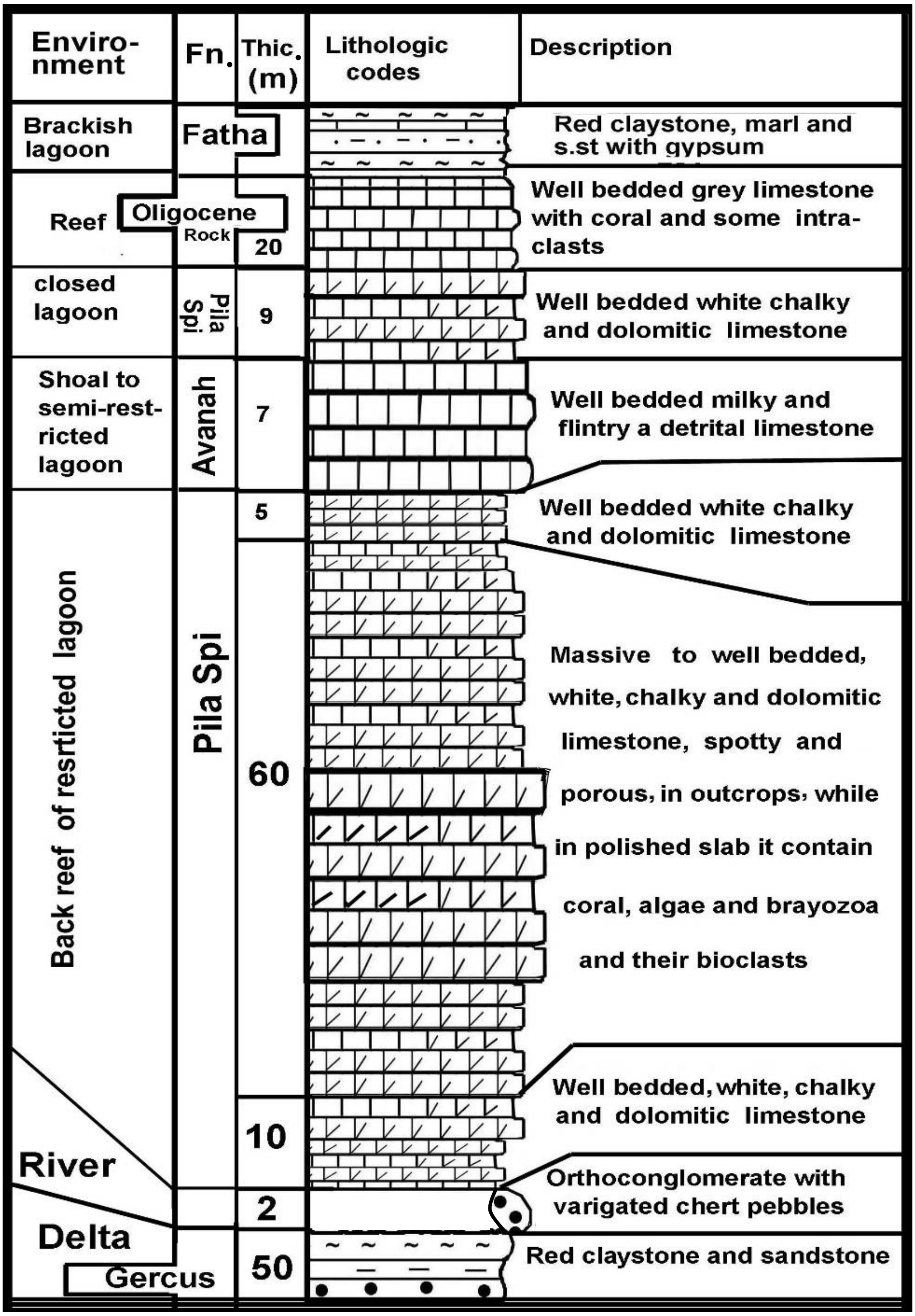

Fig.4: Stratigraphic column of the Pila Spi Formation in Balkha Gorge at northeastern limb of Sagrma Anticline

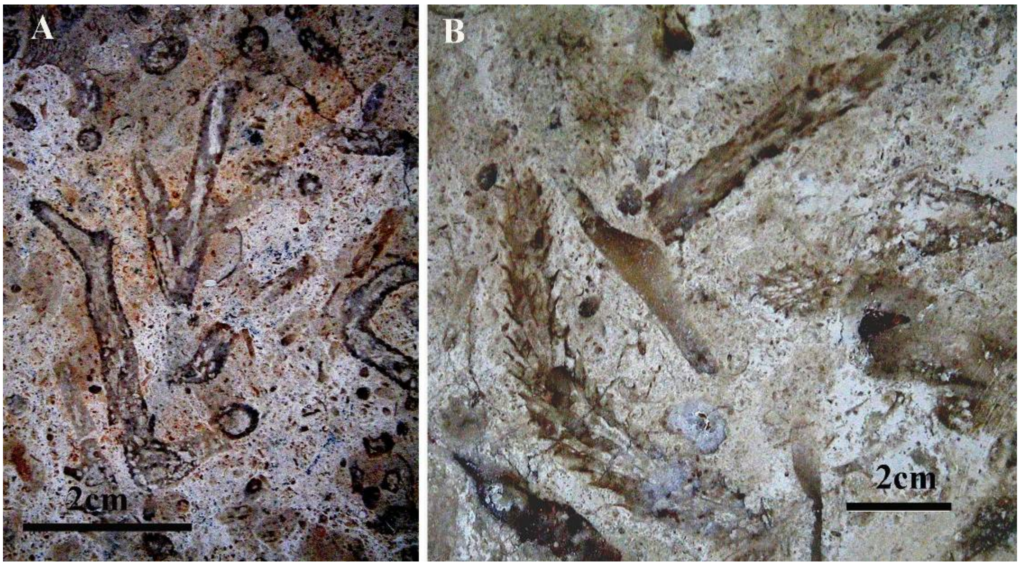

Fig.5: **A)** Bryozoan's floatstone without sculpture
B) Bryozoan's floatstone with delicate sculpture

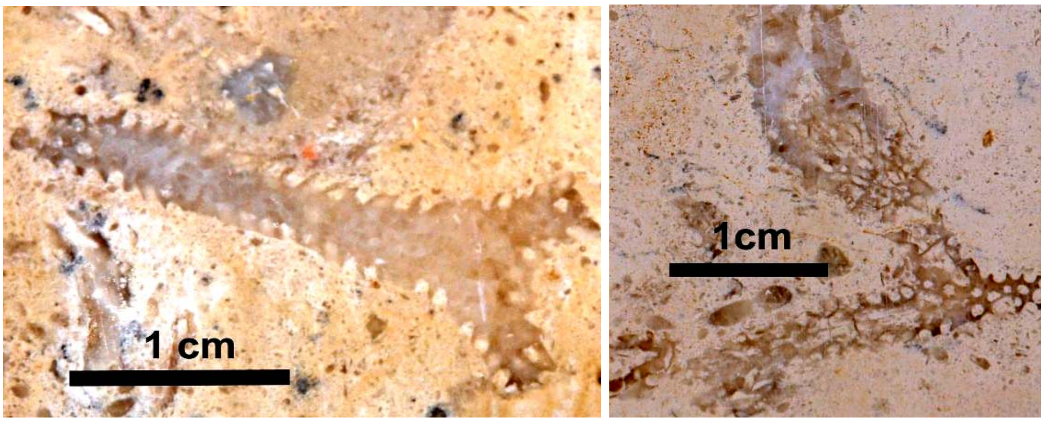

Fig.6: Coral colony with delicate accessories
Baranan Mountain south of Darband Faqara village
(10 Kms west of Zarayen town)

▪ **Bindstone Facies**

This type of facies is formed by accretion of biofilm and binding processes by Cyanobacteria, which consists of unicellular bacteria that exists as colonies in the form of filaments, sheets or even hollow balls. Cyanobacteria have a complex and highly organized system of internal membranes, which function by photosynthesis (Cribs, 1996). The cyanobacteria are mucilaginous and this together with its filamentous nature, results in the trapping and binding of sedimentary particles to produce a laminated sediment or stromatolite (Riding, 1991). The term of thrombolites has been introduced by Aitkin (1967) for that type of microbialite (stromatolite), which consists of clotted fabric and more or less rounded small bodies with general obscured internal structures. The laminations are disturbed and hardly identified, but they contain a network of small-coated fenestrae and coated grains (Aitkin, 1967 and Shpiro, 2000). Stromatolite is formed by products of trapping and binding of grains by filamentous Cyanobacteria.

The growth of thrombolite needs suitable environmental conditions for accumulation thickly enough, to be recognized in the fossil record. Such conditions may include a super saturation of calcium carbonate in the water, slow rates of sediment accumulation, or elevated salinity and temperature conditions. Modern thrombolites are found in a variety of environments including hypersaline lagoons, tidal channels and fresh water lakes (from: wikipedia.org/wiki/Stromatolite). Oliver *et al*. (2002) mentioned that the microbial crusts played an important role in the stabilization and growth of the reef body, which developed on various substrates such as corals, bivalves or bioclasts. Grotzinger *et al*. (2000) and Johnson and Grotzinger (2006) studied the thrombolitic microbialite growth and morphology in Nama Group at Namibia, and they mentioned that the stromatolite may directly affect reef growth.

The definitions of Aitkin (1967) and Shpiro (2000) for bindstone (thrombolites) are more or less applicable on those recorded in the present study (Fig.7). Photos, show crinkled and vesicular crusts around spherical algal bodies, with cavities filled by spar (**c** in Fig.7). Some cavities appear to owe their origin to primary discordances in layering of algal crusts-upper crust having bridged depressions in lower part.

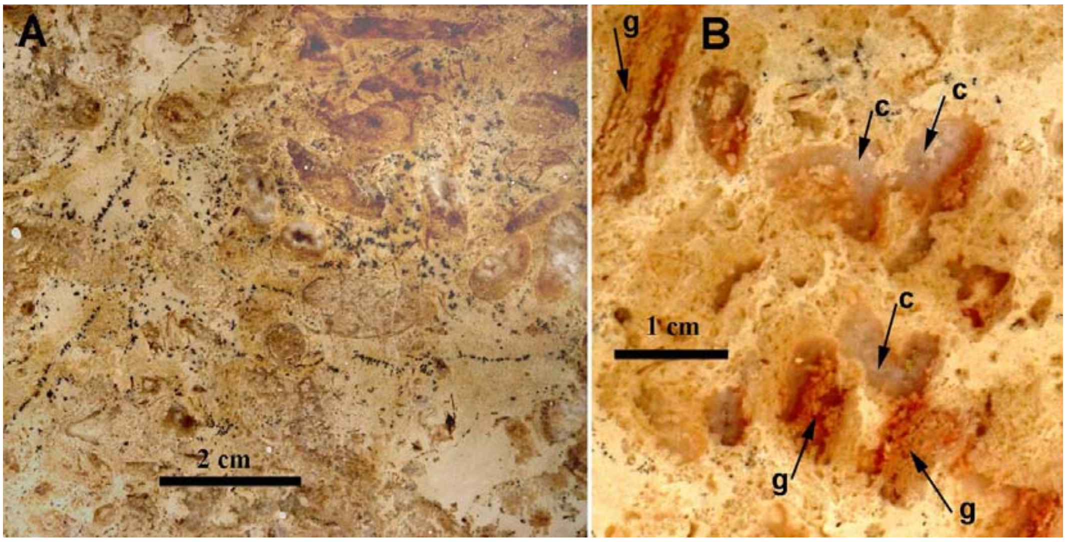

Fig.7: Polished slabs: **A)** Possible bacterial bindstone, all the dark areas have bacterial origin and only the white areas are physically deposited. **B)** Algal (g) bindstone with cavities filled with calcite. The white areas are filled by lime mud (micrite). The overall view of the facies resembles Swiss cheese structure

- **Bafflestone**

This facies contains elongated (circular in cross section) coral and bryozoa colonies, which appear as single elongated steams that are about (0.3 – 3) cm thick and more than 5 cm long (Fig.8). This facies is badly developed due to sparse arrangement of branches and the sections are cut obliquely. The spaces between the branches are filled by white lime mud and sand size bioclasts. In literature, this facies is called bafflestone (Emery and Klovan, 1971), because it has dendritic form and acts as sediment collector from the nutrient bearing current and waves by filtering; and trapping sediments. Walker and James (1992) have considered this facies in the colonization stage of the reef structure (Fig.8). The presence of corals indicates normal marine salinity (Riding and Tomas, 2006). According to Flugel (2004) the feature for identifying the Bafflestone is the presence of large number of in situ stalk-shaped fossils. This facies is found by Pomar *et al*. (2005) in the rocks of Upper Cretaceous platform in the Pyrenees, Spain.

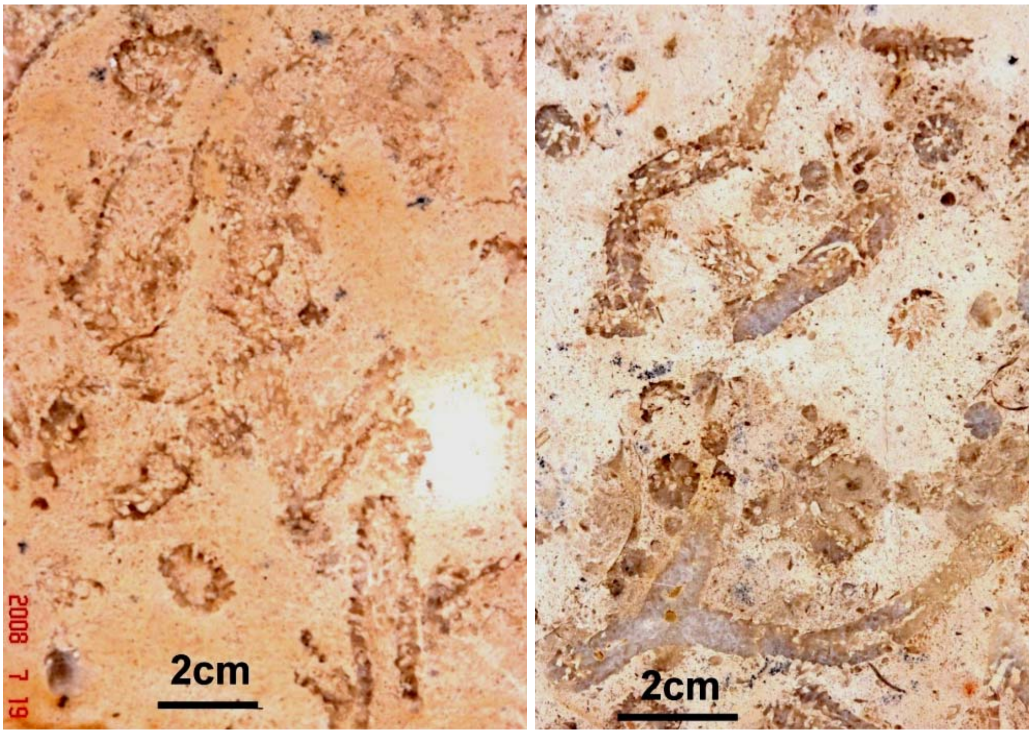

Fig.8: Two photos of the coral bafflestone, between the stems, fine lime mud and sand size allochemes are deposited (Balkha section).
The two polished slabs are cut obliquely; therefore, the elongated corals appear sparse

- **Framestone**

This facies (as subdivision of boundstone) is defined by Flugel (2004) as the occurrence of sessile benthic fossils that are densely spaced and preserved in life position. The morphology and distribution of the fossils should fit into an imaginary three dimensional organic framework. Organisms contributing to the formation of framestone have changed during Phanerozoic and include corals, coralline sponges, stromatoporoids, rudist bivalves and calcareous red algae.

In the studied sections, the frames tone facies is found in the limestone succession between Fatha and Pila Spi formations. This succession is about 20 m thick and consists of hard, milky, fossiliferous and detrital limestone. Under hand lens hex-corals and lepidocyclina can be seen in some beds. Most possibly, it belongs to Oligocene, which recently was found in the studied area by Khanaqa *et al*. (2009). The framestone microfacies consists of coral skeleton with well developed framework (Figs.9, 10 and 11). Coral fragments and individual skeleton also exist in the Pila Spi Formation, but they are too small to form framestone.

- **Rudstone**

According to Flugel (2004), rudstone is equivalent to packstone and grainstone, which is defined by him as "grain supported carbonate rocks containing more than 10% grains larger than 2 mm. Rudstone must be further characterized by compositional and textural criteria. Generation of rudstone needs erosion and transportation". He farther added that erosion can be triggered by shallow water settings allowing destruction by storm. When the definition of Flugel (2004) is used the occurrence of this facies is found to be common; especially in the lower part of the studied sections, which consist of the large self-supported bioclasts (or reworked whole skeletons).

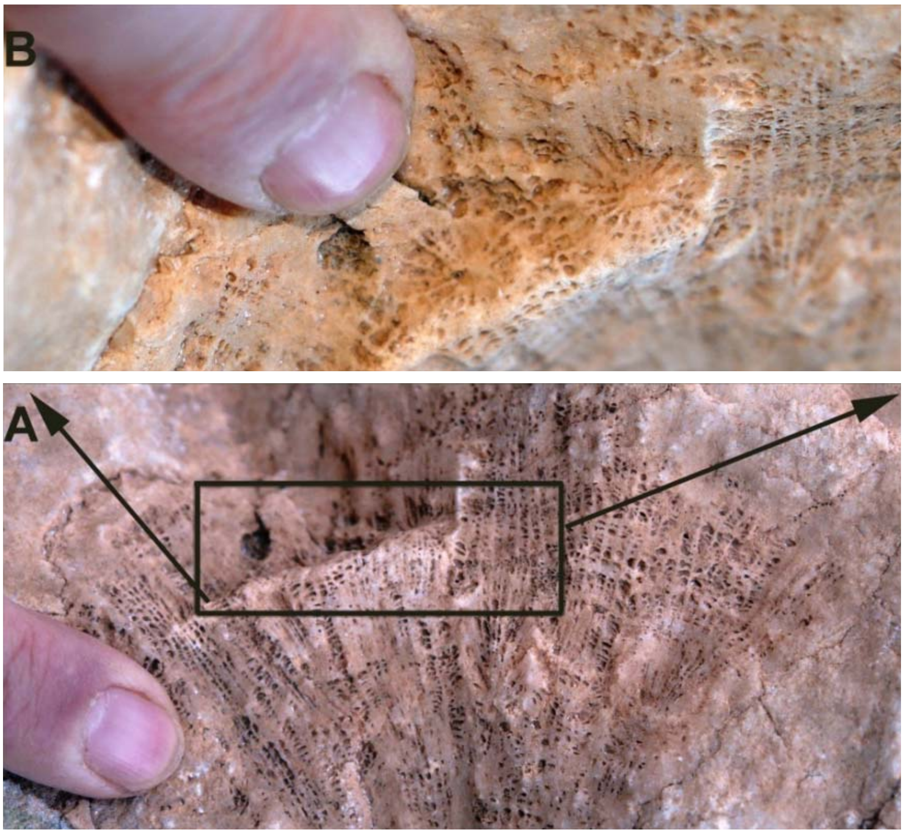

Fig.9: **A)** Longitudinal section of a coral framestone in the Oligocene rocks in the Balkha Section. **B)** Top view of the coral showing cross section of two single corals polyp can be seen to the right of the finger

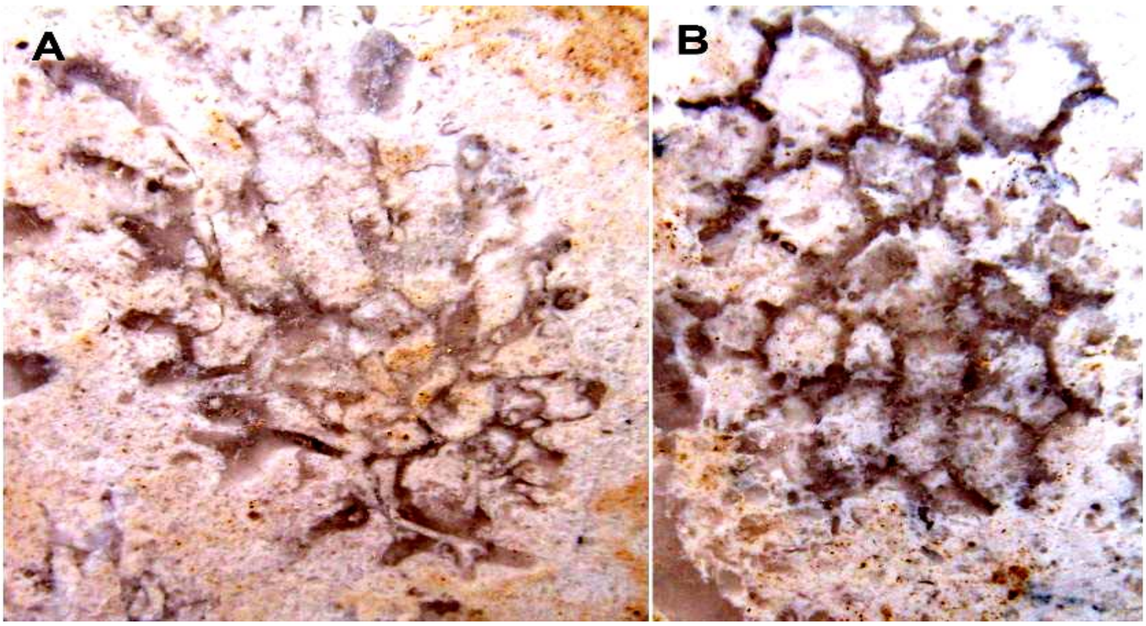

Fig.10: Coral framestone, (**A**) oblique section and (**B**) cross section from Darband Faqara Section (Magnification: X2)

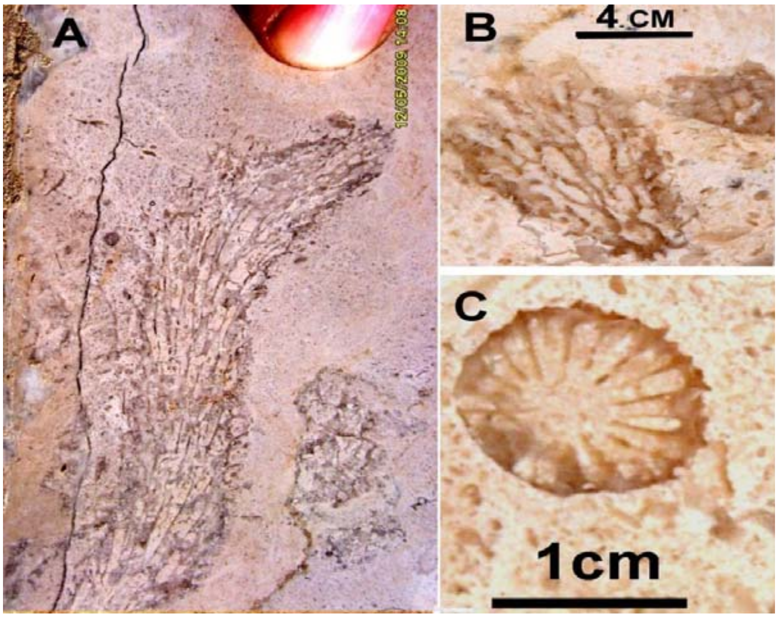

Fig.11: **A** and **B)** Coral framestone, **C)** Cross section of a single coral polyp

The allochemes are bound by fine grained matrix such as: sand and silt sized carbonate grains in addition to lime mud. This facies is introduced into Dunham (1962) classification by Emery and Klovan (1971), it consists of self-supporting large allochemes (more than 2 mm thick) bounded by mudstone (micrite) (Fig.12). This facies is rare and was seen in one sample in the lower part of the Glazarda section and cannot be seen in the other sections. This facies mostly consists of micritic limestone intraclasts and bioclasts of coral, bryozoans, gastropods and pelecypods. In some cases, this facies grades to conglomeratic grainstone, as milky and spotty appearance and cemented by spary calcite or dolomite. According to Wilson (1975), this facies is deposited in fore-reef environment; where strong waves and current action are prevalent. According to Wilson (1975), the allochemes of this facies must be derived from the reef, but many authors have included the non-reefal allochemes in this facies, such as Sadooni and Al-Sharhan (2003), they have assigned the orbitolina bearing limestone as orbitolina rudstone.

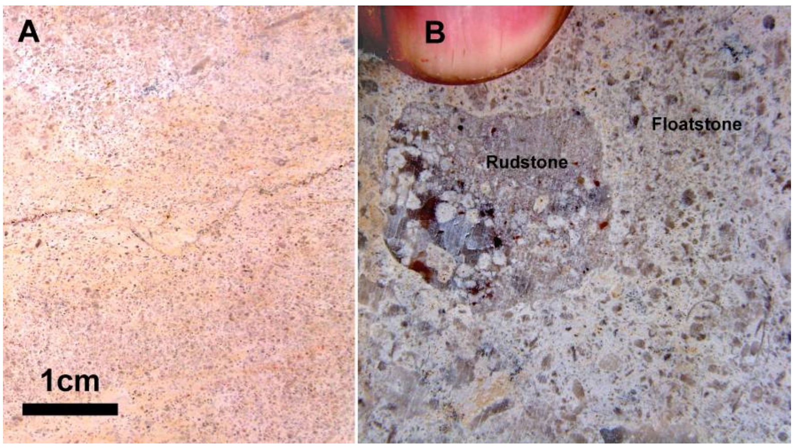

Fig.12: **A)** bioclast floatstone in micritic matrix
B) Rudstone with sparetic matrix as a pocket (below the finger)
inside bioclast floatstone (as background)

INTERPRETATION OF NEW FACIES FOR ENVIRONMENTAL INDICATION

According to Karim *et al*. (2008), at the beginning of the deposition of Pila Spi Formation (Middle – Late Eocene), the Zagros Foreland Basin was separated into two smaller basins. The Walash – Naopurdan Group (flysch facies) was deposited in the northern one (Sub-foreland Basin), while Pila Spi Formation was deposited in the southern one (Main Foreland Basin). They added that the source area had retreated northeastwards to a position, which may coincide with the present position of Sanandaj – Sirjan Zone, inside Iran and the basin of the Pila Spi Formation remained without source area and nutrient influx (Fig.13).

The discovered new facies, in this study, coincides with the above citation of Karim *et al*. (2008). This is because the general lithology of the formation, as indicated in the present and previous studies, is chalky limestone and dolomitic limestone. Moreover, the grainstone facies is rare and exists only as pockets in the packstone and wackestone. The fossils such as: coral, algae and bryozoans are delicate and their occurrence is sporadic and did not form large and extensive biostroms or bioherms. Therefore, the environment was generally calm and consisted of restricted lagoon.

The best place, for the new discovered facies, within the carbonate depositional environment is back-reef. The reef was part of the Middle Eocene ramp that associated with small lagoon and bioherms (patchy reef). The ramp was gently sloping towards south and southwest, and distally combined with basinal facies of Jaddala Formation (Early – Late Eocene) at the south of the studied area. The gradual facies change and absence of significant grainstone (accept a small patch as can be seen in Fig.12B) and oolitic facies indicate the presence of low energy ramp and absence of shelf. Because, in the latter setting, the facies changes suddenly from low energy to high energy facies.

Field evidence shows that the lagoon was located mostly inside the High Folded Zone, which extends from Darbandi Khan to Dohuk city passing through Koi Sanjaq town. The type and supplementary sections of the formation are located in the area of the lagoonal environment, therefore, the present facies are not observed by Lees (1930) and Wetzel (1947), in Bellen *et al*. (1959). The back-reef was located to the south of the above towns. The indication of the geographic location of the patchy reef is difficult to be estimated because the formation has no outcrops in the Foothill Zone.

The previous studies however, are used for indicating the possible location of the patchy reef, which must be represented by lithologies of condition that is more open and of the same age of the typical Pila Spi Formation (lithology of the type section). The only lithologies that have the above properties is that of the Avanah Formation, which according to Bellen *et al*. (1959), Buday (1980) and Jassim and Goff (2006) consists of 210 m of shoal limestone and dolomitized limestone with Alveolina forams. They added that it was deposited on the Paleoridge, which separates basin of Gercus Formation from the open sea of the Jaddala Formation.

It is possible that the new facies that are found in the present study are deposited directly behind the ridge (reef) and during high storms some of the constituents reworked forming rudstone. The type section is deposited in lagoon; in more distance way from the reef (Fig.13). In the Sartak Bamo valley (20 Kms to the Southeast of Darbandi Khan town) there is thick and massive succession of Pila Spi and Avanah formations (Karim, 1997) in the boundary between the High and Low Folded Zones. It is possible that the succession represents one of the locations in which the reef of the Middle – Late Eocene succession existed (Fig.14). In this succession, coral and Alveolina forams can be seen in alternating with lithology of Pila Spi Formation.

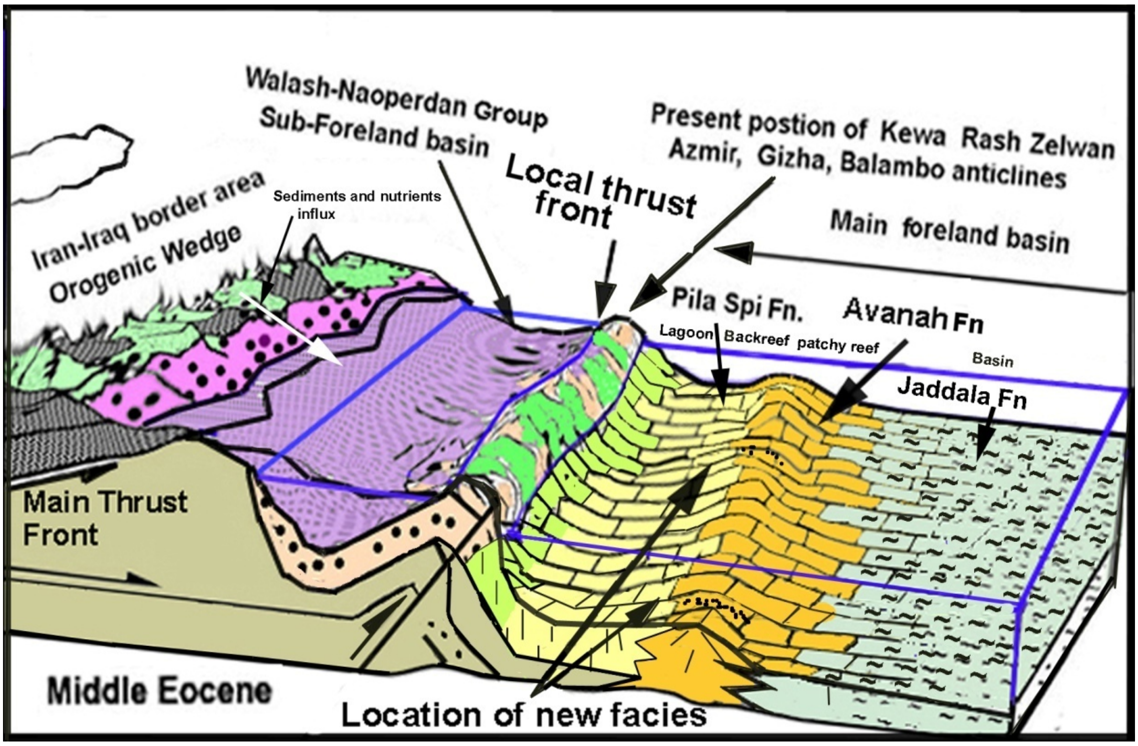

Fig.13: Tectonic and paleogeographic model of the Middle – Late Eocene as inferred from present study (modified from Karim *et al*., 2008)

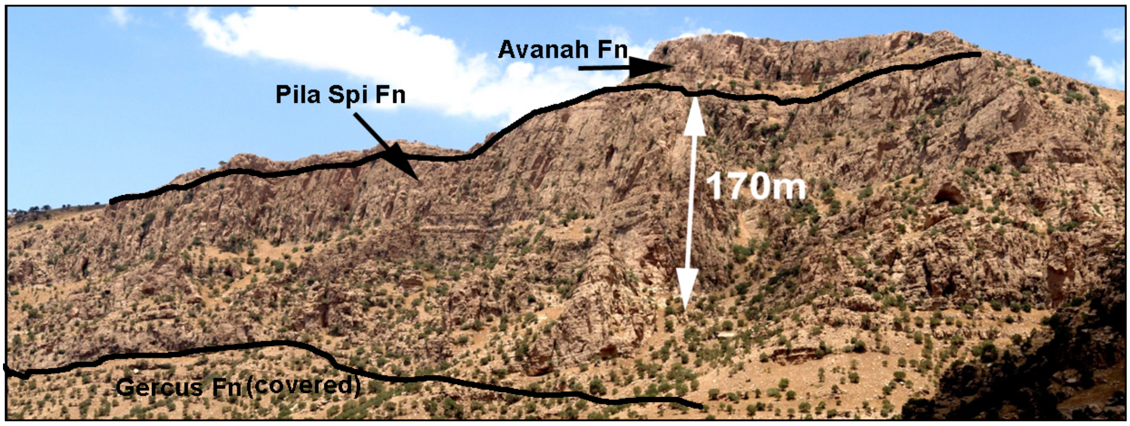

Fig.14: Western side of the Sartak valley showing massive succession of the Avanah and Pila Spi formations

CONCLUSIONS

This study has the following conclusions.

- Many new facies are found in the Pila Spi Formation such as floatstone, bafflestone, rudstone, packstone and framestone.
- The new environment and paleogeographic setting of the Middle – Late Eocene indicate patchy reef, back-reef and restricted lagoon.
- The lagoon was without source area and influx of nutrient.
- The Oligocene succession was found in the studied area too.

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