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Depositional environment of the Sarmord Formation (Valanginian-Aptian) in selected areas, northeastern Iraq

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Abstract
The current study deals with microfacies and the depositional environment of the Lower Cretaceous Sarmord Formation at selected sections in Sulaimani and Erbil Governorates, northern Iraq. The Sarmord Formation alternates rhythmically between yellowish grey marly limestones and grey black marls. These lithologies are observed in all studied sections of Sarmord Formation in northern Iraq. Petrographic investigation of this study based on 240 thin sections demonstrated that the carbonate constituents are mainly composed of skeletal and non-skeletal grains. The skeletal grains include a variety of foraminiferas (planktonic and benthonic), bioclasts, calcispheres, ostracods, radiolaria, echinoderms, sponge spicules, ammonoids and belemnites. The non-skeletal grains consist of rare intraclasts. Based on field observations, two major lithofacies are recognized in the studied sections, namely marly limestone and marl lithofacies. Depending on the detailed microfacies analysis, two main microfacies, which in turn are divided into four sub-microfacies, were identified. These facies were subdivided upon their environmental interpretation into two types of facies associations: deep shelf and basinal.
From the results of petrographic, facies, and textural analyses, it is concluded that Sarmord Formation in the studied sections was deposited at a rimmed carbonate platform. With a gradual shallowing of the basin from basinal sediments at the lower part overlying by deep shelf sediments in the uppermost part of the formation in the studied sections.

Keywords: Facies, Depositional environment, Sarmord Formation, Outer shelf, Basinal environment.

البيئة الترسيبية لتكوين السارمورد (الفلانجينيان – الابتيان) في مناطق مختارة شمال شرق العراق

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الخلاصة
تتناول الدراسة الحالية السحنات الدقيقة والبيئة الترسيبية لتكوين السارمورد الكريتاسي الاسفل في مقاطع المختارة ضمن محافظتي السليمانية و أربيل شمال شرق العراق. يتألف تكوين السارمورد من تعاقب بنمط متكررين الحجر الجيري الصلصالي ذي لون الرمادي المصفر مع الصلصال ذي اللون الرمادي المسود.وقد تم ملاحظة هذه الصخارية في جميع المقاطع المدروسة لتكوين السارمورد في شمال العراق. أعتمدت الدراسة

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البتروغرافية للحجر الجيري على 240 شريحة رقيقة وأظهرت ان المكونات الجيرية تتألف بصورة رئيسية من الحبيبات الهيكلية والحبيبات غير الهيكلية .تحتوي الحبيبات الهيكلية على انواع مختلفة من الفورامنفرا (الطافية والقاعية),الفتاتات العضوية, الرديولاريا, الكورويات الكلسية, شوكيات الجلد, أشواك الاسفنجيات , الأمونايت والبلمنايت. تتألف الحبيبات غير الهيكلية من الفتاتات الداخلي النادر التواجد. بالأعتماد على المشاهدات الحقلية, تم تميز سحنتان صخريتان رئيسيتان في المقاطع المدروسة تسميان سحنة الحجر الجيري الصلصالي وسحنة الصلصال. وبالأعتماد على تحاليل السحنات الدقيقة التفصيلية, تم تشخيص سحنتين دقيقتين الرئيسة واللتان تقسم بدورهما الى أربعة سحنات ثانوية معرفة. وتبعاً للتفسيراتهما البيئية , تقسم هذه السحنات الى نوعين اساسيين من السحنات المترافقة وهما الرف العميق والحوضية .

من خلال نتائج التحاليل البتروغرافية والسحنية والنسيجية , استنتجت ان تكوين السارمورد في المقاطع المدروسة ترسب في رصيف كاربوناتية حافية مع تضحل تدريجي للحوض من ترسبات حوضية في الجزء الاسفل تعليها رواسب الرف العميق في اقصى الجزء العلوي من التكوين في جميع المقاطع الدراسة.

1. Introduction

The Sarmord Formation was first defined by Wetzel [1] in the Surdash Anticline-Sulaimani area in northern Iraq. The type sections of the Sarmord Formation from the two locations. The total thickness of the formation is 455 m, and the uppermost 80meters contain a significant amount of fossils that give the Age as Barremian to Hauterivian. The Sarmord Formation was defined to include the succession deposited in a neritic to deep-water environments and composed of brown and bluish marls, with alteration of marly limestones in a rhythmic manner[1].

The Sarmord Formation represented part of tectonostratigraphic megasequence AP8, which lasted about 57 my [2]. AP8 ranges from Late Jurassic to Late Cretaceous. The lower boundary of this megasequence is at the base marked by the Early Tithonian unconformity, and its upper boundary is marked by the Middle Turonian widespread unconformity [2]. A new phase of ocean floor spreading in the Southern Neo-Tethys coincided with the deposition of this Megasequence, and differential subsidence occurred across transverse faults. A narrow micro-continent drifted away due to the southern Neo-Tethys opening, and a new passive edge developed along the Arabian Plate's northeastern margin. The Rutba uplift created the Mesopotamian basin's western edge. A carbonate ridge formed the NE margin along the north-facing passive margin of the Southern Neo-Tethys [3].

Several studies were conducted and proposed to identify and interpret the Sarmord Formation depositional environment. Those are mainly depending on the fossils assemblages for describing depositional environments. In the first description of the Sarmord Formation by Bellen et al. (1959), they mentioned the Valanginian-Turonian Balambo Formation as a bathyal succession in its type area, passing westwards and northwestwards into marls and marly limestones of the Sarmord Formation, the Garagu Formation, which is oolitic, arenaceous, and biostromic in some places, is found at its base [1]. After that, Buday in a general review of the formation agreed with those concluded by [4]. The depositional environment of Sarmord Formation range between an open platform (Shelf lagoon) and restricted platform [5], On the other hand, Al-Eisa and Al-Omeri concluded that the environment of Sarmord Formation ranges from the deep sea basinal environment at the bottom and neritic environment at the top [6]. The depositional environment of Sarmord Formation covers a wide scale from the open sea shelf environment [7]. The biostratigraphy and facies analysis of Sarmord Formation in Maten Anticline defined two biozones; Everticyclammina kelleri Assemblage Zone, which represented the Late Valanginian age and Pseudocyclammina lituus Assemblage Zone, indicated the Hauterivian age [8]. The main aim of this work is to identify the depositional environment of the Sarmord Formation by more than a single approach, i.e., combining results from the petrographic description and microfacies analysis.

2. Geological setting

The study areas are southwest of the main Zagros Sutured Zone in the Western Zagros Fold Belt [9]. According to its structure, the region is a part of the High Folded and Imbricated Zones [4] (Figure 1). The parallel high amplitude anticlines and synclines dominated the region, whereas numerous of them are asymmetrical, with the limbs to the southwest being steeper than those to the northeast. Most of the strata are destroyed with intense deformations, especially those located within the axis of synclines due to imposed stress of Iranian Plate. Numerous reverse faults and transverse in the area were caused by the stresses. The majority of the gorges were formed along strike slip and transversal normal faults. Due to this stress, the observed anticlines and synclines mark the area's northern boundary. In the Imbricated Zone, these features are very clear, particularly in areas around the boundary between the Balambo and Qamchuqa Formations, which runs parallel to the line between Sulaimaniya city and Rania town. The Dokan reservoir's surrounding area, which most likely represents a graben, is the main depression (plain) in the region [10]. The Sarmord Formation has conformable and gradational upper and lower contacts.

3. Location of studied sections

The study areas are located within the High Folded and Imbricated Zones in the northeastern part of Iraq (Sulaimanya and Erbil Governorates). For this study, four surface sections are selected (Table 1 and Figure 2); these sections are:

1- Sargelu section: - The section was chosen near Haladn Village, located 34km northwestern of Sulaimani city, near to Sargelu village in the center of Surdash anticline. This section provides a good exposure of the Sarmord Formation. The Balambo Formation (Berriasian-Valanginian) occupies the Surdash Anticline's core, while the limbs are occupied by the argillaceous carbonates of the Valanginian-Aptian Sarmord Formation, and the Qamchuqa Formation covers the majority of the shield, generating high cliffs.

2- Dwawa section: - The section is located at Dwawa village, southwest of Rania district (Makuk Mountain). The section includes stratigraphic succession starting with Chia Gara Formation (Upper Jurassic- Lower cretaceous), Balambo Formation (Berriasian -Valanginian), Sarmord Formation (Valanginian - Aptian) and Qamchuqa Formation (Barremian - Albian).

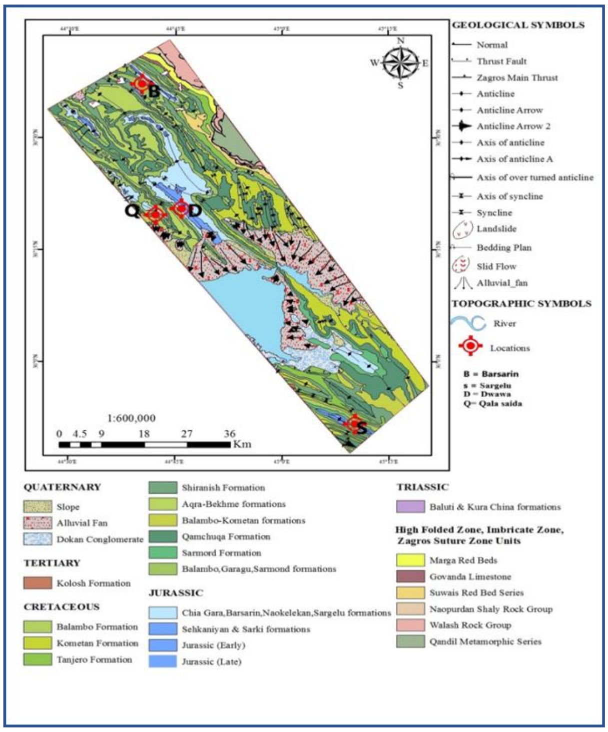
3- Qala Saida section: -Similar to the previous section, the Qala Saida section also located within the Makuk Mountain about 1oo meteres esat of Qala saida village, nearly 10 Km to the west of Dwawa Section.

4- Barsarin section: - The Barsarin section is located in the Balak valley, near Rowanduz, Erbil Governorate, Northeast of Iraq, Kurdistan region. The studied section is located nearly 200 meters east of Barsarin village and cropped out at the limb of one of thrusting anticlines (locally called Sirin Mountain), east of Barsarin village and beside the main road to Haji Omran.

Table 1: Outcrops location through geographic coordinates, thickness and number of samples.

section	*Geographic coordinate*	*Thickness (m)*

	Latitude	*Longitude*		*Number of samples*
Sargelu	*35° 51' 58"*	*45° 10' 19.2"*	*367*	*89*
Dowawa	*36° 19' 42.5"*	*44° 42' 17.6"*	*75*	*40*
Qala Saida	*36° 20' 31.4"*	*44° 46' 01"*	*71*	*40*
Barsarin	*36° 37' 12"*	*44° 40' 20"*	*144.5*	*100*



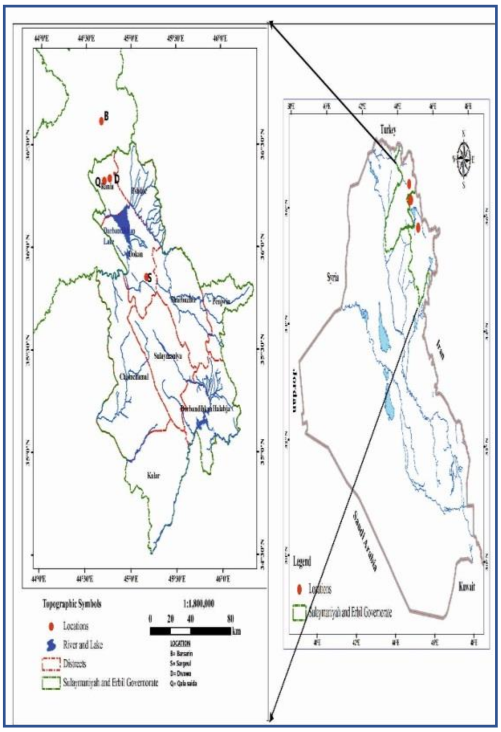


Figure 1: Geological map of study area **Figure 2:** Location map of the study area

4. Methodology

The research is a path through two major work categories: field and laboratory work. The fieldwork includes the study of the general geology of areas around all studied sections to choose the appropriate localities, description of the Sarmord succession in detail (considering lithology, macrofossils, sedimentary structures, and measurements of selected sections) and drawing columnar sections. A sampling includes both lithologies of the formation (Marly limestone and marl). Samples were usually collected at spacing ranges depending on variations in lithology, fossil continent and /or colour (random sampling). The number of collected samples is 296. Laboratory work includes making the thin sections (240 slides) from carbonates of the Sarmord Formation, which was prepared at the University of Baghdad, College of Science, Department of Geology for petrographic study, and each of them was stained with Alizarin Red Solution and potassium Ferro-cyanide, following the procedure of Dickson (1965)[11].

5. Petrographic constituents

A detailed petrographic study is carried out from selected outcrops. In the Sarmord Formation, the carbonate constituents are composed of skeletal and non-skeletal grains. These grains are minor compared to the matrix (micrite), and skeletal grains are more abundant than the non-skeletal grains. The petrographic study depended on 240 thin sections and shows the skeletal grains include; planktonic and benthonic foraminifers (Plate1: A and B), bioclasts (Plate1: C), calcispheres (Plate1: D), ostracods (Plate1: E), radiolarians (Plate1: F), echinoderms (Plate1: G), sponge spicules (Plate1: H). In addition, macrofossils include Ammonoids (Plate1: I) and belemnites (Plate1: J). The non-skeletal grains consist of intraclasts only (Plate1: K).

6. Lithofacies of Sarmord Formation

Field observations of the Sarmord Formation in all studied sections demonstrated homogenous lithology among all the studied outcrops in northern Iraq. Generally, the Sarmord Formation consists of two types of lithofacies arranged rhythmically:

6.1. Marly limestone lithofacies: This facies is dominant in all the studied sections and represents a high bulk ratio compared to other lithofacies types. The facies consists of marly limestone beds with variable thickness, yellowish-grey in weathered surface to grey dark grey on fresh, alternating with thin to thick bedded grey marls. The macrofossils include; ammonites, belemnites and rare brachiopods and gastropods. Rhythmic bedding is a common structure characterizing this facies. Biogenic sedimentary structures include bioturbation. In addition to diagenesis related structures like calcite veins and iron oxide nodules are observed (Plate 2: A, B, C, D and E)

5.2. Marl lithofacies: Similar to previous lithofacies, marl is also dominant facies all over the Sarmord Formation in all studied sections. It is characterized by friable flaky, yellowish gray to grey marl beds with a different thickness that rhythmically interbedded with marly limestones. Macrofossils include ammonites and belemnites (Plate 2: F, G and H).

6. Microfacies analysis of Sarmord Formation

Using Dunham's (1962) classification [12], the following microfacies are recorded in the Sarmord Formation in all the studied sections:

6.1. Lime Mudstone Microfacies: The microfacies is the common facies in the Sarmord studied sections and compositions greater than 50% of the marly limestone beds of the studied formation. It has bioclasts that are silt and sand size, foraminiferas, ostracods and radiolarians, in addition to sponge spicules and echinoids. This facies consists mainly of micrite, which is slowly affected by recrystallization, cementation, and dissolution processes. The micrite matrix also contains clay and iron oxide minerals (Plate 2; I). This microfacies can be subdivided into two sub-microfacies types:

6.1.1. Bioclasts Lime Mudstone Sub-microfacies: This facies is composed of micrite (more than 90%) with bioclasts, foraminifera, calcispheres and sponge spicules (Plate 2; J, K, and Plate 3; A). Sometimes this microfacies contains only micrite. The diagenetic processes are micritization, recrystallization, cementation, silicification and dissolution. This facies is equivalent to Wilson (1975) [13] Standard Microfacies 3, which belongs to (FZ-1) of Flugel (2010) [14], which was defined as Basinal environment.

6.1.2. Radiolarian Lime Mudstone Sub-microfacies: This facies is composed of micrite (more than 90%) with little (less than 10%) of a radiolarian, planktonic foraminiferas, calcispheres and ostracods, usually with dark color (Plate 2; B and C). This facies are affected by diagenetic processes like micritization, cementation and dissolution. The facies is common in the lower and middle portions of the Sargelu section and coincides with Wilson (1975)[13] Standard Microfacies 3 (SMF-3), which belongs to (FZ-1) of Flugel (2010) [14] that was defined as the basinal environment.

6.2. Lime Wackestone Microfacies: Wackestone microfacies include grains ranging between 10-50% in micritic groundmass [12]. Skeletal grains include; bioclast (sand and silt-sized usually) with fewer foraminiferas, radiolarian, sponge spicules and echinoderms. This facies in the Sarmord Formation can be divided into two sub-microfacies based on the type of grains.

6.2.1. Foraminiferal Wackestone sub-microfacies: The skeletal component of this facies is up to (15%) that includes planktonic and benthic foraminifera, sponge spicules with rare radiolarians with silt and sand-sized bioclasts. The groundmass comprises micrite (Plate 2; D, E, F and G). This microfacies is distributed in the Sarmord Formation at the Sargelu, and Qalia Saida studied sections. This facies occurs in the middle and upper parts of all studied sections. Calcite (micrite) is the main mineral constituent; non-carbonates such as quartz and iron oxides are also present. This facies is equivalent to Wilson (1975) [13] standard microfacies 3 or 8 (SMF-3 or SMF-8), which belongs to Facies Zones 1 or 2 (FZ-1 or FZ-2), described as deep sea or deep shelf marine environment.

6.2.2. Radiolarian Wackestone Sub-microfacies: This facies is characterized by predominant grains (20 - 45%) from total rock components, with a considerable rate of radiolarians (Plate 2; H, I and J). It is also included calcispheres with a minimal amount of bioclasts. The groundmass is composed of the micrite with light grey to dark grey colour. This facies is affected by the diagenetic processes such as dissolution, cementation and silicification. The facies is recognized in the gradational contact between the Sarmord Formation and the underlying formations (Balambo or Chia Gara formations). This facies is more common in the Barsarin section than in other studied sections. This facies is equivalent to Wilson (1975) [13], Standard Microfacies 3 (SMF-3), which belongs to Facies Zone 1 (FZ-1) as described Basinal environment. The criteria that indicate the environment of the Sarmord Formation is the predominance of micrite is a general indication of the deep nature and calmness of the Sarmord environment; such deduction requires support from other evidence (from fossils, for example) [15].

7. Facies associations

Depending on the field and microscopic study, several microfacies types are identified in carbonates of the Sarmord Formation in all studied outcrops. These facies were grouped into two categories of facies associations according to their environmental evidence: 1- Basinal 2- Deep shelf. The facies associations are given below:

7.1 Basinal Association

Field description

This association forms the lower portion of the Sarmord Formation in all studied outcrops. It comprised thin to medium bedded, grey to dark grey colour of marly limestones, alternating with thin to medium bedded, yellowish-grey to grey marls. The marly limestones are well bedded and contain macrofossils such as cephalopods (ammonites and belemnites).

Microscopic description

This association is composed of lime mudstone and wackestone, containing pelagic biota such as radiolarians, calcispheres, planktonic foraminiferas (Globigerina sp.), echinoids and ostracods with micrite groundmass (plate 1; A, E, F, G, Plate 3; B, C, H, I and J). Non-skeletal components consist of rare fine quartz grains (silt grade). This association is also include bioturbation and cubic authogenic pyrite. Iron oxides were deposited at the pores of matrix.

Interpretation

The pelagic biota (radiolaria and planktonic foraminifera) in these deposits indicates basinal environments are probably deposited at water depths as much as several hundred meters [14]. The common faunas in Sarmord Formation are the Ammonoids and belemnites, which denote deposits in deep or pelagic (open sea) waters. Ammonoids are marine animals with a dominantly pelagic mode of life Flugel [16]. The availability of micrite refers to the absence of high-energy currents [17]. This facies is similar to the standard facies basin apron within the zone FZ1 of Flugel (2010) [14].

7.2. Deep shelf

Field description

This association forms the upper part of the Sarmord Formation in all studied surface sections. It has medium to thick-bedded, grey to dark gray marly limestones that alternate with highly variable thickness bedded gray marls. These marly limestone beds are well bedded and contain macrofossils such as cephalopods (ammonites and belemnites).

Microscopic description

This association is composed of bioclastic lime mudstone and foraminiferal wackestone microfacies, containing bioclasts with silt and sand sized, planktonic foraminifera, small benthic foraminifera (mostly reworked), echinoderms, ostracods, rare radiolarians, calcispheres and sponge spicules. The recognized foraminiferas are globigerina sp., nodosaria sp., heterohelix sp. and miliolids (Plate 3; F, A, D and E). In which their chambers are filled by spary calcite cement. Pyrite is also recognized at filling the chambers of several fossils and in fossil pores, which are considered the ideal condition for pyrite precipitation due to the availability of organic matter that makes alkali reducing environment enhance the crystallization of pyrite [18]. Non-skeletal grains consist of rare intraclasts and fine quartz grains (silt-sized). This facies also includes bioturbation and micro-stylolites.

Interpretation

The biotas in these deposits are nekton (ammonites) and plankton (pelagic foraminifera and radiolarians), with reworked small benthic foraminifera (nodosaria sp., miliolids and plane spiral foraminifera). The biota in this deposit indicates an open marine outer shelf environment that has probably been deposited at water depths under a fair-weather wave base but within reach of storm waves and currents. The occurrences of micrite with bioclasts reflect the quite deep marine environment to the depth under fair-weather wave base. This facies is similar to the standard facies deep shelf apron within the zone FZ2 of Flugel (2010)[14].

8. Depositional Environment of Sarmord Formation

Different studies were carried out and proposed to identify and interpret the Sarmord Formation's depositional environments. Those are mainly depending on the fossils assemblages for describing environments.

Analyses of petrography and microfacies properties of the Sarmord Formation are examined to reconstruct its depositional setting. The microscopic examination of thin sections revealed various facies types, with clear similarities in the litho-and bio-contents among all the surface sections studied. This would indicate homogeneity of both facies and environment in these areas. In this study, the depositional environment of the Sarmord Formation is identified by more than a single method, so the combination of petrography, microfacies and mineralogical composition. Different types of microfacies and their petrography are identified for constructing the depositional environment model for Sarmord Formation, Utilizing these microfacies and comparing them with the Standard Microfacies (SMF) of Wilson (1975) [13] and Flugel (2010) [14], it was determined that microfacies types of Sarmord Formation in the investigated outcrops range between mudstones and wackestones. The recognized microfacies allowed the differentiation of carbonate marine environments, including deep shelf and basin. In the result, when following the concepts of SMF and FZ of Wilson (1975) [13] and Flugel (2010) [14], it is revealed that Sarmord Formation in the studied sections was deposited at a rimmed shelf carbonate platform because of the following reasons: The existence of reef-building community (barrier reef) or shoals within the shallow shelf part of the basin represented by Qamchuqa and Garagu formations, which are supporters of the shelf model. The existence of lagoonal and restricted marine facies represented in the Qamchuqa and Ratwi formations (a lateral equivalent of the Sarmord Formation) also characterise the shelf model. The slump and calciturbidites concluded the slope condition is found restricted, at least in the studied outcrops. In the present study and from the field observations, the local slump structures are found from the middle to upper portions of the studied formation at the Barsarin section, and the bioclasts wackestone microfacies may represent the distal part of the turbidites. These could be related to the possibly gentle slope of the fore reef area and the calm weather during the Sarmord Formation's deposition in northeastern Iraq (Figure 3). According to Wilson and Jordan, carbonate shelves environments are separated into the inner shelf (near the coast and tide-dominated zone), mid-shelf (extended shallow subtidal zone and the shelf break; below fair-weather wave base, but above storm-wave base) and outer shelf (in rimmed shelves, the outer shelf is a narrow area with shoals and reefs close to the shelf break. Non-rimmed shelves: a large area below the typical storm-wave base that stray ocean currents could impact) [19]. According to Walther's law, the lateral facies successions are inferred from vertical stacking patterns. The microfacies analysis of the lower to middle parts of the Sarmord Formation at Sargelu, Qala-Saida sections and the entire Dowawa section inferred that the lime mudstone microfacies is the dominant facies types. The Radiolarian lime- mudstone and lime wackestone represent the SMF 2 and 3 belonging to Facies Zones 1, described as a deep marine basinal environment (Figures 4, 5 and 6). In the middle to upper parts of the Sarmord Formation at Sargelu section the Foraminiferal wackestone microfacies is the dominant type, whereas, in the upper part of the studied formation at the Qala-Saida section, the rhythmic beds are regarded as foraminiferal wackestone and bioclastic lime-mudstones. These microfacies correspond to SMF 2, 3 and 8, which belong to Facies Zones 2, described as deep shelf environment. The Barsarin section differs from other sections in microfacies because it is accompanied by radiolarian and calcispheres wackestone and lime mudstone with a continent of cephalopods (belemnite and ammonite) that refer to high quiet deep marine environments (Figure 7). These microfacies correspond to SMF 3 which belongs to Facies Zones 1, described as a basinal environment. The Barsarin section may be represented by interfingering between Balambo and Sarmord Formations. This section ended with a bioturbated bed that separated between Sarmord and Balambo Formations. It is started by a thick bed of marly limestone containing cherty nodules and black shales of the Balambo Formation.

The other criteria and evidence that indicates to the environment of the Sarmord Formation the predominance of micrite is a general indication of the deep nature of the Sarmord environment; such deduction requires support from other criteria (from fossils, for example) [15].

Ammonites are the less frequent and notable fauna in the Sarmord Formation, which imply pelagic (open sea) or relative deep-water deposits [20]. The latter also stated that ammonites are considered marine animals with the generally nektonic mode of life. Additionally, Benton and Harper illustrated that those complex septa and ammonite sutures may have increased ammonoid phragmocone's strength, protecting the shell against possible implosion at deeper levels in the water column [21]. Unfortunately, most Sarmord ammonites are poorly preserved because of intensive neomorphism that made sutures and septa of shells hardly identifiable. The

Early Cretaceous outer platform fossils are dominant benthic foraminifera, sponges, echinoderms, bivalve and cephalopods, whereas the basinal fossils are planktonic foraminifera, calcispheres and cephalopods [14]. In the Sarmord studied sections, the appearance of these fossils.

Radiolarians are planktonic and are indicated to be exclusively marine organisms [22]. They live in open marine environments and tropical regions [23]. The radiolarians are stenohaline fauna that can endure only low saline seawater. Radiolarians may tolerate deep marine conditions down to the CCD surface [24]. It was noticed that the increase of radiolarians in the radiolarian lime wackestone submicrofacies indicates the basinal environment.

Planktonic foraminifers (Globigerina) are present in foraminiferal lime wackestone sub-microfacies. The planktonic foraminifera and radiolarians are common in deep-water environments [25].

Unwalled calcispheres are abundant in the Barsarin section but are always associated with calcified radiolarians. Such association (between calcispheres and calcified radiolarians) causes difficulties in differentiating each. However, in general, because of their affinities with planktonic foraminifera and radiolaria, calcispheres are thought to have an unknown systematic affinity and are considered signs or remnants of planktonic organisms by the majority of scientists [26]. From the environmental point of view, calcispheres have unclear significance. Calcispheres are a sign of a deep open sea [27]. Deposits from both shallow and deep water contain calcispheres [28]. While Banner illustrated that calcispheres are more dominant and widespread within the Tethyan realm than elsewhere, thus they were presumably produced by organisms favoring the tropical and subtropical climate zones [29].
The Criteria from Sedimentary Structures Some deep-water indicative sedimentary structures are noticed within Sarmord deposits. These include planar lamination, rhythmic bedding structure many finely laminated fine-grained types of sediment deposited in protected environments such as lagoons and lakes and relatively deep water marine basins below the wave base [30].

Other Criteria, pyrite common framboidal (and other types) within Sarmord sediments, the size distribution of framboidal pyrite is a measure of redox conditions within sediments [31]. The framboidal pyrite indicates reducing conditions, low oxygen, and high H_2S in the sediment [32]. From the petrographic, facies, and textural analyses, it is concluded that the Sarmord Formation was deposited in basinal and deep shelf environments characterized by quiet and reducing – euxinic conditions. The depositional model (Figure 2) illustrates the inferred paleoenvironmental conditions and elements of the Sarmord Formation (Early Cretaceous) in Northeastern Iraq.

Conclusions

Following are the main points of the present research:

1- The Sarmord Formation in northern Iraq consists of the rhythmic alternation between yellowish-grey marly limestone with brownish black marl beds with different thicknesses.

2- The petrographic study of carbonates shows homogeneity in contents among all studied sections. The main constituents are skeletal and non-skeletal grains. The grains are minor in comparison to the matrix (micrite). The skeletal grains are foraminifers (planktonic and benthonic), bioclasts, calcispheres, ostracods, radiolarians, echinoderms, sponge spicules, ammonoids and belemnites. The non-skeletal grains consist of rare intraclasts.

3- Depending on the field and petrographic studies, two lithofacies types were recognized in the Sarmord Formation in the studied sections. They are Marly Limestone and Marl.

4- The microscopic investigation and depending on Dunham's classification [12], with detailed microfacies analysis of marly limestones, two main microfacies are subdivided into four submicrofacies in the studied sections of Sarmord Formation. These facies were subdivided according to their environmental conditions into two basic types of facies associations: deep shelf and basinal associations.

5- The Sarmord Formation in the studied sections was deposited at a rimmed carbonate platform with a gradual shallowing of the basin from basinal sediments at the lower part overlying by deep shelf sediments in the uppermost part of the formation in the studied sections.

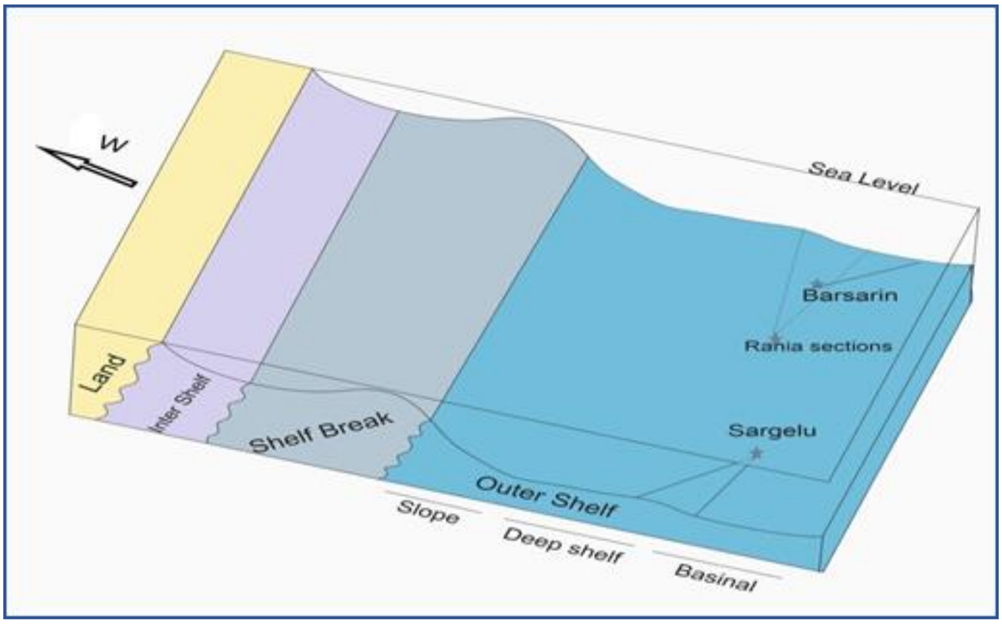


Figure 3: The depositional model of the Sarmord Formation in the study areas.

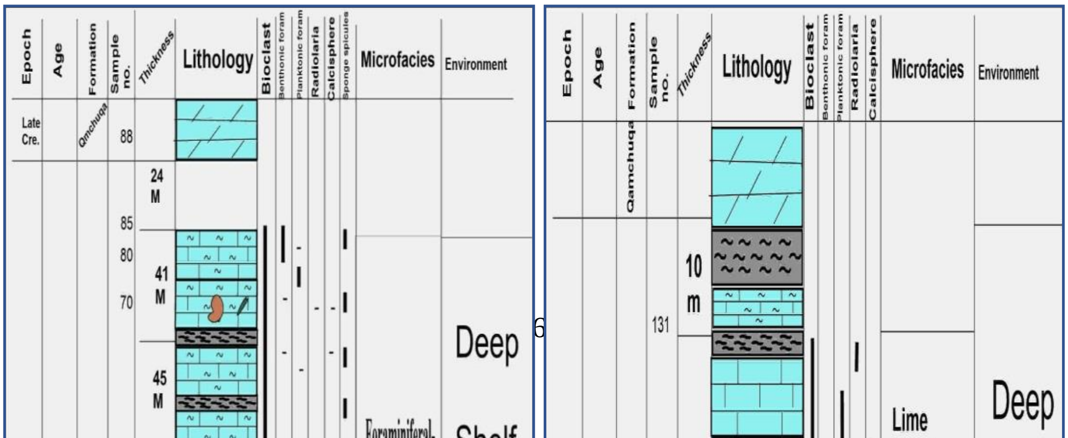
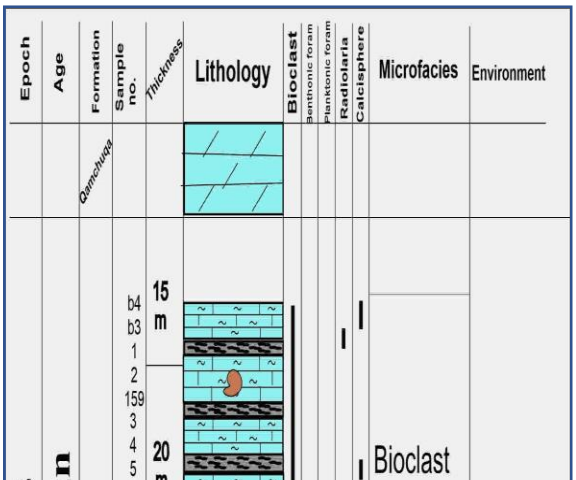


Figure 4: Stratigraphic column of Sarmord Formation (Valanginian – Aptian), Sargelu section, High Folded Zone, NE-Iraq.

Figure 5: Stratigraphic column of Sarmord Formation (Valanginian – Aptian), Qala saida Section, High Folded Zone, NE-Iraq.



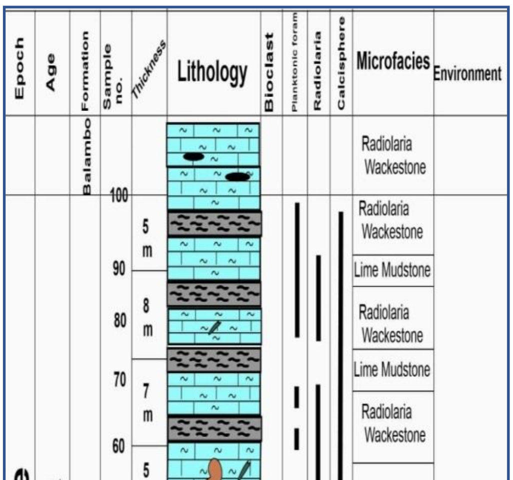


Figure 6: Stratigraphic column of Sarmord Formation (Valanginian – Aptian), Dwawa section, High Folded Zone, NE-Iraq.

Figure 7: Stratigraphic column of Sarmord Formation (Valanginian – Aptian), Barsarin section, Imbrication Zone, NE-Iraq

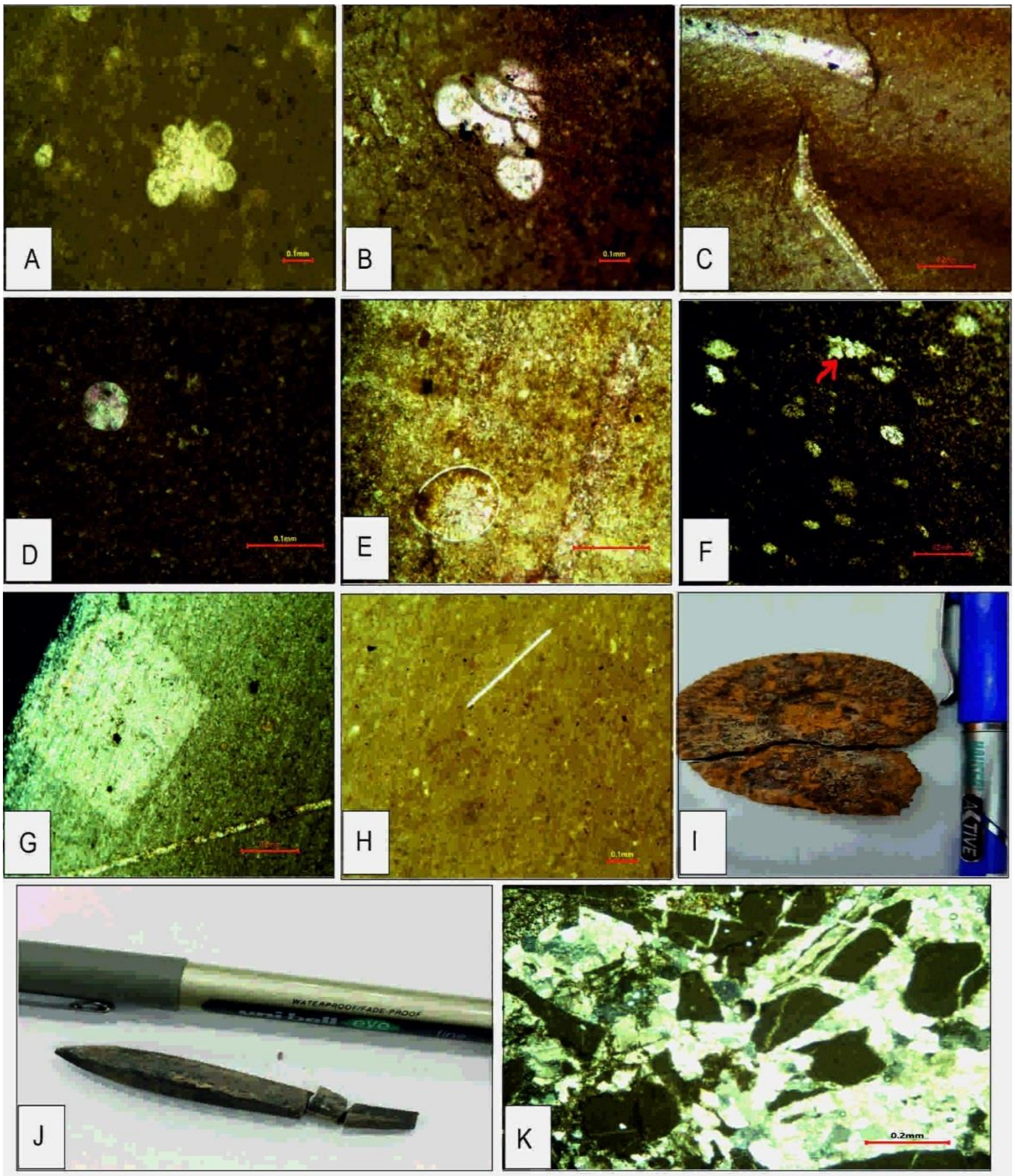


Plate 1

A. Globigerinid sp. planktonic foraminifera at Barsarin section, sample no.50 (PPL).
B. Benthic foraminifera test at Sargelu section, sample No. 51 (XPL).).
C. Bioclast at Sargelu section, sample no.8 (XPL).
D. Calcispheres at Sargelu section, sample no.52 (XPL).
E. Articulated ostracoda at Sargelu section, sample No.22 (PPL).
F. Conical calcitized radiolaria, the tests are replaced by spary calcite cement. Sargelu section, sample No.2 (XPL).
G. Echinoid fragment in bioclast lime mudstone Sargelu section, sample No. 5 (XPL).
H. Siliceous sponge spicule at Sargelu section, sample No. 45 (XPL).
I. Ammonite replacement by iron oxides at upper part of Dowawa section.
J. Belemnite sample at middle pare of Barsarin section.
K. Intraclasts at Dowawa section, sample No. 15 (XPL).

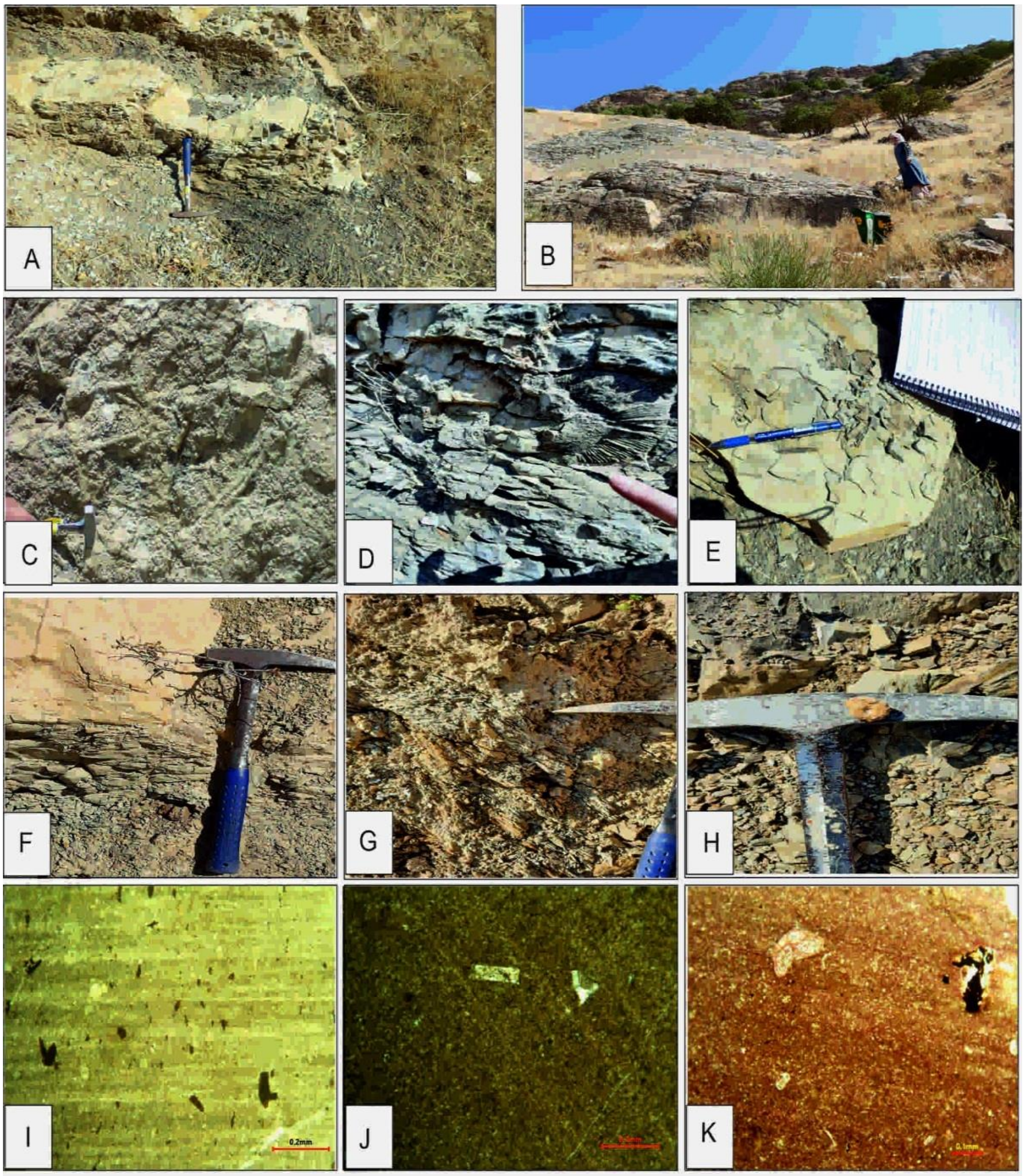


Plate 2

A. The alternating between medium beds of marly limestone lithofacies and thin beds of marl lithofacies at the lower part of Barsarine section.

B-The alternating between thick beds of marly limestone and marl lithofacies at upper part of Sargelu section.

C- Marly limestone lithofacies bioturbited bed at Barsarin section.`

D-The marly limestone lithofacies contains ammonite at the upper part of Sargelu section.

E-The marly limestone lithofacies contains beleminite at Barsarine section.

F-The marly limestone lithofacies contains iron oxides nodules at the lower part of Sargelu section.

G- The marl lithofacies at the upper part of Dowawa section.

H- The marly limestone lithofacies contains ammonite at the upper part of Dowawa section.

I.Lime Mudstone at Dowawa section sample no.19.

J- Bioclast Lime Mudstone at Sargelu section sample no.41.

K- Bioclast Lime Mudstone at Dowawa section sample no.3b.

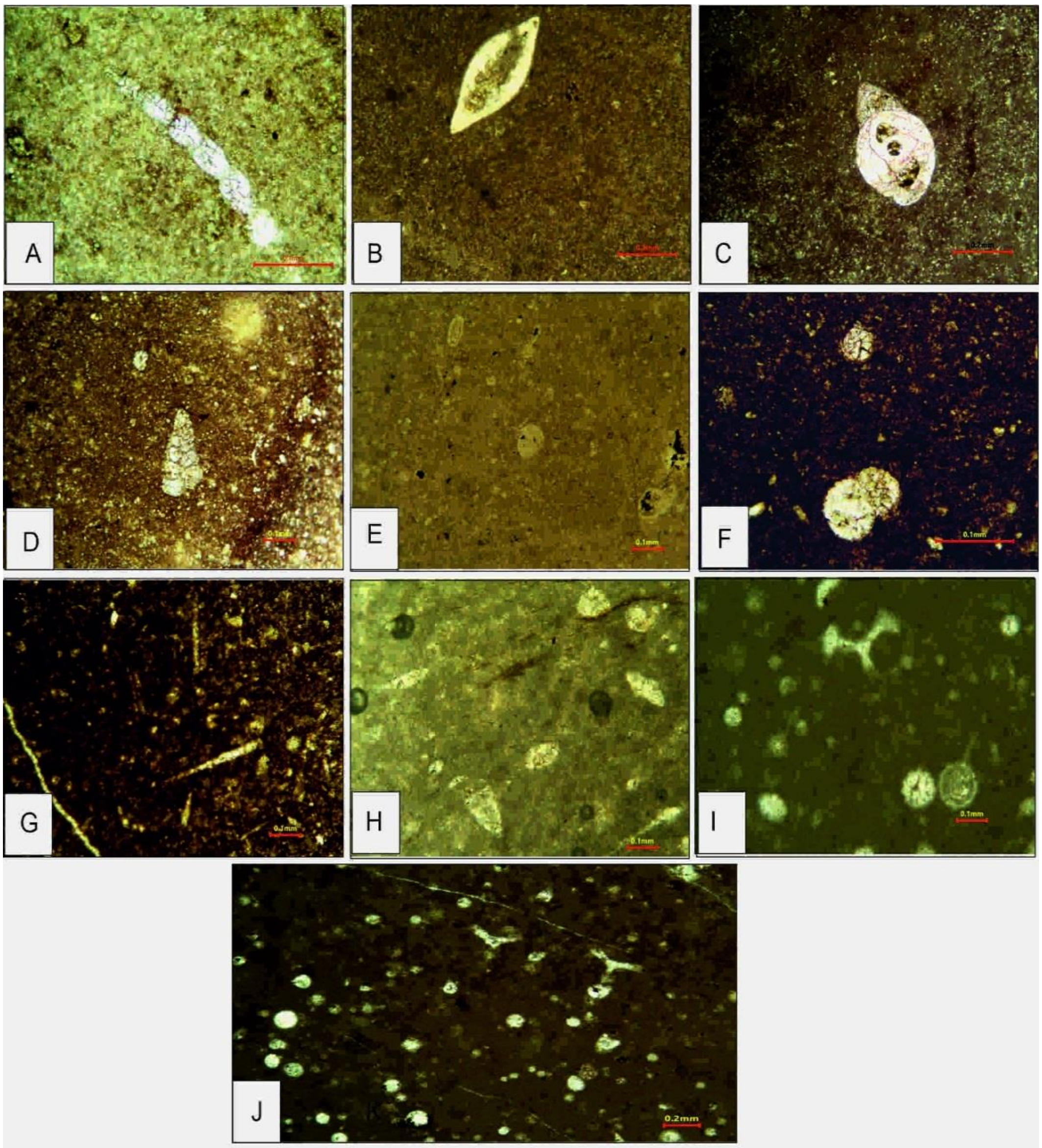


Plate 3

A. Uniserial benthic foraminifera in lime mudstone at Sargelu section, sample No.5 (PPL).
B. Radiolarian Lime Mudstone at Qala Saida section sample No.130.
C. Radiolarian Lime Mudstone at Sargelu section sample No.12.
D. *Heterohelix* sp. in foraminiferal wackestone at Sargelu section, sample No.53 (PPL).
E. Foraminiferal Wackestone at Sargelu section sample No.85..
F. Foraminiferal Wackestone(Globigerinid sp.) atSargelu section sample No.57.
G. Calcic sponge spicule in foraminiferal wackestone at Sargelu section, sample No. 66 (XPL).
H. Radiolarian Wackestone at Barsarin section sample No.8.
I. Calcitized radiolaria, in radiolarian wackestone Barsarin section, sample No. 67 (PPL).
J. Calcispheres and radiolaria in radiolarain wackestone at the contact with Ghia –Gara Formation Dowawa section, sample No.27.

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