Iraqi Journal of Science

ISSN: 0067-2904

Sedimentology and Lithostratigraphy of the Pila Spi Formation in Koi Sanjaq area, NE Iraq; New insight for depositional Environment and Basin Configuration

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Abstract

The Pila Spi formation composed of seven lithotypes; carbonates (dolomite and dolomitic limestone), marl, shale/claystone, red argillaceous mudstone, sandstone, carbonate breccias and debris flow, which are arranged in repeated cycles of mixed siliciclastic-calciturbidites in a range of gravity-flow regime in the Koi Sanjaq area. Sedimentologic and facies evidences suggest developed marine environment for the Pila Spi Formation. Facies analysis and associated sedimentary structures including graded beddings decide turbidity and gravity flow regime origin of the rocks. Marine environment is supported by the identifying glauconite and fossils types, which is reported here for the first time rather than lagoon environment.

The Pila Spi sequences are grouped into four facies associations confirming developed marine depositional systems, these are (from bottom to top) channeled-slumped fine and mega carbonate breccias, calciturbidites, faulted and slump carbonate mega-breccias, slump/slide carbonate mega-breccias facies associations respectively.

Petrographic analysis of carbonate units of the Pila Spi rocks in Koi Sanjaq area indicated that they are composed of skeletal grains with subordinate non-skeletal grains of tuffaceous fragments, chert, chalcedony, volcanic ash, metamorphic and detrital iron oxides grains, with noticeable grains of glauconite. Varieties of marine fossils are identified includes planktonic bivalves and benthic forams of cool water, which support the deeper marine environment.

Microfacies analysis reveals (15) types, these are; green algal boundstone, algal wackestone dolomudstone, algal dolostone/mudstone, framestone-mudstone, small benthic foraminiferal wackestone, algal packstone-mudstone, foraminiferal packstone-mudstone, algal dolostone, fossiliferous grainstone, foraminiferal packstone, stromatolite framestone, algal boundstone, calci-microbial grainstone-packstone, and large benthic Foraminiferal bioclasts floatstone. These microfacies types are grouped in four facies associations representing the depositional environments of the formation, these are; outer shelf, reef, forereef, reef, backreef.

Key wards*:* Pila Spi, turbidites, gravity flow, Late Eocene, NE Iraq.

الدراسة الرسوبية والطباقية الصخرية لتكوين البلاسبي في منطقة كويسنجق شمال العراق: نظرة جديدة في بيئة الترسيب البحرية وتطور الحوض الرسوبي

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الخلاصة

تشير الدلائل الرسوبية والسحنية الى بيئة ترسيب بحرية لتكوين البلاسبي وان التحليل السحني والتراكيب الرسوبية المصاحبة مع وجود التدرج الطبقي تشير جميعها الى بيئة المتعكرات العميقة لهذه الصخور. ان دلائل البيئة البحرية قد دعمت بوجود معدن الكلوكونايت ذو الاصل البحري والذي يشار اليه للمرة الاولى.

يحتوي التكوين على سبعة انواع من الصخور هي: الصخور الجيرية (الدولومايت والحجر الجيري المدملت)، الطين–الطين الصفيحي والمارل والماتركس الطيني الاحمر والحجر الرملي والبريشيا الجيرية والفتات الصخري الزاحف، والتي تتواجد في دورات متعاقبة من رواسب المتعكرات السليكاتية الفتاتية–الجيرية ضمن نظام جريان الزحف. تترتب تتابعات رواسب الجركس في أربع مجموعات سحنية تثبت البيئة البحرية للتكوين (وهي من الاسفل الى الاعلى) البريشيا الجيرية الزاحفة–ذات القنوات البحرية، المتعكرات الجيرية، البريشيا الجيرية الصدعية الزاحفة والبريشيا الجيرية المنزلقة الزاحفة على التوالي.

تشير الدراسة الصخرية المايكروسكوبية الى ان الحجر الجيري يتكون من حبيبات هيكلية وغير هيكلية ومن حبيبات صخرية يتكون اغلبها من قطع التف والجرت الصوان والكالسيدوني وقطع الصخور المتحولة والرماد البركاني مع نسبة من حبيبات الكلوكونايت. لقد تم تمييز انواع متعددة من المتحجرات البحرية وتتضمن الفورامنيفرا الطافية والقاعية والستروماتولابت والمرجان والاشنات البحرية وذات المصراعين الطافية والتي تشير الى البيئة البحرية العميقة.

يشير تحليل السحنات الدقيقة الى وجود (١٥) نوعا جميعها تدل على البيئة البحرية والتي من الممكن تصنيفها الى مجاميع سحنية كل منها يمثل نظام ترسيب بحري معين وهي: الرصيف القاري الخارجي والحواجز المرجانية والحواجز المرجانية الامامية والحواجز المرجانية الخلفية.

استنادا الى السحنات الصخرية والتحليل الطباقي السحني فأن تكوين البلاسبي قد ترسب في بيئة بحرية متطورة ومتأثرة اساسا بتيارات التعكر الجذبية ذات الكثافة العالية والمنحدرة الى الاعماق مكونة مراوح تحت بحرية.

Introduction

This paper presents new details on lithofacies, associations and lithostratigraphy of the Pila Spi Formation in Koi Sanjaq area, and new suggested marine environment of deposition, where the previous workers suggest lagoon environment.

Bellen et al., [1] was firstly described the Pila Spi Formation from Derbandikhan area in the High folded zone. The type section situated under the Derbandikhan Lake. Another type section was selected in the Kashti in the Barand Dagh. The Pila Spi Formation forms the ridges for the anticlines in the High Folded Zone. The thickness of the formation ranges between 100-200 m. The previous workers are subdivided the formation into two parts, in which the upper composed of well bedded, bituminous, chalky and crystalline limestones, with chert nodules towards the top. While the lower part consists well bedded hard, bituminous, white, limestone, with algal or shell fossils [1,2].

Dolomitic and chalky limestone beds with chert nodules was recognized in the supplementary type section, in which some of the limestone beds are oolitic with rare layers contains gastropod debris [1]. Previous studies suggest shallow lagoon depositional environment for the formation where the containing fossils indicates a Late Eocene age [2]. The lower contact of the formation is conformable in the Pila Spi Village. [3] Was observed interfingers between the Pila Spi and the Gercus Formations. While [4] observed, conglomerate bed occurs at the base of the formation in the Derbendikhan area. The upper contact shows unconformable relationship throughout. The formation is overlying with Miocene age. The Pila Spi Formation shows regional equivalent with part of Midiyat Limestone formation in NE Syria [5] and SE Turkey [6]. While the Jarum Formation is correlated with the Pila Spi Formation in the SW Iran, [7, 2].

Field works and Methodology

Clear out cropping section selected for sedimentary structure and lithostratigraphic study, which is lying in the southeastern side of Jabal Hiebat Sultan Mountain c.f. 3 km for Koi Sanjaq City in north east Iraq (Figure- 1). The Pila Spi Formation is cropping out directly on the main road connecting Koi Sanjaq and Ranya-Dokan. Examinations were carried out for the study on lithology, petrography,

lithofacies, stratigraphic sequences and associated sedimentary structures. Photographic documentation was enforced for the whole stratigraphic section, for lithologies, sedimentary structures and the different lithofacies types. Detailed descriptions of the studied section are discussed in Figure- 2.

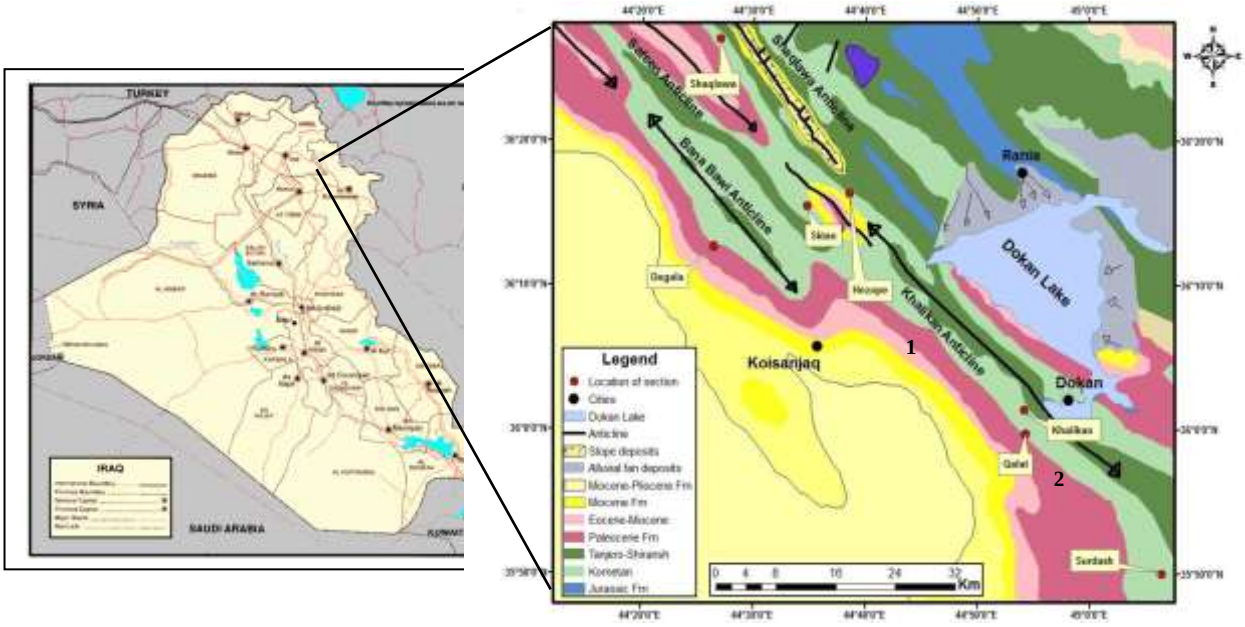


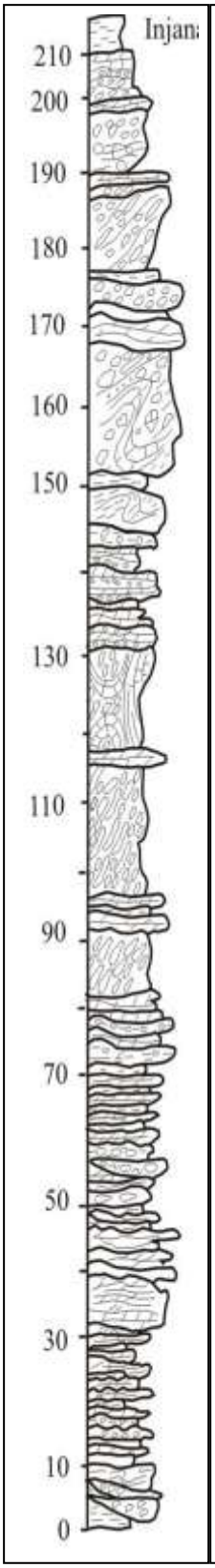
Figure1- Location and geological maps of the study areas show the studied sections (solid black lines) in Hiebat Sultan Mountain-Koi Sanjaq (1).

Sedimentology

Sedimentary structure

Varieties of sedimentary structures of characteristic turbidity and gravity flow regime were identified in Pila Spi formation, these are: load, flute, rill and groove casts, submarine channels, furrows, slump, slide and convolute structures with various types of scours and fills, all are of typical turbidity origin [8,9,10,11,12].

Submarine channels; successive sets of channel structure are recognized in the lower and middle units of Pila Spi Formation. The first channel is recognized directly on the contact with the underlying Gercus Formation, which filled with debris flow and carbonate breccias (Pl/1A,F). The channels are of large scale and attain more than 10 m in diameter.



Injana Formation cf. former Lower Fars Formation (gradational contact)

20 m carbonate breccia, red argillaceous matrix supported, interbedded with 1 m dolomite massive beds. The fragments of the breccia are coarse and fine-grained. The color is dark gray

50 m slump and slide carbonate breccia, red argillaceous-matrix supported, with convolute structures and slide blocks of bedded carbonates. The breccia includes disturbed and dis-organized beds of red claystone and sandstone. The breccia clasts are majority of carbonate with little chert fragments. The breccia is interbedded with thick bedded of massive dolomite beds. The color is dark gray and red

15 m thick and thin bedded massive dolomite beds, scoured, load and flute casted. The color is dark and pale gray

50 m sequence of Faulted carbonate breccia-matrix supported, interbedded with 1m massive dolomite beds, scoured and load casted. The breccia includes mega and small clasts. The color is dark gray, brown and reddish color

60 m successive of interbedded thick and thin massive dolomite with marly dolomite beds. Most of the beds are slumped and channeled and attains wedge like habit. The beds are scoured and load casted and some are with flute casts
The color is dark and pale gray

20 m carbonate breccia, matrix supported clast are carbonate, red claystone and chert fragments, interbedded with massive and bedded dolomite, scoured and load casted. In part, some beds are slump, slide and convoluted.

Gercus Formation (gradational contact)

Figure 2- Stratigraphic section of the Pila Spi Formation in Jabal Hiebat Sultan Mountain shows description of different lithologic units.

Rill marks; forms small-scale dendritic channel network (Pl/1B,C). Rill marks are recognized in the lower and middle parts of the Pila Spi Formation.

Load, scour and fill structures; are observed in the lower and upper bed surfaces of all units of the Pila Spi Formation. It is observed as isolated, elongate, U, or v-shaped depressions, and sometimes are slightly or moderately sinuous over various distances (Pl/1D,E).
Flute marks; observed in the lower and middle parts as crescent or horseshoe-shaped depressions without obstacles and of various shapes e.g. narrow elongate to broad transverse scours (Pl/1B).
Groove casts; represent striated pavement due to slump and/or slide of large masses of sediments on finer-grained sediments, which are acting as lubricant materials when saturated with water. It was recognized in the upper part of the section of Jabal Hiebat Sultan Mountain.
Furrows structures; is a longitudinal scour, which are recognized in the upper surface of carbonate beds in the middle part of the formation. It is formed by creeping of grains reorganization on the bed surface, and minor erosion along flow-parallel furrows (Pl/1C).
Obstacles scours; are observed in both studied sections of the Pila Spi Formation. It forms depressions like crescent or horseshoe-shaped formed around stationary obstacles on the bed surface (Pl/1D).
Slump structures; are recognized in the middle and upper parts. Slump structures are the more abundant type of primary structures and show internal folding, recumbent and asymmetric and associated thrusting in the successive carbonate and sandstone beds (Pl/1G,H).
Slide structures; represent a slide blocks of bedded or massive limestone slides along slope surface with little internal deformation (Pl/1G).
Convolute beddings; represent overturned or recumbent folds formed due shearing stress by the slump of the semi-coherent sediments along slope margin. They are recognized in the middle and upper parts of the Pila Spi Formation. Large scale of convolute beddings is observed (Pl/G,H).
Biogenic structures; represent different types of burrows and borings of various sizes.

Petrography

Petrographic examination of the carbonate units in the Pila Spi Formation reveals skeletal and non-skeletal grains The non-skeletal grains composed of intraclasts, carbonate breccias fragments, chert, chalcedony, volcanic ash and bubbles, quartz, cristobalite, gypsum, tuffaceous, igneous and argillaceous fragments with glauconite grains (Pl/2,A-H). The skeletal grains are composed of stromatolites, forams, corals, calcisphere, planktonic bivalve, with few ostracods and gastropods varieties. Three (3) sandstone beds are recognized, which reveals majority of carbonate fragments with subordinate chert, chalcedony, spherules and argillaceous fragments (Pl/3,F-H). Sandstones grains are supported by argillaceous matrix and classified as lithic greywacke type [13].

Lithofacies analysis

Lithologically, the Pila Spi Formation consists of massive and bedded hard, grayish, scoured, wedge like fossiliferous dolomitic limestone, dolo-marls and dolostone with stromatolite, algae, foraminifera with few ostracod and gastropod.

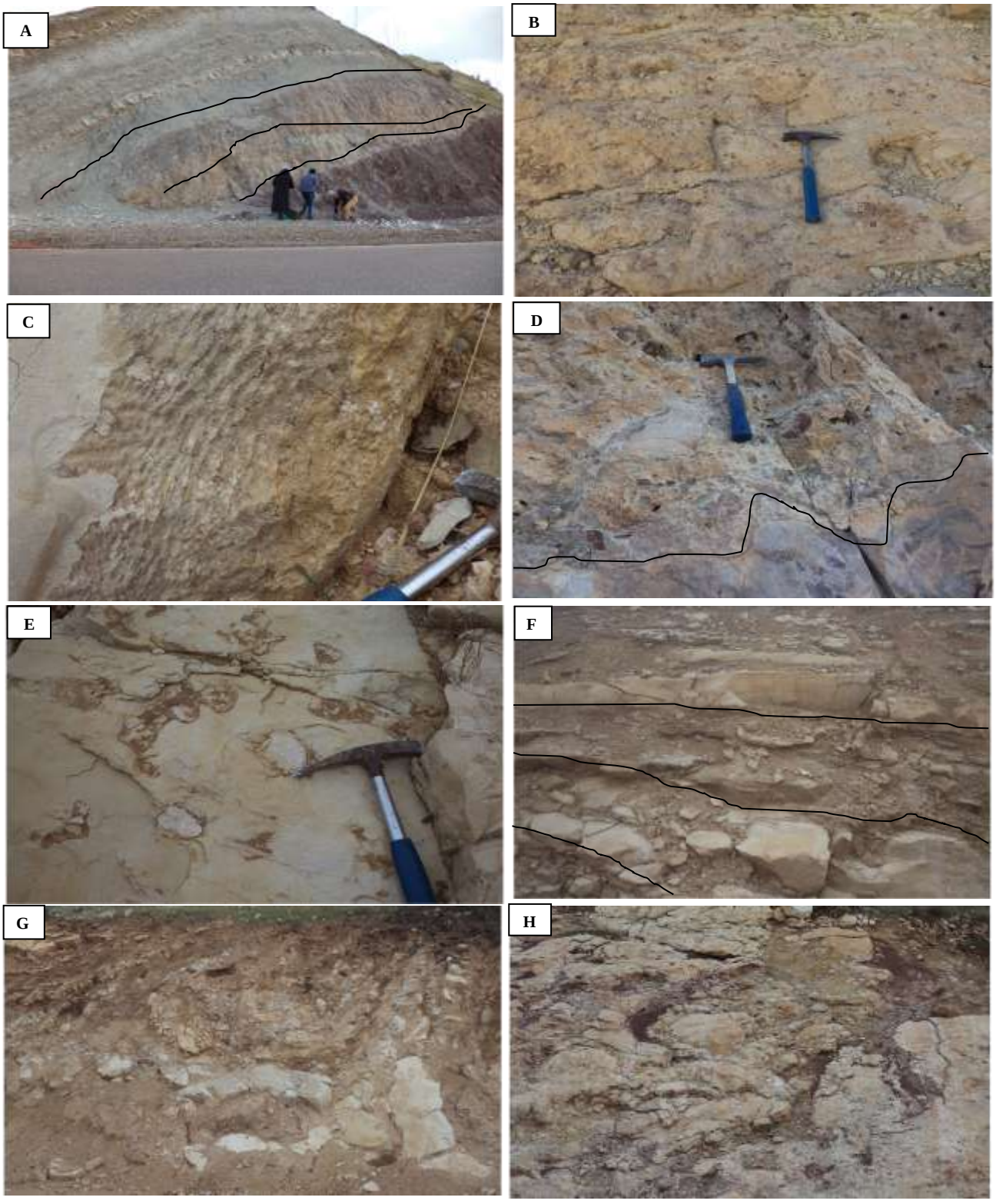


Plate 1 -Field photographs shows various sedimentary structures observed in the Pila Spi Formation; **A)** Channel structures, **B)** Flute casts, **C)** Rill marks, **D)** Scour and obstacles fill structures, **E)** Load casts, **F)** Wedge beds with carbonate breccias, **G)** Slump and slide beds,

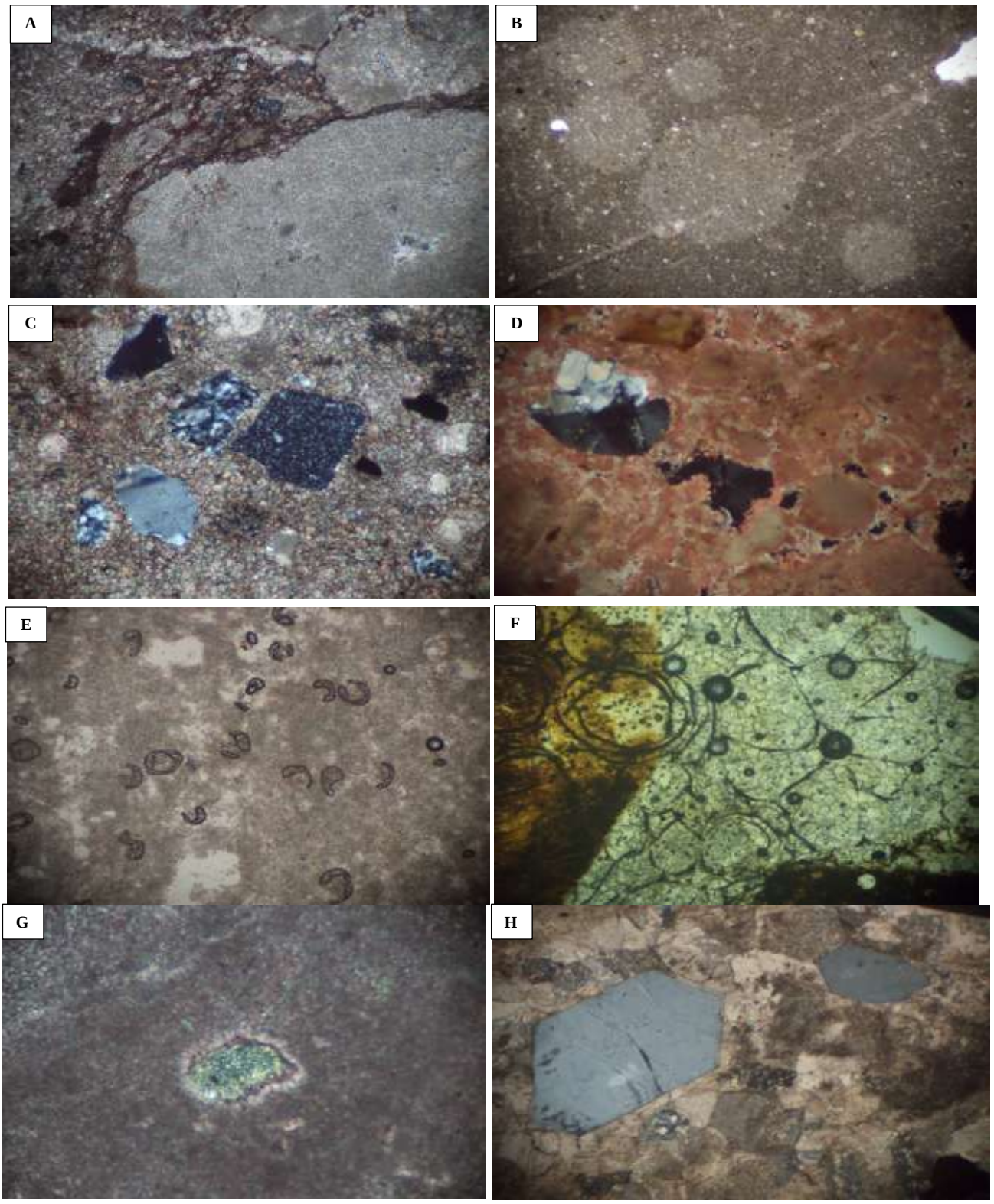


Plate 2- Photomicrographs shows mineralogical and non-skeletal components of the carbonate units in the Pila Spi Formation; **A)** Breccias fragments, **B)** Pellets, **C)** Chert, chalcedony and quartz grains, **D)** Igneous and argillaceous fragments, **E)** Volcanic ash and liquid bubbles, **F)** Concentric perlitic texture, **G)** Glauconite grain, **H)**. Euhedral gypsum crystals.

Field observations have revealed the presence of eight lithofacies types, which are distinguished and classified based on the differences of certain sediment characteristics e.g. grain size, color,

sedimentary structures and changes in lithological composition. The boundaries between lithofacies types are defined based on such characteristics, however they are generally transitional, and sometimes sharp boundaries. These lithofacies types are;

Dolomite lithofacies (*LF1D*)

Description; dolomite represents the main recognized lithofacies in most of the rock units in the formation. It is mostly massive, gray to dark gray color and medium to thick beds. Thickness of these beds range from 0.5 to 0.75 m with little of 1 m thick. The surfaces of the dolomite bed rock are undulated and scoured (Pl/3A) and recognized in all studied units of the formation.

Carbonate breccia lithofacies (*LF2Cb*)

Carbonate breccias are new identified lithofacies and is recorded here for the first time in details. It is most important lithofacies types to forms the major lithotype in the formation. Several types of carbonate breccias are identified and classified here according to the type of supporting materials into three type:

I. Matrix-supported breccia, is supported by argillaceous sandy clayey matrix with subordinate marly materials. The matrix is of almost of red and gray in color (Pl/3B). This type of breccias are recognized in all studied succession of the formation.

II. Grain-supported breccia, is supported fragments smaller than those of breccia's fragments with low percentages of clayey carbonate materials. The color is variable according to the types of breccia's fragments, which is almost of gray and red colors (Pl/3D,F). This type is recognized in all studied succession of the formation.

III- Marly-supported breccia, is supported by marly materials of gray to yellowish color. The marly supporting material is mostly soft and/or friable (Pl/3B) and shows few occurrences in the formation.

[14,15] are defined a specific nomenclature to describe various types of carbonate breccias, such as tectonic breccia, stylolitization breccia, collapse breccia, slump breccia, and debris flow breccias. According to this nomenclature, four types of carbonate breccias are identified and classified to lithofacies types;

A. Slump Carbonate breccia lithofacies (*LF2ASCb*)

Description; this lithofacies is composed of angular and variable sizes of carbonate fragments range from pebbles to boulders, most of it are composed of dolomite and dolomitic limestones. The carbonate breccias reveal slump, disturbed and convolute beds (Pl/3B,D). The thickness of this lithofacies ranges from 1.5 to 6 m. Most of slump carbonate breccias are matrix-supported type. This lithofacies attains gray to brown color and recognized in the lower and upper parts of formation.

B. Tectonic carbonate breccia lithofacies (*LF2BTCb*)

Description; this lithofacies is recognized in between fault planes where the carbonate beds are fractured and screening due to the movement of the fault planes e.g. fracture zone. This breccias are supported by marly materials and few by red clayey materials (Pl/3C). The breccia's fragments are variable in size and range from 0.3 to less than 1 m in size. In some places, slide blocks of bedded carbonate are recognized in the fractured zone. The color of this lithofacies is almost gray. This lithofacies is recognized in the middle and upper part of the formation.

C. Carbonate debris flow breccia lithofacies (debrite) (*LF2CDf*)

Description; this lithofacies is composed of variable sizes of breccia's fragments, which attains 5-10 m in thickness and of gray to brownish red in color (Pl/3E). These breccias composed of accumulation of fragments in a channel like structure. These breccias are of both grain and matrix-supported types and recognized in the lower part of the formation.

D. Collapse carbonate breccia lithofacies (*LF2DCCb*)

Description; this type of breccia represents highly fractured and fragmented bed due to the collapse in karstic cavities due to the weight of roof beds (Pl/3F). This type of breccia is supported by red clayey matrix. It was recognized in the middle part of the Pila Spi Formation.

Dolomitic limestone lithofacies (*LF3Dl*)

Description; It is mostly massive, grayish in color and mostly thick beds of 0.5 to 0.75 m with little 1 m bed. The surfaces of the dolomitic limestone beds are undulated and sometimes scoured (Pl/3G). This lithofacies is recognized in the lower and middle parts of the formation.

Marly dolomite lithofacies (*LF4Dm*)

Description; this lithofacies attains 0.3 to 0.5 m thick and dark gray in color and is almost scoured, ripples and cross-laminated (Pl/3H). It comprises a part of graded upwards succession overlying the

carbonate breccias or dolomites beds. Sometimes, this lithofacies contain sandy grains and of wedge like beds. This lithofacies is recognized in the lower and middle parts of the formation.

Marl lithofacies (*LF5Ml*)

Description; this lithofacies attains 0.3 to 0.5 m thick, of gray color and is almost scoured, ripples and cross-laminated (Pl/4H). It comprises a part of graded upwards succession overlying the carbonate breccias or dolomites beds. This lithofacies is recognized in the lower and middle parts of the formation.

Red Argillaceous matrix mudstone lithofacies (*LF6Am*)

Description; this lithofacies represents thin beds of 15 to 25 cm thick of red argillaceous matrix, recognized in the middle part of the formation. It composed of red and sandy clayey materials with little angular pebbly carbonate fragments. It is interbedded with thick and thin carbonate beds (Pl/4F). This lithofacies is recognized in the whole formation interbedded with carbonate breccia and carbonate beds.

Sandstone lithofacies (*LF7Ss*)

Description; two highly deformed sandstone beds are recognized in the upper part of the formation. These sandstones are fine-grained supported by argillaceous matrix (Pl/4D). Sandstones are identified in a succession of slump and convolute beds of mudstone and carbonate breccia. It is of brown color.

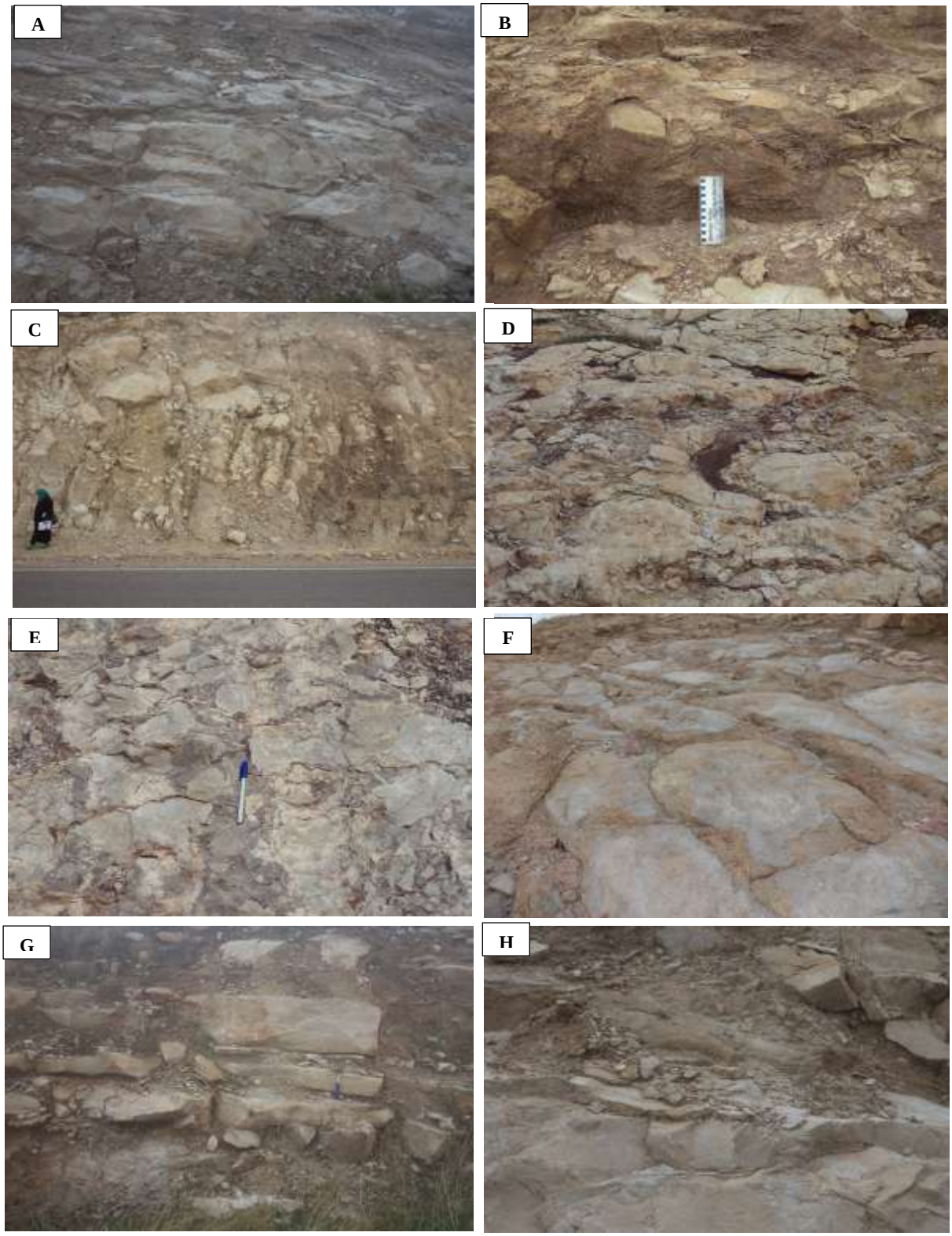


Plate 3- Field photographs shows various lithofacies types observed in the Pila Spi Formation; **A)** Dolomite lithofacies **(***LF1D***)**, **B)** Carbonate breccia **(***LF2Cb***)** matrix supported, **C)** Faulted carbonate breccia (*LF2Cb*) marl supported, **D)** Slump carbonate breccia (*LF2Cb*) matrix supported**, E)** Debris flow carbonate breccia (*LF2Cb*) marl supported, **F)** Collapse carbonate breccia (*LF2Cb*) matrix supported, **G)** Thin and thick bedded dolomitic limestone lithofacies (*LF3D*l), **H)** Marly dolomite lithofacies (*LF4Dm*)**.**

Lithostratigraphic classification

Lithofacies analysis of the Pila Spi Formation shows major effect of turbidity currents on the sediment, which are classified according to lithotypes, sedimentary structures and the stratigraphic arrangement of the litho-units in the formation. The identified lithofacies types can be grouped into facies associations. each of which is referred to certain depositional system. These groups of lithofacies associations are referring to marine depositional environment.

The stratigraphic classification and nomenclature of each identified lithostratigraphic unit of the Pila Spi Formation are sited based on the [16,17,18,19].

Hiebat Sultan Mountain section of the Pila Spi Formation can be classified into four lithostratigraphic (4) units, representing lithofacies associations and discussed herein form bottom to top;

Unit-A, Channeled-slump carbonate breccias

Description; thickness of unit-A ranges from 15 to 20 m, characterized by several observed subaquatic channels. This unit displays alternations of thick beds, fine and mega-carbonate breccias interbedded with marl and muddy marl in a graded upward succession. The carbonate breccias are composed of fragments rang from pebble size to boulders. Some beds are of carbonate debrites, while the others are slump-breccia. The carbonate breccias are graded upwards to marl, marly limestone and dolomite lithologies. The thickness of carbonate breccias range from 1 to 5 m, while the marl and marly limestone beds range from 0.5 to 1m. The beds of the upper part of this unit attains wedge or lens like shape. Channels are the characterized sedimentary structure observed in this unit with load casts, rill marks, graded beddings, scour and fill, scour and obstacles, flute casts…etc. ripple and cross-bedding are also identified in the marl and marly limestone beds.

Unit-B, Calciturbidites

Description; thickness of unit-B ranges from 55 to 60 m. Variation in thickness may be due to slump of the carbonate bed. It composed of alternative thick beds of dark gray dolomite (e.g. 0.5 to 0.75 m) grads upward to red argillaceous matrix (e.g. 0.2 m). Some beds show wedge like shape referring to channel structures. This succession attains about 25-30 m in thickness. The remain 30 m of Unit-B includes alternative thick grayish dolomite/red argillaceous matrix mudstones (e.g. 0.5 to 0.7 m), interbedded with brownish slump carbonate breccia (e.g. 2 to 3 m). These breccias are composed of slump beds of dolomites, marly limestone and muddy marl beds. Most of breccias fragments are cobble to boulder size with sliding blocks. Most of the beds are not uniform with wedge shape and characteristic sedimentary structures are the slump, slide and convolute beddings, flute and load casts with scoured and undulated surfaces. All successions are characterized by graded bedding, in fining upward cycles.

Unit-C, Faulted and slump carbonate mega-breccias

The thickness of Unit-C is about 65 m, which composed of alternations of thick beds of dark gray dolomite (e.g. 0.5 m) graded upwards to marl and red argillaceous matrix mudstones (e.g. 0.25 m). Some beds reveal wedge or lens shape most probably of channel structures. These successions are interbedded with faulted carbonate breccias of boulder sized fragments. The fault breccias are supported with marly materials. The thickness of fault breccias range from 5 to 10 m wide. Slump carbonate breccia are also recognized and have 3 to 4 m in thickness. These breccias are not uniform in thickness and of gray to brownish yellow color. Some of carbonate breccias are interbedded with reddish brown mudstone horizons of 0.3 to 0.5 m in thickness. The characteristic sedimentary structures of this unit are the slump, slide and convolute bedding, scoured and undulated surfaces as well as flute casts and channel structures.

All the successions of Unit-C are graded upwards to finer-grained mudstone or red argillaceous matrix.

Unit-D, Slump/slide carbonate mega breccias

Description; thickness of unit-D is about 65 to 70 m, which composed of alternations of thick beds of carbonate breccias of gray to brownish yellow color. The breccias are composed of dolomite fragments (e.g. 1 to 3 m thick) graded upwards to red argillaceous matrix mudstones (e.g. 1 to 2 m thick). Most beds reveal slump and convolute bedding with disturbed and disorganized beds. These successions are interbedded with faulted carbonate breccias of boulder sized fragments, which are supported with marly and/or red argillaceous matrix mudstones. The thickness of fault breccias range from 5 to 10 m. Slump and convolute carbonate breccias are 3 to 4 m in thickness. These breccias are not uniform thickness. Some of carbonate breccias are interbedded with reddish brown argillaceous

matrix mudstones of 1 to 1.5 m in thickness. The characteristic sedimentary structures are slump, slide and convolute, with scour and undulated surfaces. Flute, load and groove casts and channel structures are also observed. All beds carbonate breccias and red argillaceous matrix mudstones shows graded upwards turbidity cycles.

Microfacies analysis and depositional environment

Petrographic examination reveals seven (7) main microfacies types based on the classifications sited by [20] and modified by [21], these are; green algal boundstone, algal wackestone dolomudstone, algal packstone-mudstone, red algal framestone-mudstone, foraminiferal packstone, stromatolite framestone, algal boundstone and calci-microbial grainstone-packstone microfacies (Pl/4A-H). The stromatolite and algal types are classified according to [22] *Brachydactylus reisi*, *Coprolite, Brachydactylu reisi*, *Cchlorellopesis coloniata*. and *red domal stromatolite algae*.

The foraminiferal types are, *miliolids*, *Discocyclina sp. Textularia sp. Orbitolite sp. And Alveolina sp*. Calci-microbs spheres are observed in several units. Moreover, Shells of pelecypods, ostracods and gastropods are also identified [23].

Microfacies types are grouped in facies associations followed [24] classification, to interpret the depositional environments. Because of most lithological units are composed of carbonate breccias, the employment of lithotypes can be used in beside the facies association group to give an actual picture for the depositional model. In general, the carbonate breccias suggest that microfacies types and associations are slumped to deeper margins forming carbonate debrites and breccias. Basically, interpretation of environment can define relative to tectonic movements and volcanic activities (Fig 3).

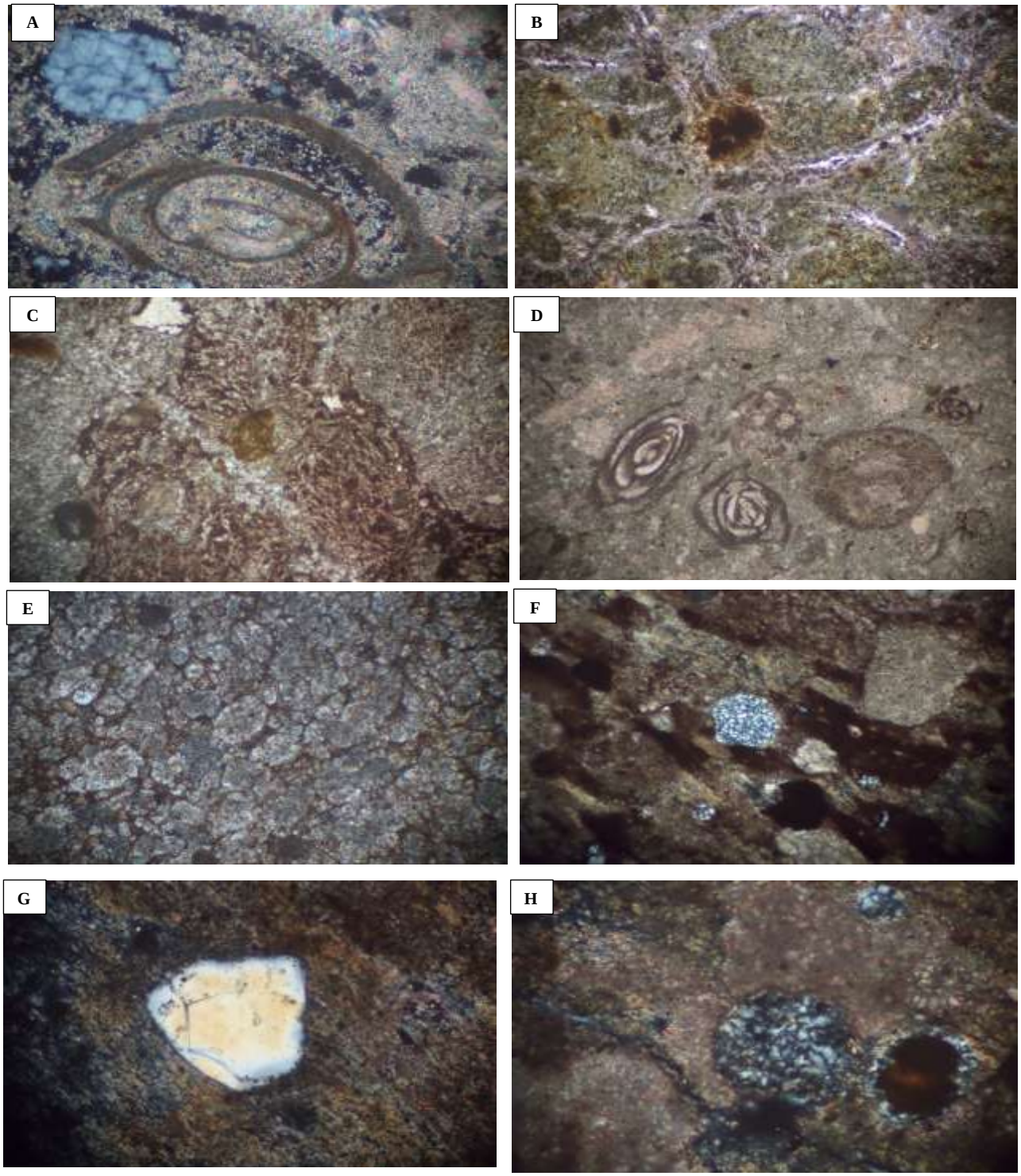


Plate 4- Photomicrographs shows mineralogical and skeletal components in the carbonate units and the sandstone composition of the Pila Spi Formation; **A)** Cristobalite and benthic foram, **B)** Green algae, **C)** Red domal stromatolite, **D)** Benthic and planktonic forams, **E)** large dolomite crystals, **F)** Carbonate, chert and argillaceous fragments in sandstone, matrix supported, **G)** Quartz grain, **H)**. Carbonate, Chert and spherules grains supported by argillaceous matrix.

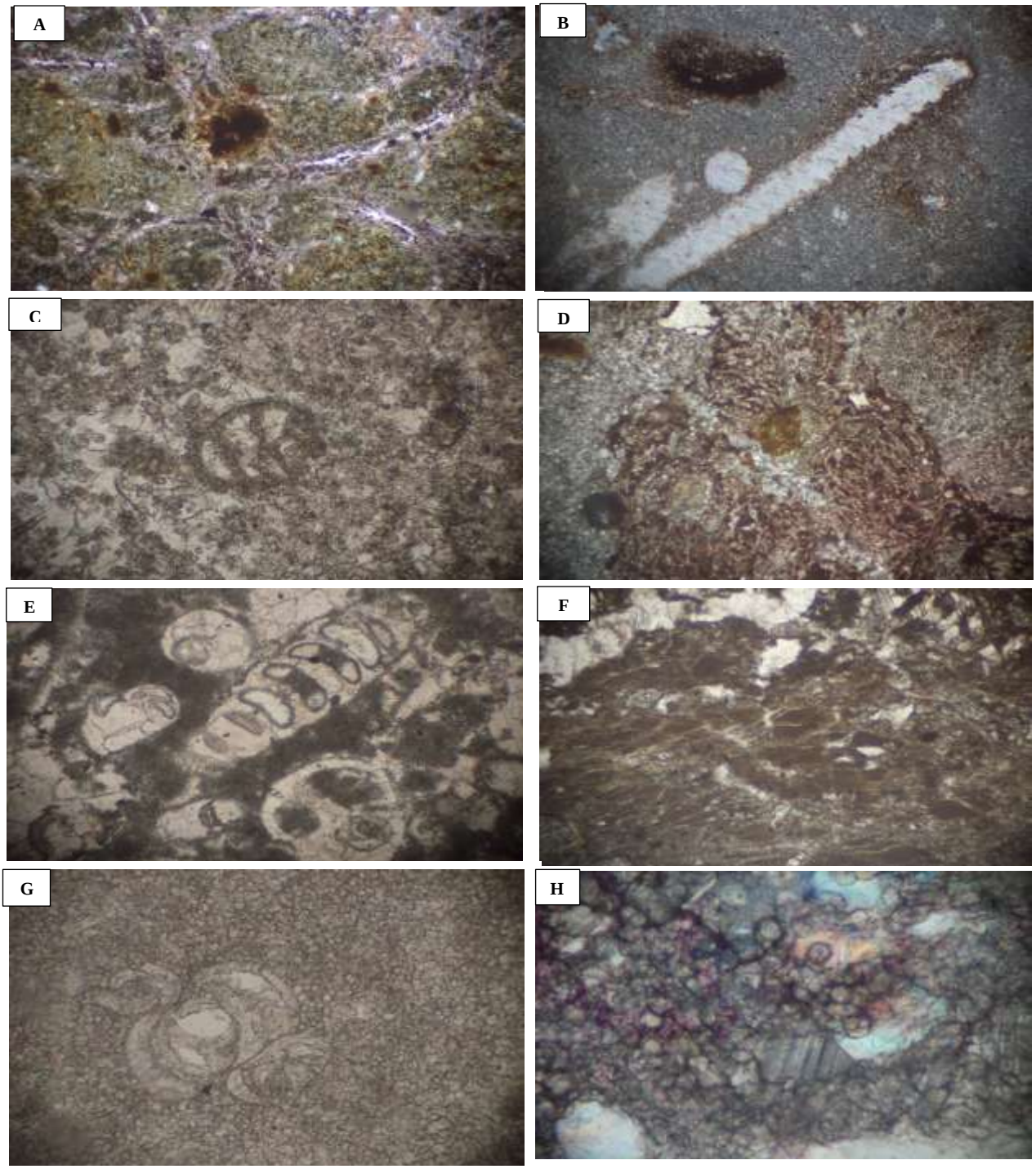


Plate 5-Photomicrographs show microfacies component in the Pila Spi Formation.
(A) Green algal boundstone**, (B)** algal wackestone dolomudstone, **(C)** algal packstone-mudstone**, (D)** red algal framestone-mudstone microfacies, **(E)** foraminiferal packstone, **(F)** stromatolite framestone**, (G)** algal boundstone**, (H)** calci-microbial grainstone-packstone microfacies

Table 1- The main microfacies types and related facies associations and the primary depositional environments of the Pila Spi Formation (after Dragastan and Richter 2011).

Microfacies	Facies association
Fossiliferous grainstone Calci-microbial grainstone-packstone microfacies Packstone- mudstone Foraminiferal packstone	Outer shelf
Framestone-mudstone	Forereef
Green algae boundstone Algal wackestone dolomudstone Algal dolostone Algal packstone mudstone Algal boundstone mudstone Stromatolite framestone Algal grainstone	Reef
Large Benthic Foraminiferal Bioclasts Floatstone Microfacies	Backreef

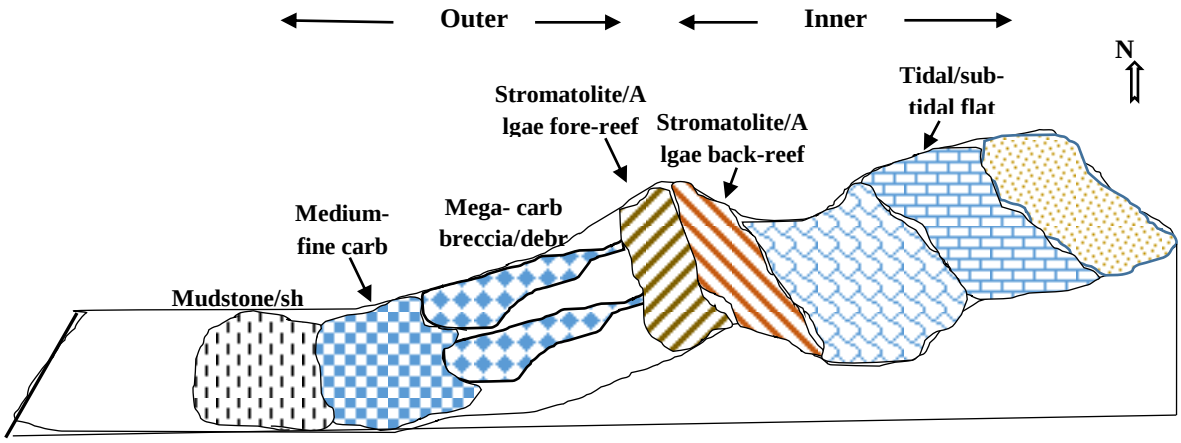


Figure3- Schematic diagram shows the suggested depositional mechanism of the Pila Spi Formation in North and Northeast Iraq.

Discussion and interpretation

Sedimentary structures, lithofacies, petrographic analysis and lithofacies associations refer to achieve sedimentation by gravity flow regime and turbidity currents. Field observations, sedimentary structures and lithofacies types show that carbonate breccias, dolomite and dolomitic limestones are grading upwards to shaly marl and red argillaceous matrix mudstones, which are associated with characteristic turbidity sedimentary structures. The Pila Spi beds are arranged in fining upwards calci turbidity cycles. Graded beddings and associated sedimentary structures support the idea of turbidity origin c.f. flute, load, rill, scour and fill, scour and obstacles and groove casts, slump, slide and convolute structures [25,26,9,10,27,12].

Sedimentation of the Pila Spi Formation was carried out in active tectonic region and continues volcanism during Eocene [28,29], and accordingly continuous shocking of earthquakes that led to slump the accumulated sediments on a slope surface to form high density turbidity currents

[26,9,10,12]. These are evident by the successive siliciclastic-calci turbidity cycles. The red argillaceous matrix mudstones are most probably comes from the flows of continuous volcanism [30]. Moreover, the studied thin-sections show actual percentages of volcanic ash, volcanic gas and liquid bubbles, cristobalite, chert, chalcedony, spherules, tuffaceous fragment and concentric perlitic texture indicating referred to intense volcanic activities [28,29].

Most of the beds surfaces are scoured with slump, slide and convolute beddings support the idea of gravity flow and turbidity current origin. Red argillaceous mudstones are most probably originated from the marine volcanic arc at the border of the basin [30].

Moreover, continuous subduction movement led to uplift of the volcanic arc to dissected more faster providing volcanic fragments and red argillaceous mudstones. During Late Eocene, the Pila Spi basin is still slightly deeper and regression is most probably start in Miocene.

This is supported by observed carbonate debris flow, slump, slide and convolute beddings of mixing carbonate, claystone beds as well as the slumping carbonate breccias. Lithostratigraphy is important to define the evolution of sedimentation through space and time.

The four lithostratigraphic units of the Pila Spi Formation discus the history of the development of sedimentation during Late Eocene, where each unit represents certain depositional system and reveals a sedimentation in more active tectonism and volcanism during this time.

It is observed that the sedimentation is continuous without any hiatus and both the lower and upper contacts are conformable and refers to continuous deposition. The previous studies report an unconformity between the Gercus and overlying Pila Spi Formation and is rejected here. The previous reported conglomerate bed of unconformity in the Hiebat Sultan Mountain is in fact a carbonate debrite, which is grades laterally to thick marl bed and upwards grading to successive marl and shale beds.

Conclusion

Pila Spi Formation is cropping out in a belt parallel to the Zagros Thrust Belt in the High Folded Zone of northern Iraq. It is stratigraphically distributed from NE to NW margins and encountered in several oil wells in northern Iraq. Petrographically, the formation is mainly composed of carbonate and few sandstone beds. The carbonates composed of non-skeletal grains c.f. volcanic ash, cristobalite, tuffaceous fragments, volcanic bubbles and concentric perlitic texture, acidic igneous fragments, glauconite grains…etc. In addition, skeletal grains are stromatolites, green and red algae, forams and few gastropods and bivalva. The sandstones are lithic greywacke type of reddish gray in color and composed of carbonates, chert chalcedony and argillaceous fragments, supported by red argillaceous matrix. The formation composed of dolomites, dolomitic limestones, marly dolomites, carbonate breccias c.f. tectonic-slump, faulted and collapse breccias, sandstones and red argillaceous mudstone lithofacies. These are grouped in four associations c.f. (from bottom to top) channeled-slumped fine and mega carbonate breccias, calciturbidites, faulted and slump carbonate mega-breccias, slump/slide carbonate mega-breccias facies associations respectively. All lithofacies are arranged in fining upwards siliciclastic-calciturbidite cycles characterized by sedimentary structures of turbidity origin c.f. submarine channels, scour, flute, load, scour and groove casts, convolute, slide and slump bedding…etc.

The development of stratigraphic units refers to geodynamic evolution of the basin characterized by active tectonic and volcanism. These are evident by the presence of carbonate breccias and the presence of different grains of volcanic origin such as volcanic ash, bubbles and concentric perlite texture. Volcanose is activated along the northeastern border with Iraq c.f. the eastern boarder of the foreland basin during Eocene and reveals more than 3000 m successions of volcanic and pyroclastic rocks.

The suggested depositional model is represented by deposition of carbonate sediments in reef and fore reef zones, which are later slumped to deeper margins forming carbonate breccias in gravity flow and turbidite regime. Gravity flow deposits are affected by turbidity currents and arranged in siliciclastic-calciturbidite cycles and interbedded with flows of red argillaceous mudstones of volcanic origin.

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