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Facies Analysis and Depositional Environment of Garagu Formation (Valanginian- Hauterivian) in Gara Mountain, Gali Garagu, Sarsang District, Iraqi Kurdistan Region

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Abstract

Facies analysis and depositional environment of Garagu Formation (Valanginian-Hauterivian) in the Gara Mountain in Gali Garagu of High Folded Zone, Sarsang District, and northern Iraqi Kurdistan is studied. Lithologically, the formation consists of oolitic sandy limestones, with shale, marl and sandstones in its upper and lower parts and organic detrital limestones in its middle part. The petrographic study of carbonate rocks on 30 thin sections shows that the limestones are dominated by mudstones and wackestones.The skeletal grains include variety of benthic foraminiferas, gastropods, brachiopods, echinoids, pelecypods, green algae, and ostracods. Non-skeletal grains include ooids, peloids and intraclasts. Garagu sandstones are immature, lithic subarkose to subarkose and occur as medium to thick beds within the lower and upper parts of the formation, and composed mainly of sedimentary rock fragments with minor amount of quartz and feldspars (plagioclase). The X-ray diffraction analysis of the bulk shale samples revealed that the abundant clay mineral in Garagu Formation is kaolinite and non-clay minerals include calcite, quartz, geothite and nacirite. The formation can be divided into three lithologic devisions from base to top: lower oolitic; middle organic detrital limestone; and upper oolitic. Eight different microfacies were recognized which were subdivided according to their environmental interpretation into two basic types of facies associations; shelf margin (shoal) and shelf lagoon association. Generally the Garagu Formation represents shallow water environment with two high energy belts in the lower and upper parts.

Introduction

The Garagu Formation is a typical unit of the basal Cretaceous in northern Iraq, where it crops out and occurs in subsurface on the area of the Unstable Shelf, roughly to the northwest of a line connecting Awasil - Kirkuk and the Ru Kuchuk (Buday, 1980) [1].

The Garagu Formation is a carbonate-siliciclastic unit, consists of alternation between bedded, yellow to brown, shale, marl - marly limestone and limestone from the middle part and limestone, oolitic limestone, shale and sandstone beds from the both upper and lower parts.

The formation can be a good reservoir when occurs in the subsurface (Buday, 1980 [1]; Aqrawi et. al., 2010[2]), therefore it offers a good opportunity for the study and interpretation of the depositional environment and paleogeography in view of their vast outcrop area and well-recognized succession in terms of bed thickness and observed lower and upper contacts. The formation was first described from the Chia Gara anticline, Gali Garagu, Amadia district, High Folded Zone of northern Iraq by Wetzel (1950 in Bellen et. al., 1959) [3]. Since that time there are few detailed studies conducted on the Garagu Formation either in the outcrops or subsurface sections. These included the works of Amin (1989) [4], Mirza et al. (2016 in Press) [5] and Ghafor and Mohialdeen (2016 in Press) [6]. The main topics of these studies were biostratigraphy, geochemistry and paleontology, respectively. The present study aims to determine the litho and microfacies of the Garagu succession in order to interpret its depositional environment.

Study Area

The Garage Formation cropping out in Garagu village in Gali Garagu on south western limb of Gara anticline of High Folded Zone, southeast of Sarsang district, Duhok Governorate, Iraqi Kurdistan region. The studied section is located 10 km East of Sarsang city with latitude (37° 1' 21.0" N) and longitude (43° 23' 17.3" E) (Fig. 1).

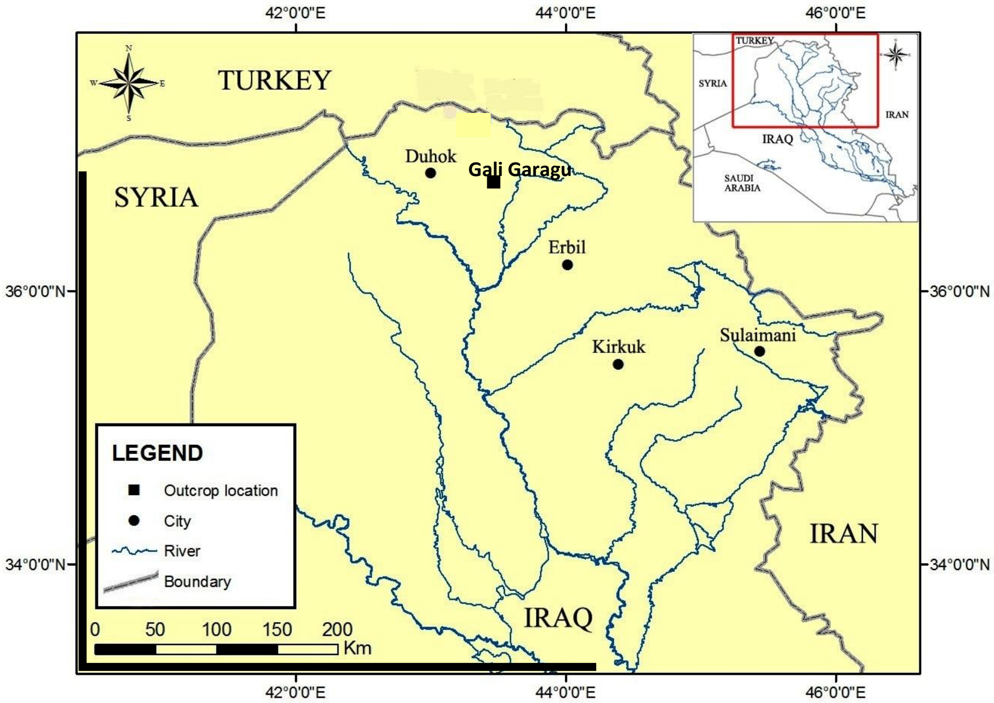

Figure 1: Location map of study area

Materials and Methods

Field work was done in the Gara Mountain in order to study the general geology and structural relations of the area and choosing the appropriate section for the Garagu Formation. The section is measured and studied in detail to collect the sedimentological information such as thickness, lithology, and sedimentary structures. Thirty carbonate samples were collected from the outcrop section and 15 samples from the sandstones. Petrographic investigation for the carbonate rocks was studied in thin sections from different stratigraphic levels using traditional petrographic microscope to identify their textural and compositional characteristics. Calcite and dolomite were differentiated by staining with Alizarin Red S according to procedure of Friedman (1959) [7]. Selected samples of shale and marly limestones were also studied using X-Ray Diffraction at the laboratories of the Research Center of Soran University.

Geologic Setting

The Garagu Formation was originally described by Wetzel (1950, in Bellen et. al., 1959) [3] from the Gali Garagu of the Chia Gara anticline in the High folded Zone of Northern Iraq (Kurdistan region) (Fig. 2). According to Bellen et al. (1959) [3], the formation has three subdivisions, the lower and upper oolitic division comprising of limestone, oolitic limestone and sandstones. Middle division consists of marls - marly limestone and limestone beds.

The Garagu Formation is believed to have been deposited in a shallow water environment contemporaneously with the Yamama/Zangura Formation of the Central Iraq (Bellen et al., 1959) [3]. Chatton and Hart (1960) [8] described the formation as an independent unit, including the beds comprising it into the Yamama. This practice was not accepted by Ditmar et al. (1971) [9] who used the name Yamama for the Zangura Formation of Late Berriasian age of the Awasil area only and retained the Garagu Formation for the oolitic limestones conformably overlying Yamama (Zangura). The Yamama/Garagu Formation have a wide distribution in southern Iraq which contain a relatively thick section of porous oolitic and skeletal limestones (Sadooni, 1993) [10]. In the Northern Thrust Zone at Banik, similar to Gara Mountain the Garagu Formation unconformably overlies the Chia Gara Formation. In Central Iraq, the formation often described as the Yamama Formation, is unconformable overlain by the Zubair Formation in Awasil-5 and Kifl-l (Al-Naqib, 1960) [11].

The Garagu Formation has no clearly proved facies and age equivalents in and outside Iraq. In age and partly in facies too, the lower parts of the neritic Fahliyan Formation of southwestern Iran (Furst, 1970) [12], Yamma Formation from the Saudi Arabia (Powers et al., 1966 [13]; Jassim and Goff, 2006 [14]) and Minagish Formation in Kuwait (Jassim and Goff, 2006) [14] might be correlated with the Garagu Formation. In Iraq, the lateral equivalent of Garagu Formation is Sarmord, Lower Qamchuqa, Ratawi and Zubair formations. The latter two formations are in their lowermost parts only.

Gara Mountain is one of the cliff, more appearance mountains within the series of rock units, which constituently (lithologically and paleontologically) represents the Garagu Formation which located in the northeast of Duhok city, Iraqi Kurdistan (Figs. 3 and 4).

The lithostratigraphic units in the study area (Gara anticline) represented by several depositional cycles, some of them deep marine and others shallow (shoal) water settings. The formation bordered from the top by Sarmord Formation (Hauterivian-Albian) and from the bottom by Chia Gara Formation (Upper Jurassic-Lower Cretaceous) (Fig. 2).

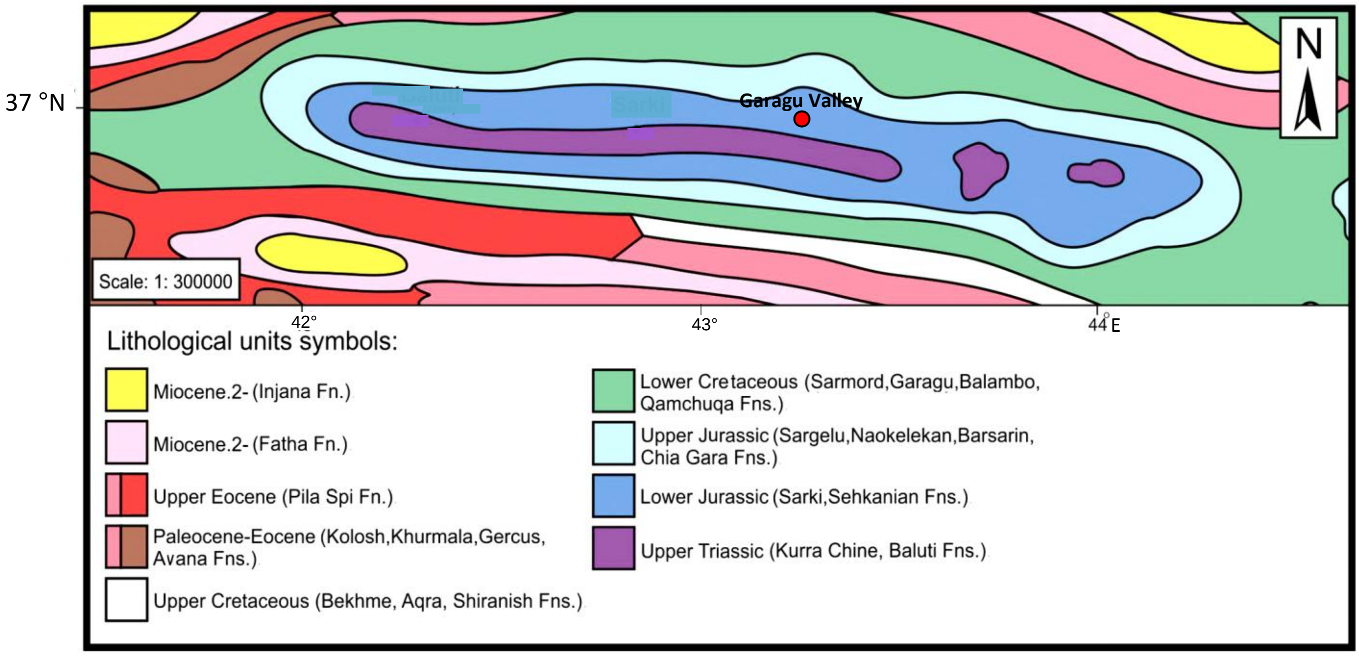

Figure 2: Geological map of the study area, modified from Sissakian (2000) [15].

Lithofacies

In the studied outcrop, from bottom to top, the Garagu Formation can be divided in to three divisions (Fig. 3); the lower oolitic division (46 m. thick) is clearly exposed and composed mainly of thin to medium beds of limestone, gray to yellow in color, and alternated with thin to thick bedded shale, marl- marly limestone, oolitic limestones and sandstones of yellow to oxidized color. The middle organic detrital limestone division (24 m. thick) consists of alternation between medium to thick bedded, grayish yellow organic detrital and ferruginous limestone with thin to medium bedded shale- marls and marly limestones. The upper oolitic division (24 m. thick) is very similar to lower oolitic unit. Lithologically consists of marls and marly limestones of yellow to gray in color alternated with medium to thick bedded oolitic limestones, sandstones and calcareous shale. The Garagu Formation overlies the Chia Gara Formation gradationally and conformably. The contact is taken at the base of oolitic sandy beds and above dark brownish silty limestones (Fig. 4.1). The upper contact with Sarmord Formation is also gradational and conformable and it placed at the top of oolitic marls and sandstones and immediately below thick continuous yellow-brown marls with organic detrital limestones of overlying Sarmord Formation (Fig. 4.2).

The Garagu Formation has been divided into four lithofacies:

1- Oolitic limestone lithofacies: This facies consists of medium to thick bedded oolitic limestone, hard, yellow to gray in color and mostly oxidized alternating with tin to medium bedded shale. The facies occur in lower and upper parts of the formation (Fig. 4.1and 2).

2- Sandstone lithofacies: The facies consists of thick bedded oolitic sandstones, yellowish in color, fine grained, soft and cemented by iron oxides, alternating with medium to thick bedded shale, and oolitic limestones. The occurrence of the facies is obvious within the lower and upper parts of Garagu Formation.

3- Marl and marly limestone lithofacies: The upper part of Garagu Formation is composed of alternating between medium to thick bedded marls and marly limestones olive to gray in color. (Fig. 4. 4)

4- Organic detrital limestone lithofacies: These sedimentary rocks are consists of medium to thick bedded (45-120cm) of gray detrital limestone alternating with thick bedded (470cm) yellowish to oxidized ferruginous limestone and shale within the middle part of Garagu Formation (Fig. 4.4).

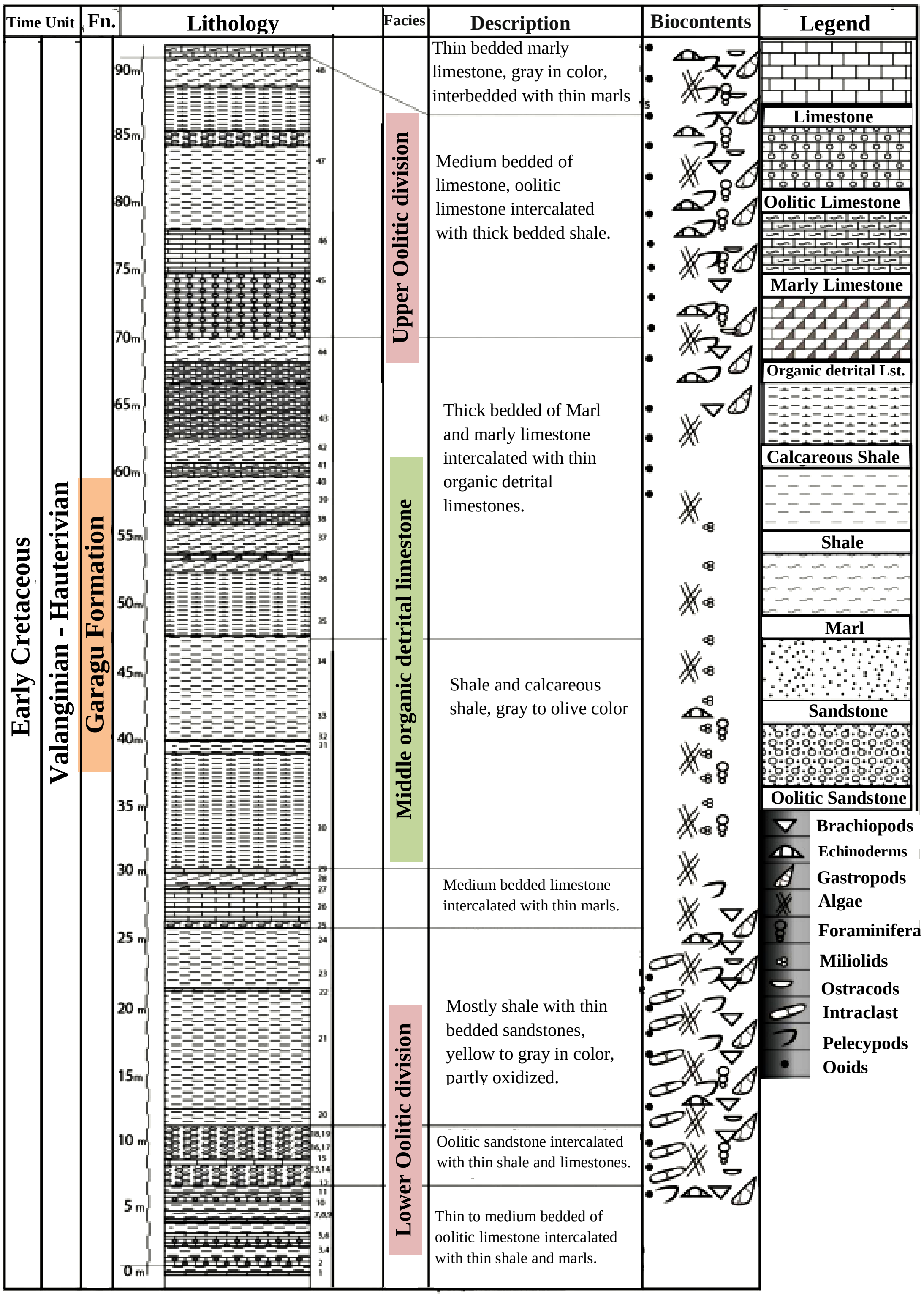

Figure 3: Stratigraphic column of Garagu Formation (Valanginian- Hauterivian), Gali Garagu, Gara Mountain.

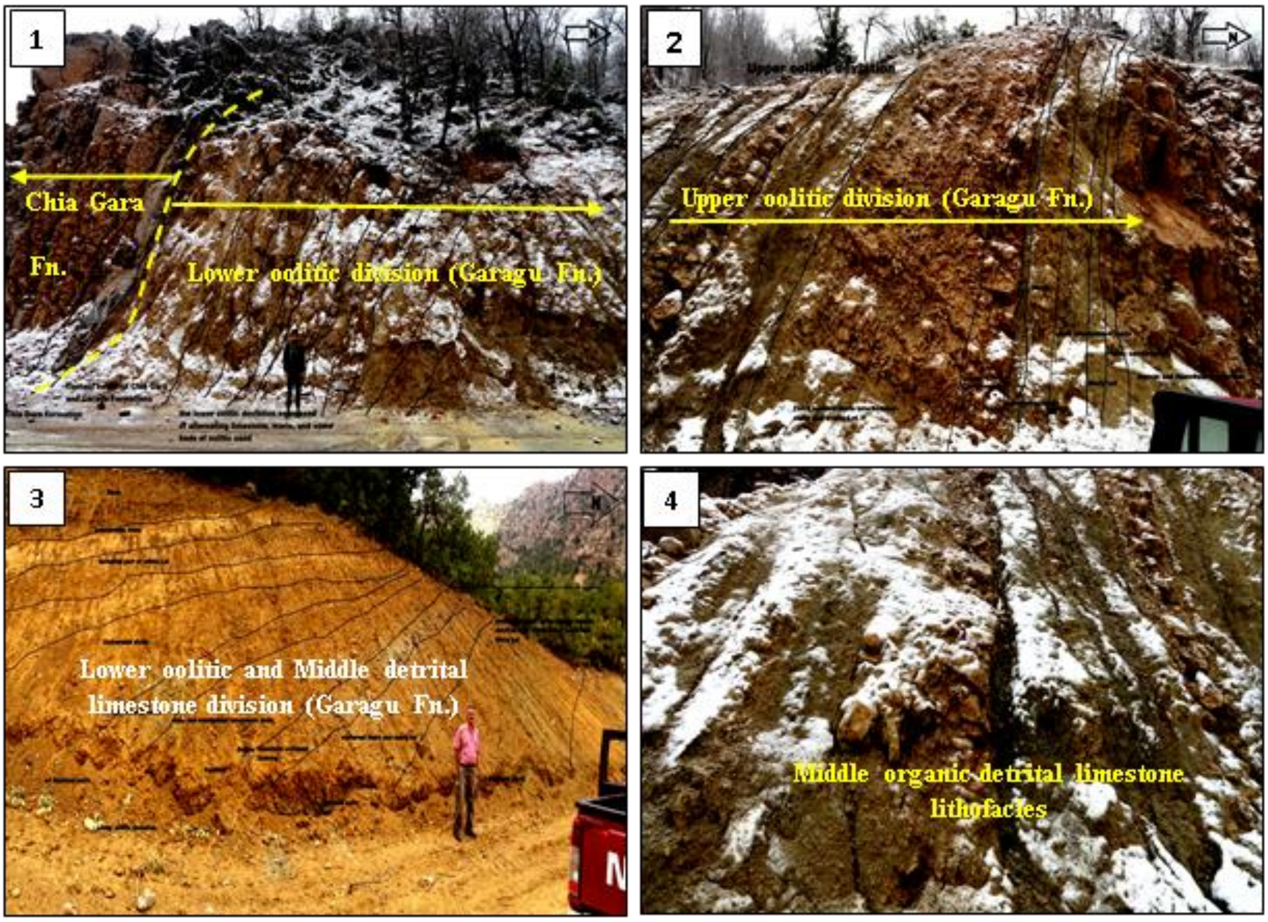

Figure 4: Litho unit subdivisions of Garagu Formation, Gara Mountain

1) Lower oolitic unit composed mainly of thin to medium beds of limestone alternated with thin to thick bedded shale, marly limestone, oolitic limestone and sandstones. 2) Upper oolitic unit is very similar to lower oolitic unit. 3) Lower oolitic division and organic detrital limestone (Middle division) dominated with shale, marls, thin beds of oolitic sandstones and marly limestone. 4) Middle organic detrital limestone lithofacies is composed mainly of limestone, ferruginous limestone, alternating with thin beds of shale.

Petrographic description

1- Petrography of carbonate rocks

Using polarizing microscope, 30 thin sections of carbonates of Garagu Formation were examined to demonstrate petrographic constituents. The major petrographic constituents are micrite, sparry calcite cement, pseudospar and replacement dolomite. Fossils include variety of benthic foraminiferas, gastropods, brachiopods, echinoids, pelecypods, green algae, and ostracods (Fig. 5). Non-skeletal grains include: ooids, peloids and intraclasts (Fig. 6).

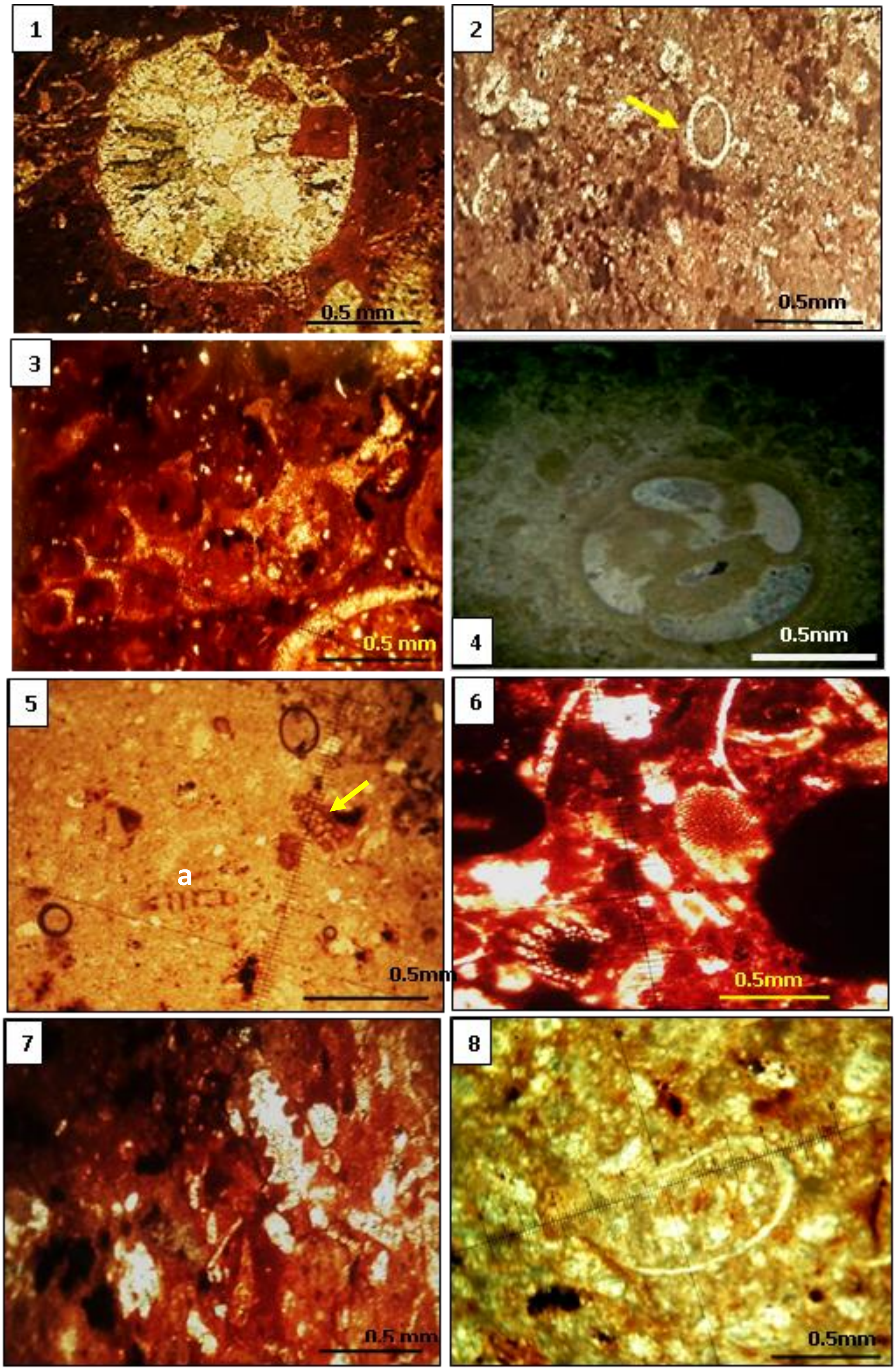

Figure 5: Carbonate petrographic components

1) Echinoderm plate partly replaced by dolomite crystals, G10, P. L. 2) Echinoid spine (arrow) within a micritic matrix, G6, P. L. 3) Gastropod within a ferruginous silty micritic matrix, G48, P. L. 4) Miliolid (benthonic foraminifera) in a micritic matrix, G10, P. L. 5) Benthic foraminiferal mudstones-wackestone with both uniserial type (a) and biserial (Textularidae) (arrow) in a ferruginous micritic matrix, G6, P. L. 6) Echinoid spine surrounded by pelecypod valves in a ferruginous micritic matrix, G48, P. L. 7) Dasycladacean green algae *(Mastopora sp)*. in a ferruginous micritic matrix, G10, P.L. 8) Ostracod fossil in a neomorphosed micritic matrix , G28, P.L.

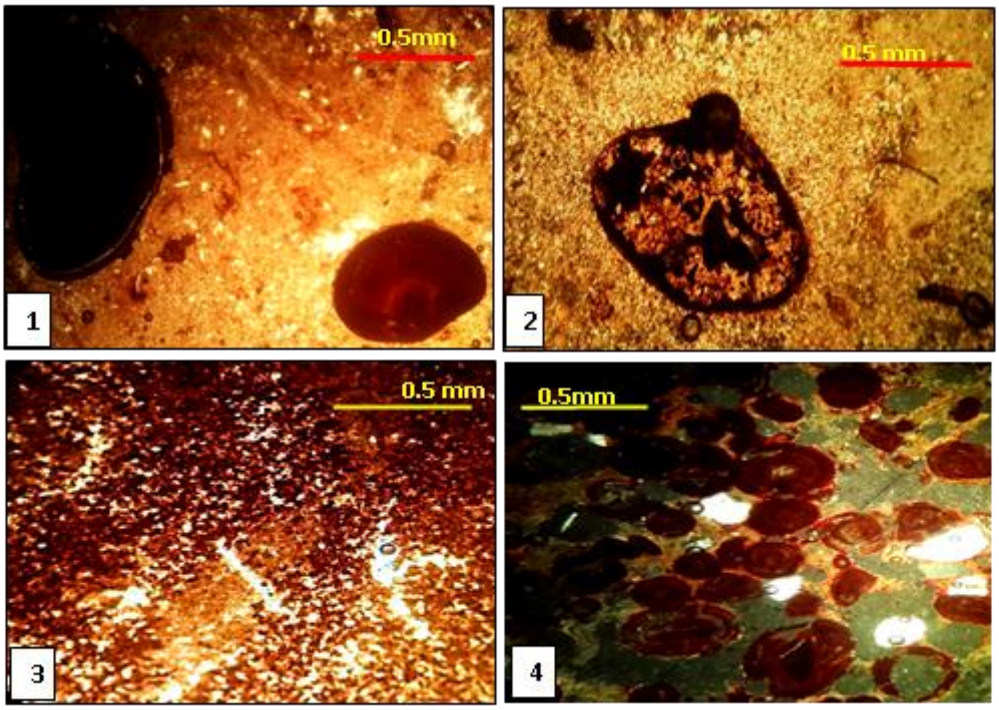

Figure 6: Carbonate petrographic components

1) Micritized ooid in a silty sparite ground mass, G26, P. L. 2) Grapestone, intraclstic mudstone, G9, P. L. 3) Peloids micritized. Note uniformity in size, G3, P. L. 4) Ferruginous ooids with sparry calcite cement matrix, G48, P. L.

2- Petrography of Sandstones

The Garagu Formation characterized by the presence of thin to medium bedded (30-45cm) sandstones in its lower and upper parts. The sandstones are bluish green, grayish green in color, coarse grained in the lower part and fine grained in the upper parts, sub-rounded to angular and consists of quartz, rock fragments, and feldspars.

The following components of Garagu sandstones can be recognized:

i- Quartz

The Garagu sandstones are characterized by its low content of quartz grains. Although the existing quartz grains are dominantly monocrystalline, well sorted, sub angular to subrounded, fine to medium-coarse grained, with straight extinction (Figs. 7.1 and 2).

ii- Rock fragments

Rock fragments are the most abundant of the detrital components of the Garagu sandstones. It includes mostly the fragments of sedimentary rocks with rare igneous particles (Fig. 7.3).

iii- Feldspars

Minor feldspars were present among other constituents of detrital grains, and were dominated by orthoclase and plagioclase (Fig. 7.4).

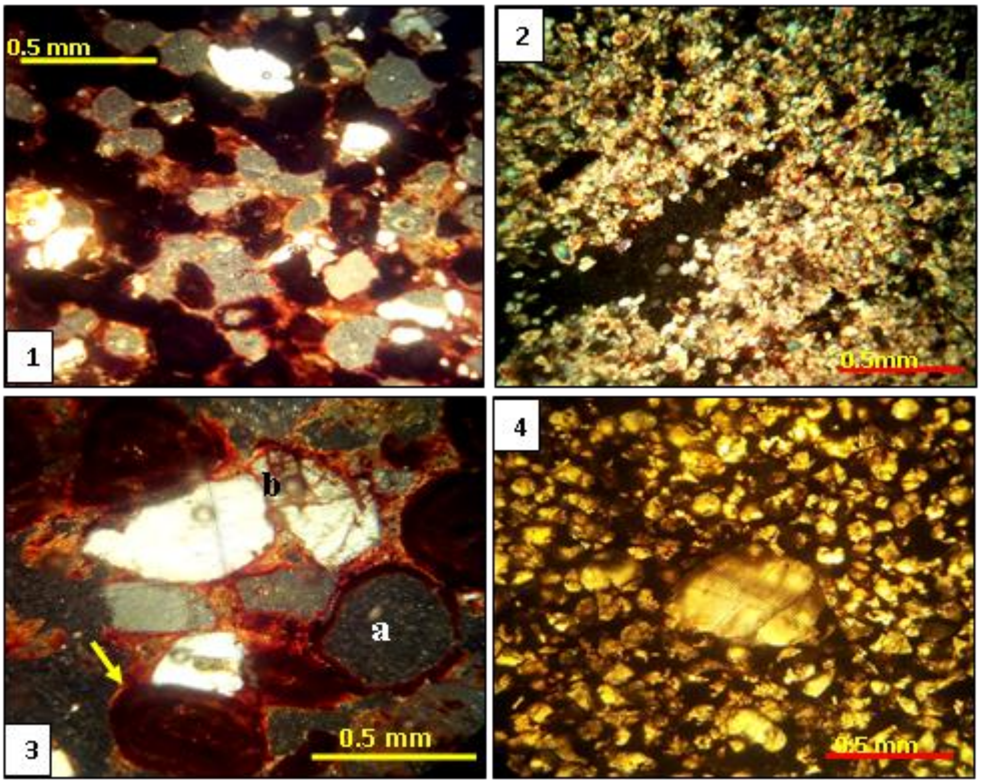

Figure 7: Sandstone petrographic components

1) Medium grained, moderately sorted sandstone showing carbonate rock fragments are dominant along monocrystalline quartz grains. Note, iron oxide cement between grains, G14, X. N. 2) Well sorted fine grained sandstone, quartz grains are monocrystalline in the micrite cement. Note, uniformity of quartz grains, G17, X. N. 3) Coarse grained sandstone consists mostly of carbonate rock fragments includes ooids (arrow) igneous particles (a) with minor amount of quartz (b), G18, X. N. 4) Fine grained sandstone consists of monocrystalline quartz with minor amount of feldspar (plagioclase) in the center, G43, P. L.

Textural maturity and province

According to the classification of Folk et al.(1970) [16], the sandstone units in the lower and upper parts of Garagu Formation in Gara Mountain area can be classified as lithic subarkose to subarkose (Fig. 8). The large presence of sedimentary fragments such as carbonate fragments, cherts, and shale fragments are strongly indicative of existence of sedimentary sequences in the source area.

Textural maturity is determined by the relative abundance of matrix and the degree of rounding and sorting of framework grains (Boggs, 2006) [17]. The sandstones of lower part of Garagu Formation is immature where considerable amount of matrix is present, sorting is poor to moderate, and grains are generally sub rounded to angular. Whereas in the upper part, the sandstones displays good sorting with rounded to sub angular quartz grains.

Compositional maturity refers to the relative abundance of stable and unstable framework grains (Boggs, 2006) [17] and can be represented by the ratio of quartz: (feldspar + rock fragments). In the coarse grained Garagu sandstones, the ratio of quartz and feldspars are relatively minor indicating relatively low maturity. The fine-grained sandstones of upper parts of Garagu Formation are characterized by the abundance of quartz grains. The majority of existing quartz grains is of monocrystalline type with minor amount of polycrystalline quartz. Monocrystalline quartz is generally medium to very fine size, rounded to subangular, with straight (even) extinction. The polycrystalline quartz is generally medium grained, angular to subrounded with elongate crystals and sutured contacts. Undulose extinction characterizes most of the quartzcrystals forming the polycrystalline quartz and usually a reflection of strain in the crystal lattice

(Tucker, 1981) [18]. Quartz grains derived from volcanic igneous rocks are monocrystalline with unit extinction (Tucker, 1981) [18]. Undulose extinction which characterized polycrystalline quartz grains indicate metamorphic source. In general the presence of feldspar fragments indicates plutonic provenance (Pettijohn, 1975) [19]. The little ratio of feldspar fragments within the Garagu sandstones indicates that derivation from a source terrain dominated by sedimentary rocks with a minor contribution from plutonic rocks. A sedimentary source terrain was also indicated by the fact that the majority of the framework grains were of sedimentary origin. The occurrence of fresh feldspars indicates dry climatic conditions.

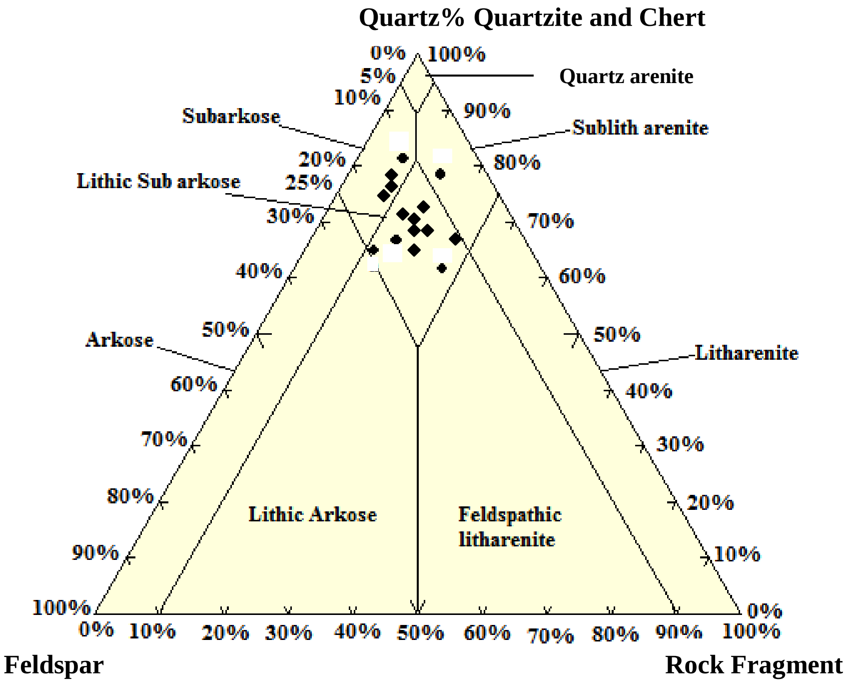

Figure 8: Classification of terrigenous sandstones of studied samples of Garagu Formation (after Folk et al., 1970) [13].

Mineralogy

XRD analysis

The results of the XRD analysis are illustrated in (Fig. 9). The bulk-rock is crushed to <4 µm, then X-Ray diffraction (XRD) analysis was used to determine the whole-rock mineralogy. Depending on XRD analysis for selected calcareous shales and marly limestone samples indicates the presence of phyllosilicates with abundant calcite and common occurrence of quartz and minor feldspar content . Calcite is the most abundant non-clay minerals in the studied sediments. It is recorded with high abundance in the bulk and clay- size minerals. Calcite and phyllosilicates show opposite behavior. This may explain the carbonate dilution by the land derived terrigenous materials (Chamley, 1989) [20]. The dominance of calcite over other minerals in the bulk fraction is consistent with the high abundance of calcareous fossils within the Garagu Formation. Quartz, geothite and nacirite contents are recorded with relatively low to moderate abundance. On the other hand, Kaolinite is most abundant clay mineral within the studied samples of Garagu Formation. Kaolinite is resulted from the chemical weathering of acidic igneous and metamorphic rocks or their detrital weathering products under tropical to subtropical humid climatic conditions (Hendriks, 1985) [21]. Kaolinite can crystallize during both shallow and deep burial. The presence of abundant kaolinite in the studied samples possibly indicated large amount of feldspar before dissolution. The relative abundance of kaolinite as a detrital mineral may reflect proximity to the sediment source and deposition in relatively near-shore shallow marine settings (Flugel, 2004) [22].

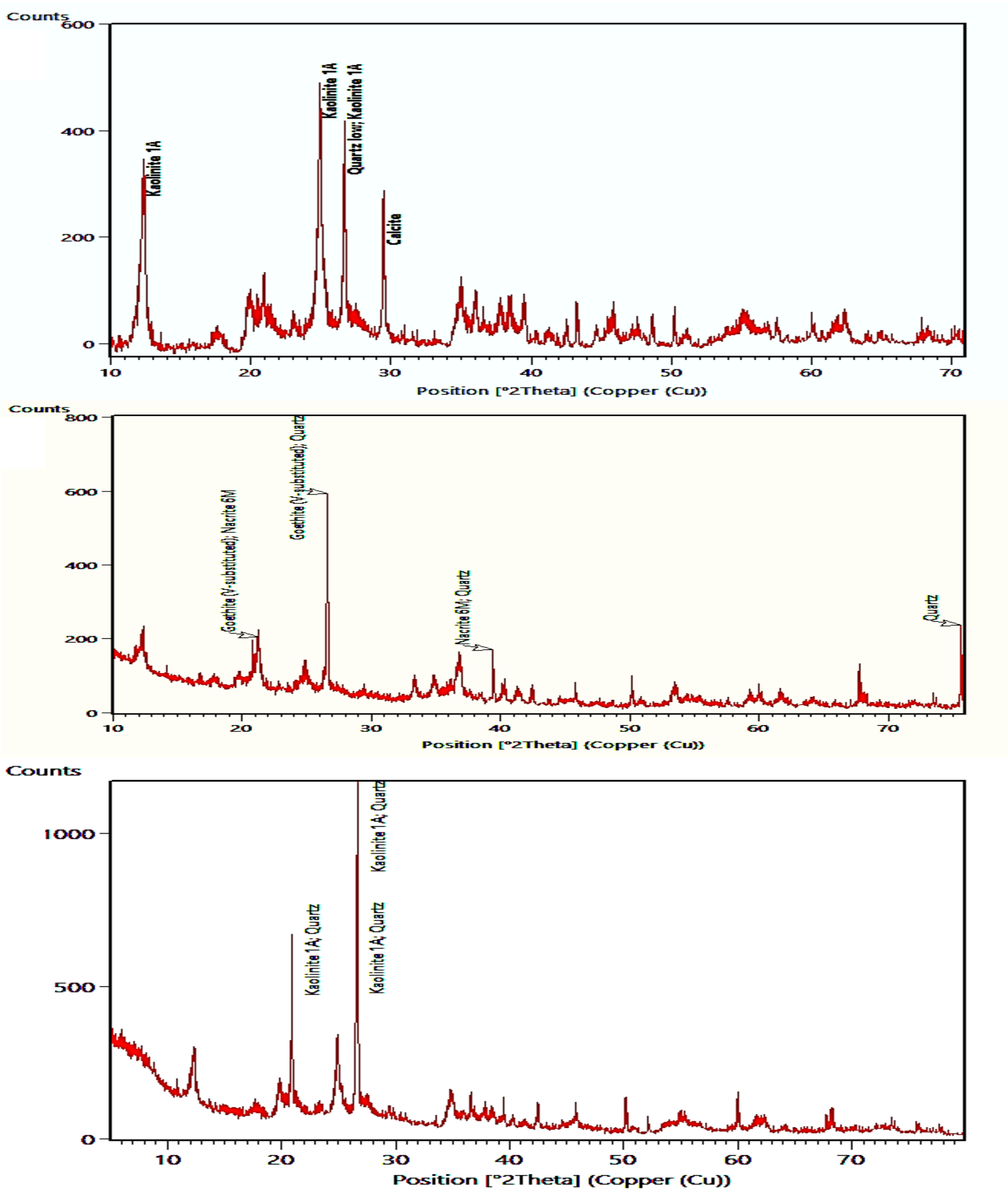

Figure 9: X-ray diffractograms of the bulk clay samples of the Garagu Formation from the Gara Mountain, High Folded Zone.

Microfacies analysis

The following microfacies are recognized:

1- Bioclastic lime mudstone microfacies

This microfacies occurs as yellowish to brownish micritic limestone which consists of homogenous aggregates of microcrystalline calcite with few bioclastics, algae and fine quartz grains (Fig. 10.1).

2- Silty mudstone microfacies

This microfacies is composed of micrite with 30 % or more of terrigenous admixture by volume with few mollusks bioclasts (Fig. 10.2). It is reddish to brownish in color. The terrigenous materials are silty, equi-granular, angular quartz grains in micritic matrix.

3- Gastropod- lime wackestone microfacies

This microfacies is composed of structure less brownish micrite including of about 30% of skeletal components like: gastropods, pelecypod valves, and ostracods (Fig. 10.3).

4- Foraminifera lime wackestone submicrofacies

This microfacies occur as yellow to light brown in the middle part of Garagu Formation. The constituents of this facies are benthic foraminifera (Textularidae and Milliolids) with echinoid spines (Fig. 10.4).

5- Echinoderms lime wackestone microfacies

This microfacies consists mainly of echinoderms with minor amount of pelecypod valves and ostracods in dark micritic matrix (Fig. 10.5). The occurrence of this facies is restricted to the middle part of the Garagu Formation.

6- Bioclastic lime wackestone microfacies

Bioclastic wackestone microfacies consist mainly of bioclasts with minor amount of corals and echinoderms in a micritic matrix (Fig. 10.6). The occurrence of this facies is limited within the upper part of the studied formation.

7- Peloidal lime packstone microfacies

The peloidal packstone is made up of reddish to brownish of fine peloids. Most peloids are uniform, micritized with indistinct outlines and are probably of algal origin (Fig. 10.7). The occurrence of this facies is limited within the middle part of Garagu Formation.

8- Ooidal grainstone microfacies

This facies type comprises abundant ooids and coated grains, whereas peloids and clasts are only rarely observed. It occurs mainly in the lower and upper parts of the studied formation.Ooids have concentric laminar microfabrics (Fig. 10.8). Various skeletal grains, peloids and quartz grains act as nucleus of the ooids.

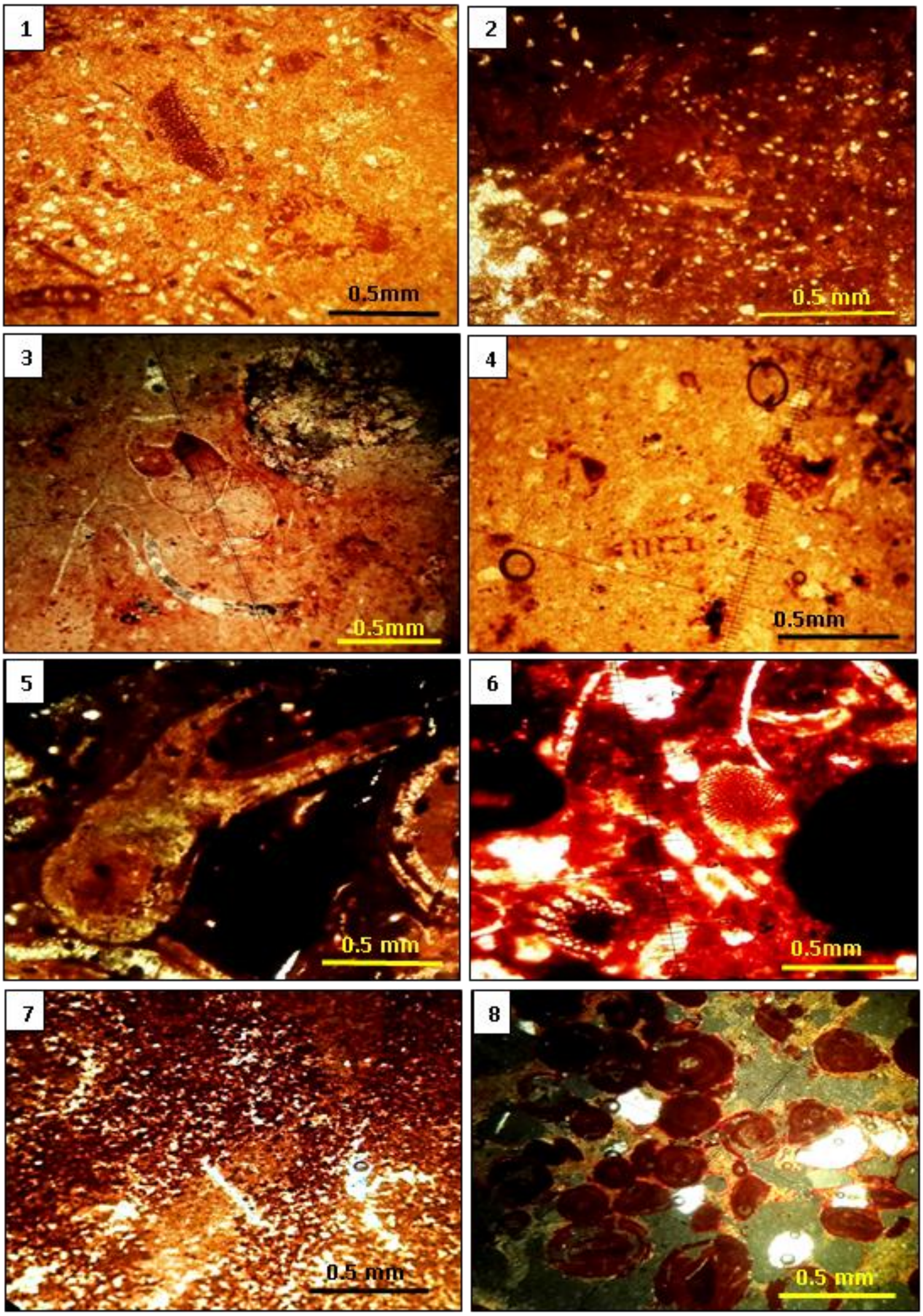

Figure 10: Limestone microfacies types

1) Bioclastic lime mudstone microfacies, G6, P.L. 2) Silty mudstone microfacies, G10, P.L. 3) Gastropod lime wackestone microfacies, G10, P.L. 4) Foraminifera lime wackestone microfacies, G10 P.L. 5) Echinodermslime wackestone microfacies, G6, P.L. 6) Bioclastic lime wackestone microfacies, G48, P.L. 7) Peloidal lime packstone microfacies, G3, P.L. 8) Ooidal grainstone microfacies, G14, P.L.

Facies associations

Field and petrographic analyses of the Garagu Formation in the study area led to the recognition of shelf margin and shelf lagoon associations which were deposited on a narrow rimmed carbonate shelf. The facies are considered briefly in turn below:

Shelf-margin (Shoal) facies association

Shelf-margin (Shoal) sediments are characterized by ooid grainstones, bioclastic-peloidal packstone and bioclastic wackestone, which separate the fore-shoal and lagoon facies. Shelf-margin facies occur in thick to massive units of oolitic limestone and sandstone beds from the both upper and lower parts with lamination, small cross beddings and erosional surfaces. Some ooids show diagenetic modification such as dolomitization and micritization in Gara Mountain area.

Ooids with quartz and bioclastic nuclei had concentric cortices at outcrops of the study area in the Valanginian- Hauterivian deposits.

Interpretation

The presence of lamination, cross-bedding and erosional surfaces indicates wave and current activity in a high-energy depositional environment supported by the presence of grain-supported and mud-free textures (Lucia, 1999 [23]; Palma et al., 2007 [24]).

Development of micritic envelopes indicates low sedimentation rates (Palma et al., 2007) [24] within the photic zone. On the Bahamas Platform, ooids are generated in carbonate shoals in water depth of 2-5m (Flugel, 1982 [25]; Tucker and Wright, 1990 [26]). A relationship between dry climate, hypersalinity and ooid formation was suggested by Selley (1988) [27].

Lagoonal facies association

This association comprises the middle part of the Garagu succession and sandwiched between shoal association in both lower and upper parts of the studied formation.

Lagoonal facies are characterized by benthic foraminiferal, ostracod and peloid wackestone and packstones. Foraminiferal and ostracod wackestone contain calcite pseudomorphs after anhydrite/gypsum with no evidence of subaerial exposure. The facies is brown to reddish in color and medium to thick-bedded.

Interpretation

The presence of benthic foraminifera (Miliolids) along with micritic facies indicate shallow water environment (Bismuth and Bonnefous, 1981) [28]. The presence of peloids within this association represents shallow warm waters (Flugel, 1982) [25]. The significantly high micrite matrix also supports calmness of the environment (Boggs, 2006) [17].

The presence of ostracod fragments indicates the restricted circulation of open-marine waters across the platform (El-Tabakh et al., 2004) [29]. Dasycladacean algae are common in lagoonal environments (Palma etal., 2007) [24]. Highly Bioturbated carbonates indicate a shallow-marine environment, suggesting a low sedimentation rate (Strasser et al., 1999) [30]. The wackestone and packstone textures indicate deposition in the proximal part of a subtidal lagoon (Lasemi et al., 2008) [31].

To imply all these interpretation a schematic block diagram (Fig. 11) is drawn. This figure illustrates the inferred paleoenvironmental conditions of Garagu Formation in the High Folded Zone, Iraqi Kurdistan.

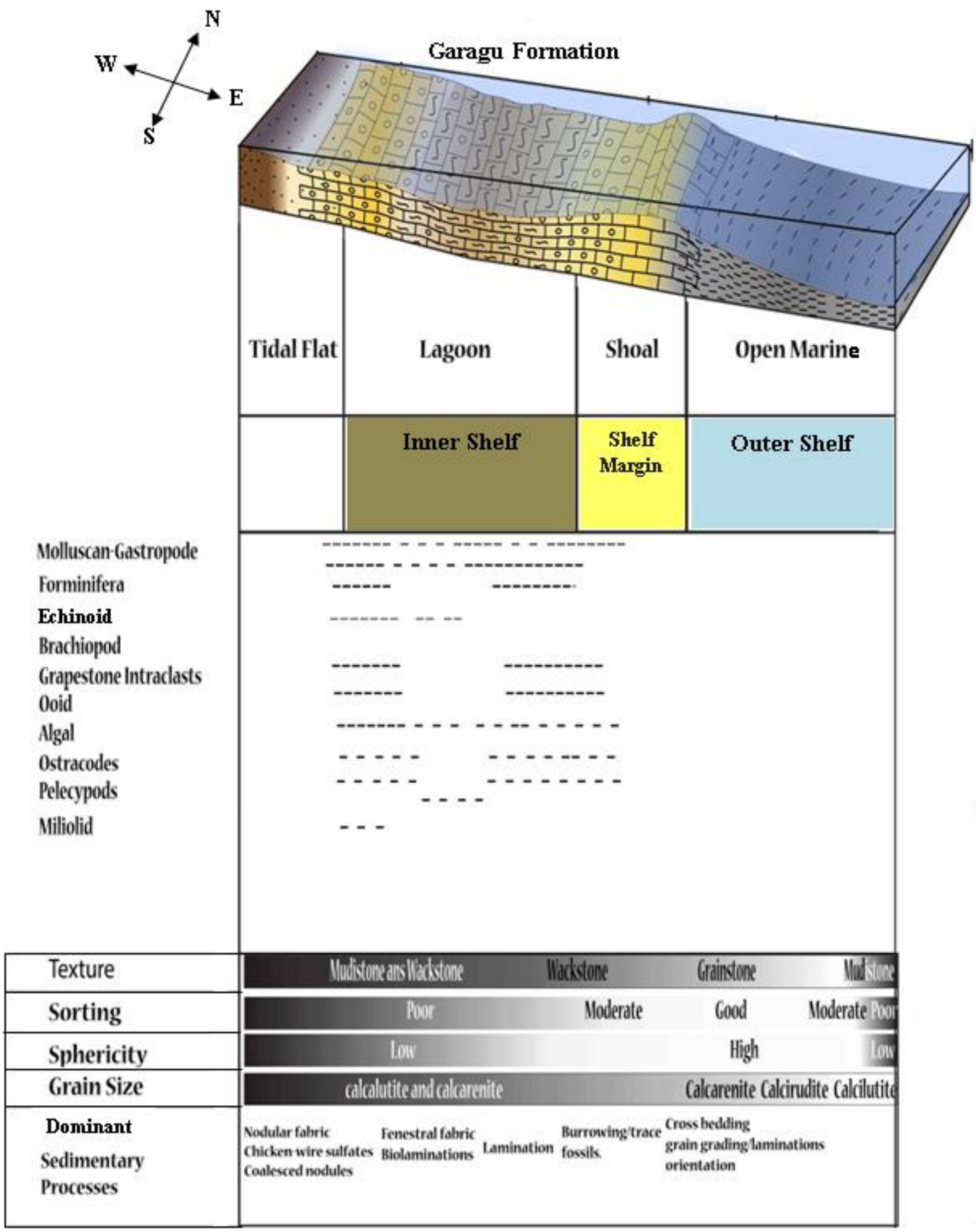

Figure 11: Lower Cretaceous Garagu Formation facies model integrating depositional, petrographic, sedimentological attributes in Gara Mountain, High Folded Zone.

Conclusions

1- The Garagu Formation is a carbonate-siliciclastic unit, consists of alternation between bedded, yellow to brown, shale, marl- marly limestone and limestone from the middle part and limestone, oolitic limestone and sandstone beds from the both upper and lower parts.

2- Depending on field observations and petrographic analysis, four different litho facies were recognized in the Garagu Formation, these are: Oolitic limestone, Sandstone, Marl and marly limestone and Organic detrital limestone.

3- The petrographic constituents of carbonate rocks show that the limestones are dominated by variety of shallow water derivatives such as: benthic foraminiferas, gastropods, brachiopods, echinoids, pelecypods, green algae, and ostracods. Non-skeletal grains include: ooids, peloids and intraclasts.

4- Garagu sandstones are immature, lithic subarkose to subarkose and occur as medium to thick beds within the lower and upper parts of the formation, composed mainly of sedimentary rock fragments with minor amount of quartz and feldspars (plagioclase).

5- The X-ray diffraction analysis of the bulk shale and marly limestone samples revealed that the abundant clay mineral in the Garagu Formation is kaolinite and non-clay minerals include calcite, quartz, geothite and nacirite.

6- Eight different microfacies were recognized from the Garagu Formation which was subdivided according to their environmental interpretation into two basic types of facies associations; Shelf margin (Shoal) and Shelf lagoon association.

7- Generally, the Garagu Formation represents shallow water environment with two high energy belts in the lower and upper parts.

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