Journal of Environment and Earth Science www.iiste.org
ISSN 2224-3216 (Paper) ISSN 2225-0948 (Online)
Vol.7, No.8, 2017

Facies Analysis and Depositional Environment of the Mulussa Formation at the Ga'ara Depression, West of Iraq

Mazin Y. Tamar-Agha Najah A. Owaiz*
Department of Earth Sciences, University of Baghdad, Collage of Science

Abstract
A detailed study on the facies and depositional environment of the Mulussa Formation (Carnian-Norian) at the southern rim of Ga'ara depression, west of Iraq is carried out. The investigation is based on ninety six thin sections collected from five outcrop sections. This formation is dominantly composed of carbonate, marls and subordinate sandstone. Three lithofacies are recognized, depending on field description and microscopic examination, namely: dolomite, dolomitic sandstone and marl. The dolomite lithofacies is divided into four main microfacies, namely: dolomitized lime mudstone (four submicrofacies), dolomitized wackstone (two submicrofacies), dolomitized packstone (three submicrofacies) and dolomitized algal boundstone. Dolomitic sandstone lithofacies is two microfacies, namely: calcarenite and basal conglomerate of sandstone microfacies. By facies analysis, the deposition of Mulussa Formation took place in subtidal, lagoon, tidal flats, tidal ponds, tidal channels and coastal dunes. It generally represents deposition in shallow inner shelf environment with some continental influence in hot, arid to semi-arid climate.
Keywords: facies analyses, depositional environment, carbonate rocks, Mulussa Formation, Ga'ara depression, Iraq.

1. Introduction
This study deals with the the Mulussa Formation which is exposed at the southern rim of the Ga'ara depression, western desert of Iraq. The formation was first introduced by Williamson and Pickles in 1931 and described in detailed by Dunnington (in Bellen et al., 1959). Based on molluscs (pelecypods) and foraminifera, the Mulussa Formation is of Carnian-Norian Age (Buday and Hak, 1980). It overlies the Ga'ara Formation unconformably and underlays the Zor Hauran Formation conformably. The formation passes laterally towards the N and E into the anhydrite-bearing Kurra Chine Formation. To the west, it passes into the carbonates of the Lower Dolaa Group of Syria (Dubertret, 1966) while the formation passes into the Abu Ruweis Formation in Jordan. The passage of the Mulussa Formation into the Minjur Formation of Saudi Arabia and Kuwait is not well defined, but the upper part of this formation in Kuwait is considered to be of Liassic age (Douban and Al Sahlan, 2001 in Jassim and Goff, 2006).

The Mulussa Formation dominantly comprises carbonate rocks with some sandy and clayey admixture, forming dolomite, dolomitic marl and marly dolomite and sandstone. It is characterized by dolomicrosparite with dolomitised pelmicrite or pelsparite and laminated dolomite and lime mudstone suggesting a supratidal to intertidal and lagoonal environment. The upper part of the formation is gypsiferous indicating a sabkha depositional environment (Buday and Hak, 1980).

2. Geology of the study area
The study area is a part of the Stable Shelf of the Nubio-Arabian Platform (Buday & Jassim, 1987; Jassim and Goff, 2006); the stable shelf covers most of central, S and W Iraq. This Shelf is a tectonically stable monocline little affected by Late Cretaceous and Tertiary deformation. The orientations of the structures in this tectonic unit were influenced by the geometry of the underlying basement blocks and faults, Palaeozoic epirogenic events and Mesozoic arching. It is divided in Iraq into three major tectonic zones including the Rutba-Jezira Zone. The Ga'ara depression is part of the Rutba Subzone, located above a broad N-S trending Rutba Uplift (Buday & Jassim, 1987). Numerous unconformities occur within the Mesozoic and Palaeogene section. The Lower Permian Ga'ara Formation is unconformably overlain by Upper Triassic Mulussa Formation that forms the cliffs on the southern rim of the depression. The Ga'ara formation represents fluvial deposition of high sinuosity meandering rivers while the latter represents a new phase of marine transgression, however there is along gap between them (Tamar-Agha, 1986).

3. Methods and study area
Five outcrop sections of the Mulussa Formation (A4- 19.40m, C2- 56.30m, D1- 62.80m, G2- 42.20m and G1- 51.15m thick) were measured and described in the field by the geologists of the Iraqi Geological Survey. These outcrop sections extend from W to E of the southern rim of Ga'ara depression about 65km (Fig.1). Ninety-six thin sections were examined using a polarizing microscope.

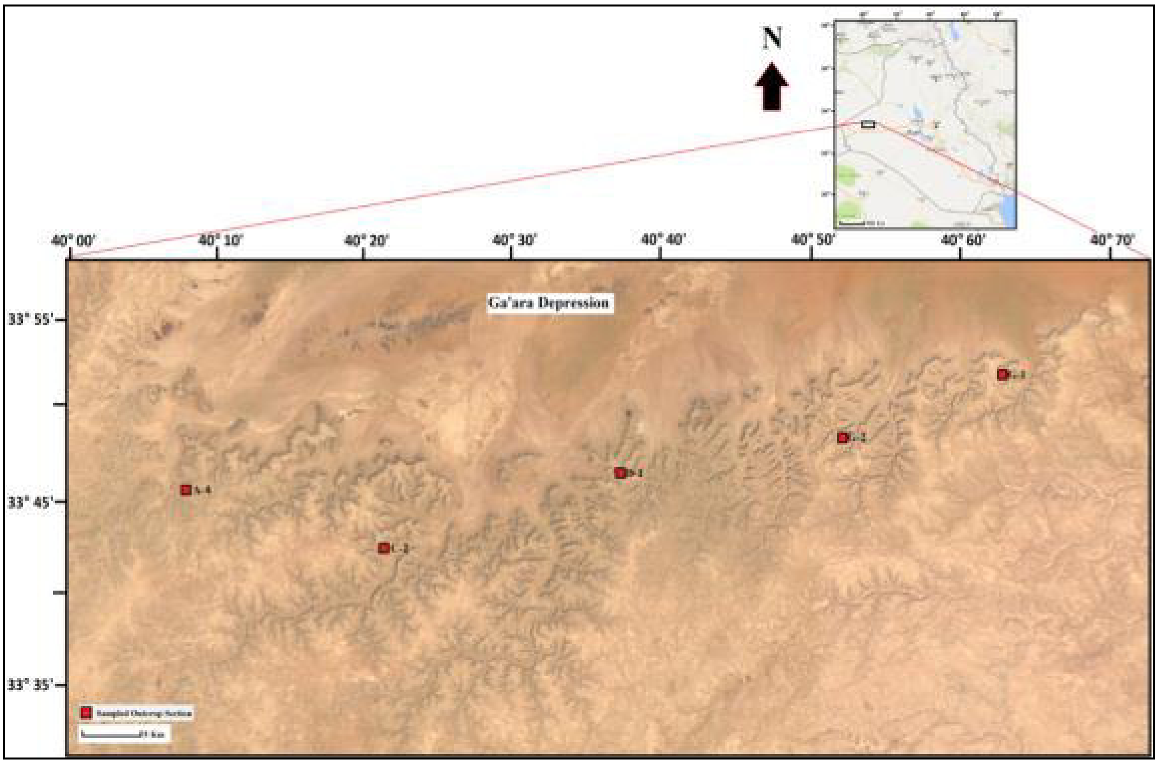


Figure 1: Locations of outcrop sections in the study area (Google Earth with GIS processing).

4. Facies analysis

The facies analysis carried out in this study is to establish the depositional environment. Using Dunham's (1962) carbonate classification, many microfacies were recognized and construct depositional model for the Mulussa Formation.Three lithofacies are recognized according to field description and microscopic examination. These lithofacies are:

4.1. Dolomite Lithofacies:

4.1.1. Dolomitized Lime Mudstone Microfacies:

4.1.1.1. Dolomitized Homogenous Lime Mudstone with Vanished Evaporites Submicrofacies (VM)

This submicrofacies is common in the studied sequences. It continuously occurs at the lower part of all outcrop sections (except C2) as well as in outcrop sections G2 (Samples No.17, 18) and G1 (Sample No.16). It reaches up to 7.8m thickness. This submicrofacies is pale grey, yellowish grey and yellow, very thin to thin-bedded and very tough. . Petrographically, this microfacies is unlaminated and/or faintly laminated, unfossiliferous and mostly very fine equant euhedral crystals of dolomite groundmass with intercrystal, vuggy and slightly cavernous porosity. This groundmass, with odd samples, includes crystals of gypsum and molds of vanished crystals of gypsum. Many of these molds are filled by coarsely crystalline calcite, as well as calcite nodules. Some of them are partially filled by authigenic pyrite. Also, this submicrofacies contains rare scattered silt-sized quartz grains, as well as patches of organic matter (Plts.1-A, B, C and D). Field description shows burrows, some of them are characterized by presence of ichnofacies such as zoophycus and/or rhizocorrallium as mottled lithological units with calcite nodules which are frequently encountered in this submicrfacies.

Unfossiliferous lime mudstone (fine-grained dolomicrite), sometimes with authigenic evaporite minerals occurs in tidal flats and arid evaporitic coasts (Flugel, 2010). Nasser and AL-Itbi (2013) studied a similar submicrofacies in Gaaraf Oil Field, Mishrif Formation (Cenomanian-Early Turonian) and believed that it is equivalent to SMF 23 according to Standard Microfacies Types of Wilson's (1975) Standard Facies Model. Hussein (1989) believed that such submicrofacies deposited either in shallow intra-shelf basin or moderately deep muddy shelf, while, Tamar-Agha (1993) believed that such submicrofacies can also be indication of supratidal flats.

This submicrofacies has been deposited under quiet water and poor circulation shallow environment as evidenced from the fine-grained nature and absent or very low diversity of fauna with presence of silt and sand-sized quartz grains which is transporting from the land by windstorm i. e. in tidal ponds of supratidal and nearly intertidal subenvironments within arid to semi-arid climate.

4.1.1.2. Dolomitized Bioclastic Lime Mudstone Submicrofacies (BM)

This submicrofacies is of minor occurring in different levels of the studied successions of Mulussa Formation. In the field, this submicrofacies is 0.5 to up 8.0 m thick of whitish grey to pale grey, very tough, thin to thick-bedded with cross-bedding. Petrographically, this submicrofacies is unlaminated and the groundmass is mostly composed of very finely crystalline, sometimes medium, subhedral to euhedral crystals of dolomite. In some thin sections, crystals of dolomite appear cloudy centre and clear rims. Skeletal fragments are mostly crinoids, uniserial foraminifera (probably *Dentalina*), bivalves, dasycladacean algae and probably echinoid. In one sample, one type of fossils is usually present only while two of these are rarely present, too. Diagenitically, biomolds are common in this submicrofacies and all bioclasts and groundmass are entirely dolomitized. Rare, subangular to subrounded silt-sized quartz grains are common in most thin sections probably from windstorms (Plts.1-E and F). Tamar-Agha (1993) showed that such submicrofacies represent deposition at or below wave base in warm shallow subtidal environment (shelf lagoon). Unlaminated, non-burrowed, low-diverse of fauna indicate low energy, poor circulation, therefore this study believed this submicrofacies resembles the non-burrowed lime mudstone RMF 19 according to microfacies types of carbonate ramps (Flugel, 2010) i. e. represent subtidal and/or lagoon environments.

4.1.1.3. Dolomitized Laminated Lime Mudstone Submicrofacies (LM)

This submicrofacies is common to frequent in the studied outcrop sections except A4. It is recorded throughout different levels, precisely continues in middle part of the Mulussa Formation. In the field, this submicrofacies ranges 0.4 to 9.0 m thick, grey to pale grey, mostly very tough, thin to thick-bedded dolomite. Petrographically, this submicrofacies is laminated and mostly composed of fine to very fine subhedral crystals of dolomite without clastic grains except rare silt-sized quartz grains in outcrop sections G2 and G1. In few thin sections, this submicrofacies contains fossils such as crinoids, foraminifera, gastropods and bioclasts as well as biomolds (Plts.2-A and B).

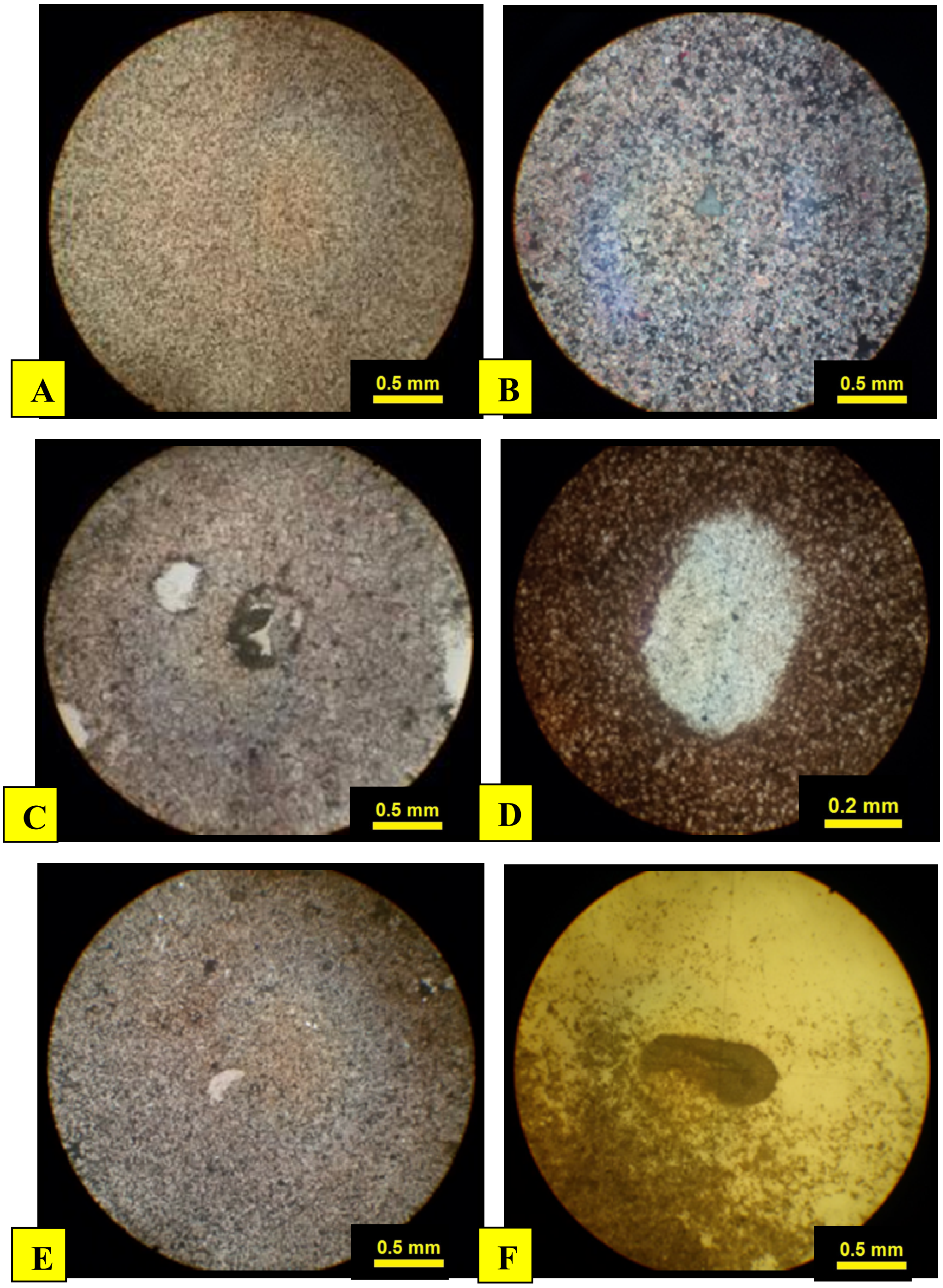
This submicrofacies was interpreted by Tamar-Agha (1986) and Hussein (1989) as a deposition in the intertidal areas of the shelf lagoons i. e. SMF 19 of FZ 8 according to Wilson's (1975) Standard Facies Model. The present study corresponds to above and believed that such microfacies deposited in the intertidal environment.

4.1.1.4. Dolomitized Laminated Lime Mudstone/Wackstone with Fenestral Porosity Submicrofacies (LM/W)

This submicrofacies is not uncommon throughout some different levels of the studied successions. Its thickness ranges 0.5 to 4.0m of whitish grey to pale grey, tough, thin to thick-bedded with cross-bedding. Petrographically, this submicrofacies is laminated with fenestral porosity and the groundmass is finely, sometimes medium, crystalline subhedral to euhedral crystals of dolomite. Crinoids, bivalves and dasycladacean algae are recognized in few thin sections. Silt to sand-sized subangular quartz grains are present in some thin sections of outcrop sections A4, C2 and G2 with variable amounts from slightly to highly affected by silicification (Plts.2-C, D, E and F).

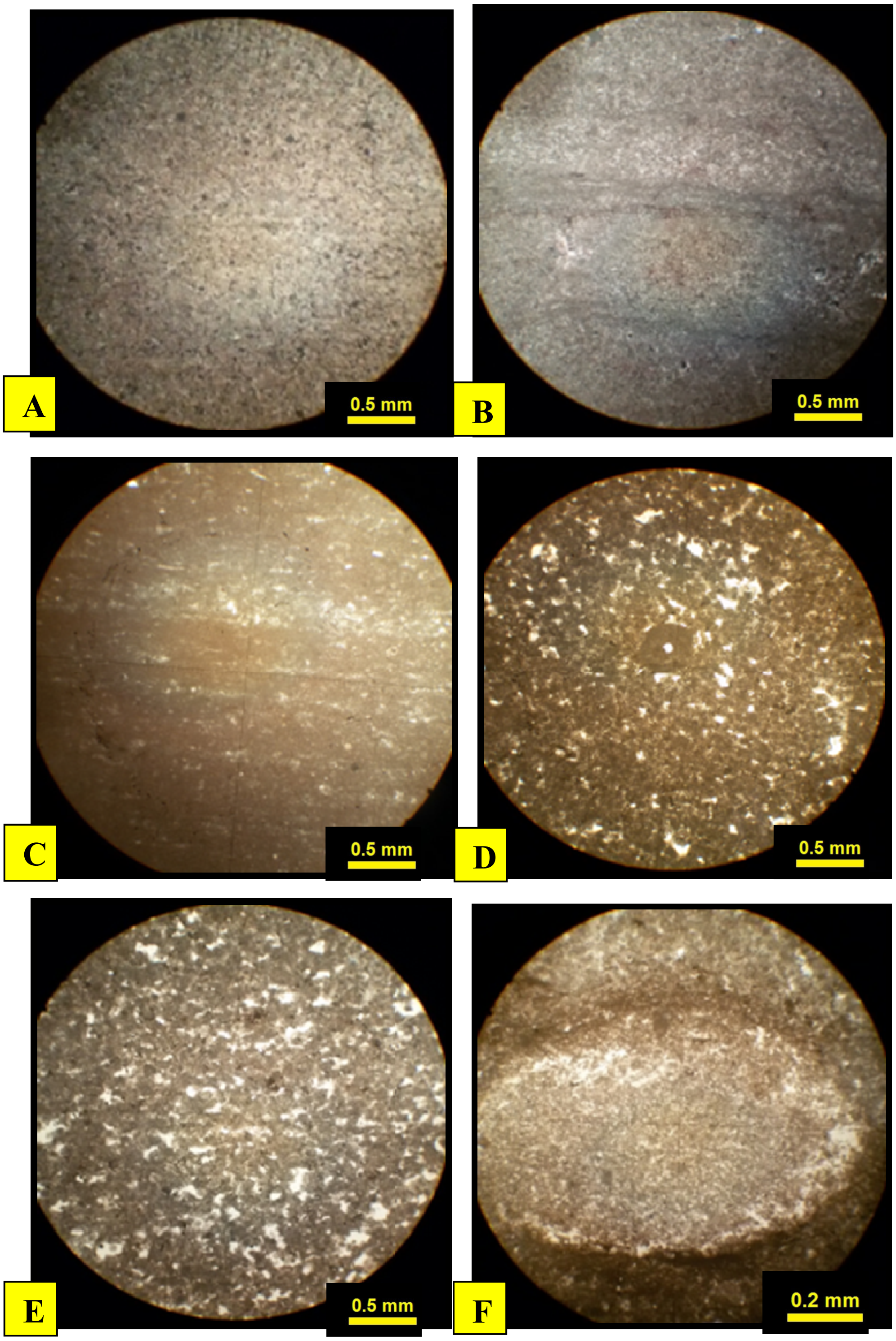
Shinn (1983) considered similar microfacies to represent a tidal flat environment, where trapped air between irregularly–shaped deposits leads to the development of birds'eyes. The fenestrate fabric and very little fauna indicate the tidal flat depositional setting (Till, 1978; Alsharhan and Kendall, 2002; Rasser et al., 2005: Amirshahkarami, 2013). In the present study, it is believed this submicrofacies represents deposition in supratidal intertidal environments and it is mostly equivalent to RMF 23 in peritidal zones.

Plate 1



A and B Dolomitized homogenous lime mudstone groundmass (D1-1, 7) XPL
C and D Crystals and molds of evaporites in dolomitized homogenous lime mudstone (G1-16, G217) PPL, XPL.
E and F Skeletal grains in dolomitized bioclastic Lime Mudstone Submicrofacies (A4-7, G2-16) XPL, PPL.

Plate 2



A and B Dolomitized laminated lime mudstone submicrofacies (G2-1O, D1-19) XPL, XPL.
C, D and E Dolomitized laminated lime mudstone/wackstone with fenestral porosity submicrofacies (D1-13) (C2-20 and 14) PPL.
F A large transverse section shows the bird's eye in later submicrofacies (A4-3) PPL.

4.1.2. Dolomitized Wackstone Microfacies:

4.1.2.1. Dolomitized Laminated Wackstone Submicrofacies (LW)

This submicrofacies is recognized in lower part of outcrop section C2 only between bioclastic wackstone submicrofacies. This submicrofacies is about 2m thick in average, porous, thin to thick-bedded and it is characterized by faint lamination, grey color, very tough and burrowed. Microscopically, it is finely to medium crystalline subhedral to euhedral crystals of dolomite. Skeletal grains are generally not identified except few grains of bivalves, crinoids and echinoids, while the clastic grains are represented by rare or little silt-sized quartz. Some of these quartz grains are scattered and others partially filled burrows (Plt.3-A).

Faint lamination, low to moderate diversity of fossils and presence of bioturbation, all these indicate to such submicrofacies nearly locates at the base wave, relatively quiet water with low circulation. This study believed that such submicrofacies deposited in intertidal to subtidal of inner shelf environments.

4.1.2.2. Dolomitized Bioclastic Wackstone Submicrofacies (BW)

This submicrofacies is present in the studied successions. In the field, it exhibits continuity of traceable in lower part in the west and in middle part in the east of the study area. This submicrofacies is 0.2 m thick in G1 up to 6.0 m thick in C2 of grey, pale grey and yellow color, mostly tough to moderate tough, thin-bedded and cross-bedding as well as slightly calcite nodules. Petrographically, this submicrofacies is mostly composed of fine crystals in the east to medium crystals of dolomite in the west of study area. Echinoderms, bivalves, crinoids, foraminifera (especially uniserial foraminifera *Dentalina*) and algae are present in variable amounts as well as few thin sections include pellets and peloids. In one sample usually one or two of these fossils are present only. Generally, it is difficult to recognize them due to extreme dolomitization. Dissolution (biomolds), cementation (syntaxial), silicification and dedolomitization are common diagenetic processes in this submicrofacies (Plts.3-B, C, D and E). Silt-sized quartz grains are rare and/or little in two thin sections, and usually scattered.

Hussein (1989) believed that such submicrofacies is deposited in relatively deep subtidal of muddy shelf and the presence of skeletal fragments has done by transporting from shallower areas by periodic marine storms. Low-energy environments below wave base with restricted circulation represent proper conditions in subtidal lagoon in protected inner shelf subenvironments. Therefore, this submicrofacies extremely resembles the depositional environment of submicrofacies (MW).

4.1.3. Dolomitized Packstone Microfacies:

4.1.3.1. Dolomitized Peloidal Packstone Submicrofacies (PP)

This submicrofacies is present in sample no. 2 of outcrop G2 (near to the bottom of lower part) only. It is 0.2m thick, yellow, moderate tough, very thin-bedded. Microscopically, it is finely to medium crystalline subhedral to euhedral crystals of dolomite. Such submicrofacies is extremely recognized moderate sorted peloids and pellets that are well-rounded spherical and/or ovoid with intragranular and Intergranular porosity as well as biomolds of them by leaching. Due to diagenesis processes, it is difficult to identified skeletal grains, but there are probably crinoids, foraminifera and bivalves (Plt.3-F).

Peloids are resulted in areas that subject to occasional storms that move grains from active areas of formation to quiet sites of destruction are especially prone to peloid formation. Such sites include back-barrier or back-bar grass flats, lagoons (Scholl and Ulmer Scholl. 2003). On other hand, the fecal pellets are usually deposited in moderate- to low-energy conditions in a basinal or lagoon environment (Land and Moore, 1980). This submicrofacies is deposited in shallow lagoon environment affecting by periodic marine storms.

4.1.3.2. Dolomitized Peloidal Oolitic Packstone Submicrofacies (POP)

This submicrofacies is present in sample no. 6 and no. 4 of outcrop sections D1 and G1 (near to the bottom of lower part) respectively. It is 0.3m thick, yellow, very tough to tough, thin-bedded. Microscopically, it is very finely to finely crystalline dolomite. Skeletal grains are gastropods, bivalves, foraminifera, crinoids and skeletal fragments as well as peloids and oolites, all of those are poorly-sorted, sparse and affected by diagenesis processes; such as dissolution, cementation, micritization and dolomitization (Plt.4-A and B).

Vaziri-Moghaddam and *et al*. (2010) studied such submicrofacies in the Asmari Formation NW of the Zagros basin, Iran and he believed it was deposited in a restricted shelf lagoon. Poor sorting, presence of peloids and oolites in very finely crystalline dolomites groundmass indicates transportation from high to low energy environment. This transportation has done by tidal currents from tidal flats (in sea regressive) to subtidal areas or more deep muddy shelf lagoon areas. Also, it probably deposited from shoals to swales in the proximity (in sea transgressive) i. e. inner ramp settings.

4.1.3.3. Dolomitized Oolitic Packstone/Grainstone Submicrofacies (PG)

This submicrofacies is present in sample no. 8 of outcrop section C2 (lower part). It is about 1.5 m thick, grey, very tough and thin-bedded. Microscopically, it is finely to medium crystalline dolomite matrix. Ooids are the most components of this microfacies as well as peloids with little skeletal grains. Skeletal grains are crinoids, bivalves and unidentified skeletal fragments, which are surrounded by a micrite. Ooids are well-sorted, well-rounded and it mostly composed of simple concentric or superficial ooids and, less frequently, composite ooids. Also, it contains sand and silt-sized quartz. This submicrofacies is mostly homogenous where the components are sand-sized and often showing arrangement in one direction. It shows alternation of grainstone with packstone. It is recognized by complete phreatic cementation and moderate grain leaching (meteoric vadose - phreatic zone). Iron oxides (probably with pyrite) are present and fill some molds partially or entirely (Plt.4-C and D).

Tamar-Agha (1986) interpreted such submicrofacies as a deposition in tidal chunnels from intertidal zone.

Tidal currents reflect high energy, clean calcareous, often rounded, coated and well-sorted sands, occasionally with quartz. Sand grains are ooids, skeletal grains and peloids. Low-diversity fauna adjusted to mobile substrate. The present study concurs with above and believed that this microfacies is deposited in narrow and limited tracks i.e. in tidal channels by tidal currents of intertidal zone.

4.1.4. Dolomitized Algal Boundstone Microfacies (A)

This microfacies is present as bioherms in the studied successions in the upper part of both middle and upper parts of the outcrop section D1. Also, It is in sample no. 6 of outcrop section C2 (upper part), i. e. it is discontinuous beds. In the field, it is 1m to 8m thick, grey to pale grey, very tough, mostly thin-bedded and burrowed, and includes calcite nodules. Petrographically, this microfacies is composed of dense branching shrubs-like algae recognized by tabular and plated structures. These structures and all bioclasts, such as gastropods, bivalves, crinoids and pellets, are mostly micritized representing in walls and pores. On other hand, dissolution highly affected on fabric forming intergranular and intragranular porosity that some of them completely or partially cemented by isopachos, drusy, blocky and syntaxial dolomitized cement. Dedolomitization is present, but unfrequently in some patches. Rare fine silt-sized quartz grains and chert are present in some samples (Plts.4-E and F), (Plts.5-A and B).

The micritized grains and pellets could occur in the intertidal or subtidal zone of a shallow marine environment (Land and Moore, 1980). This microfacies is limited in occurrence, discontinuous, somewhat well diverse of skeletal fragments with rare quartz grains as well as it overlies and/or underlies of laminated lime mudstone microfacies. This microfacies probably represents reef patches back shoals as accumulation of carbonate (bafflestone) probably occurred in the intertidal to subtidal zone of shallow marine platform.

4.2. Marl Lithofacies (ML)

This lithofacies can also be referred to as dolomitic marl and marly dolostone. It usually occurs below the dolostone beds with an upper gradual contact and lower sharp flat contact. It consists of aphanocrystalline or very finely crystalline dolomite as well as variable percentage of clay minerals. This lithofacies frequently occurs in the lower and middle parts of the Mulussa Formation. It is better identified on weathered surface as the grain boundaries become clear. They are usually friable to medium tough. However, in the field such lithofacies showed many trace fossils such as rhizocorallium (and possibly zoophycos).

Al-Wosabi and Al-Aydrus (2011) recognized such lithofacies in Tertiary carbonate sequence (Dammam Formation) and believed that it is deposited in a quiet closed**,** low energy, protected low intertidal flat reward of a shallow marine lagoon within the facies zone. This study concurs with interpretation of Tamar-agha in 1986 that this lithofacies represents deposition in the relatively deep subtidal lagoon. This assumption is supported by presence of trace fossil and sediment feeder known as rhizocorallium.

4.3. Dolomitic Sandstone Lithofacies:

4.3.1. Calcarenite Microfacies (C)

This submicrofacies is present in samples no.5 and 12 of outcrop section G1 (lower part and bottom of middle part of the formation). It is 1.3m average of thickness, yellow, very tough to tough, fine granularity and medium tough with a variety of current sedimentary structures such as lenticular bedding wavy bedding, flaser bedding and cross lamination. Microscopically, it is very finely to finely crystalline dolomite. Skeletal grains are crinoids, bivalves, foraminifera, and altered skeletal fragments, as well as peloids and oolites. Most of those allochems (more than 50 %) are sand-sized, enveloped by micritized, coated and subrounded grains, but on other hand, many of them are leached forming biomolds. Subangular to subrounded little silty quartzose grains are present (Plt.5-C).

This submicrofacies is equivalent to calcarenite which is proposed at first time in 1903 by Grabau. Calcarenites have accumulated either as coastal sand dunes (eolianites), beaches, offshore bars and shoals, turbidites, or other depositional settings i. e. high energy (Scholle and Moore, 1983; Flugel, 2010). The present study believed that this microfacies is deposited in tidal flats and probably beaches.

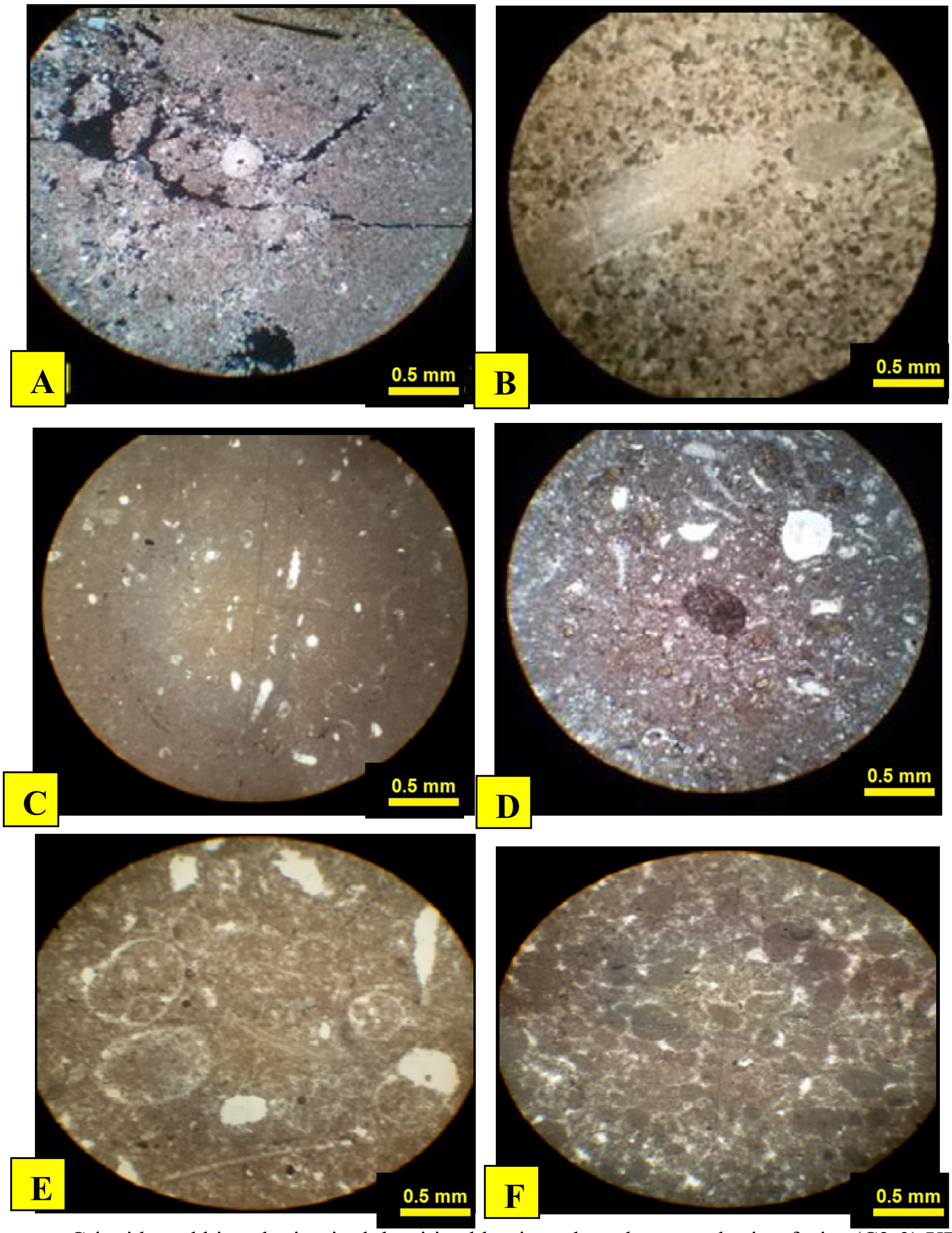
4.3.2. Basal Conglomerates of Sandstone Microfacies (B)

This facies is restricted to the lower part of the Mulussa Formation (basal beds association). Its thickness ranges between 0.3-2.5m being thicker in the eastern area of study area. It is yellow, medium tough to tough, massive and burrowed (especially zoophycus), with cross bedding and channeling is frequent too. In the field, this microfacies is recognized by presence of gravel and sand as admixture with carbonate. This microfacies usually underlays the dolomitized laminated lime mudstone and/or homogenous lime mudstone submicrofacies. Microscopically, it is usually composed of subangular to subrounded, well sorted sand to silt-sized quartz grains, and very rare other minerals grains, with dolomite cement. Dolomite cement forms up to 20% and composes of finely to very finely crystalline crystals. The texture of this facies is mostly as beds of silt or sand grains alternating with dolomite cement or mixed (Plts.5-E, F).

Sediments of terrestrial-marine settings probably occur as reworked grains in restricted environments e.g.

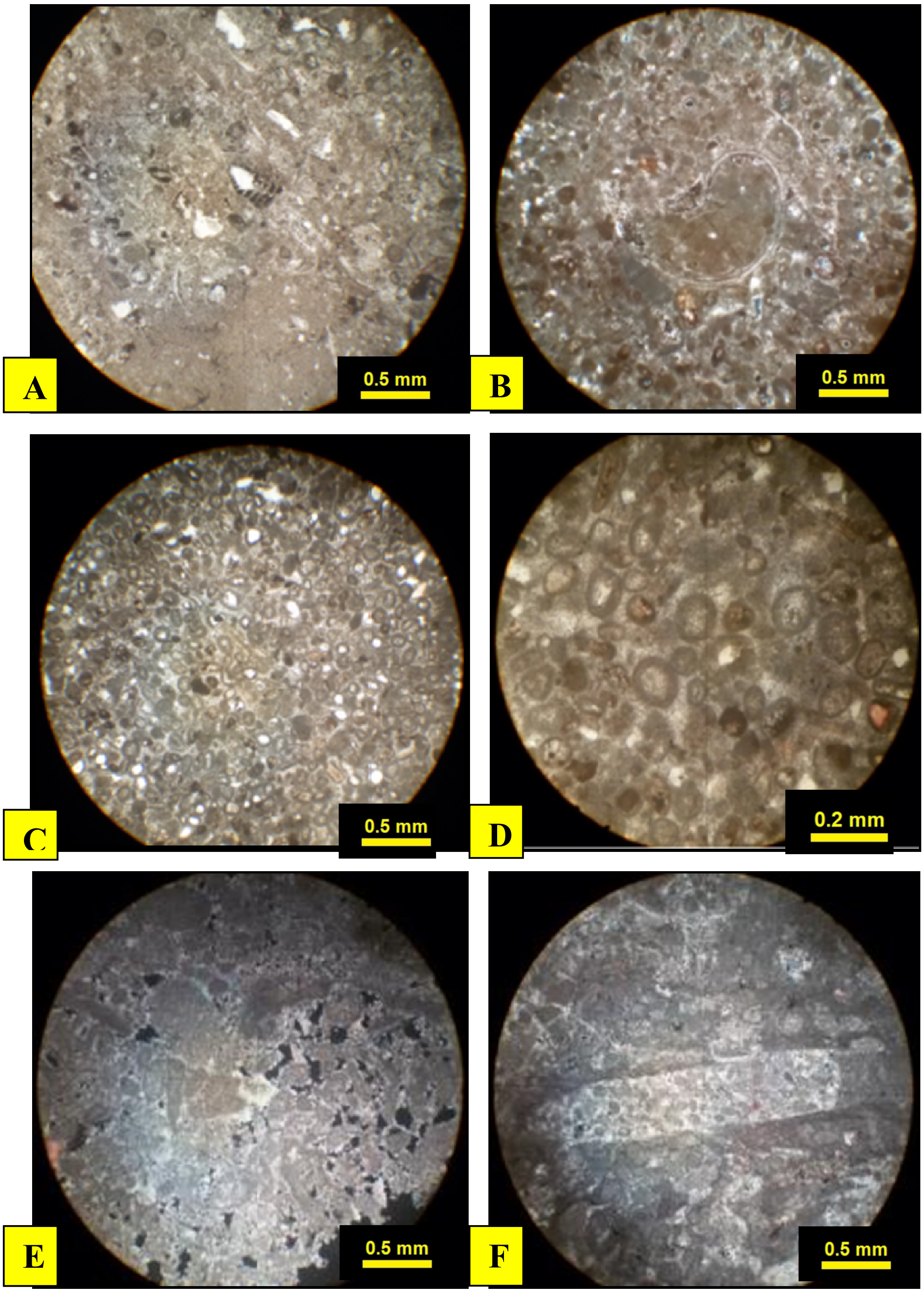
coastal ponds (Flugel, 2010). Tamar-Agha (1993) believed that this microfacies represents deposition in several different subenvironments such as tidal channels and coastal dunes. It is believed that the presence of gravel as a result to reworked sandstone and ferruginous extraclasts from the terrestrial deposits of the underlying Ga'ara Formation. It is occurred during the initial transgression of the Mulussa's sea. These deposits occurred between terrestrial grains and carbonate sediments alternatively in shallow marine environment. Therefore, the present study corresponds with Tamar-Agha assumption that this microfacies probably deposits in tidal channels and coastal dunes.

Plate 3



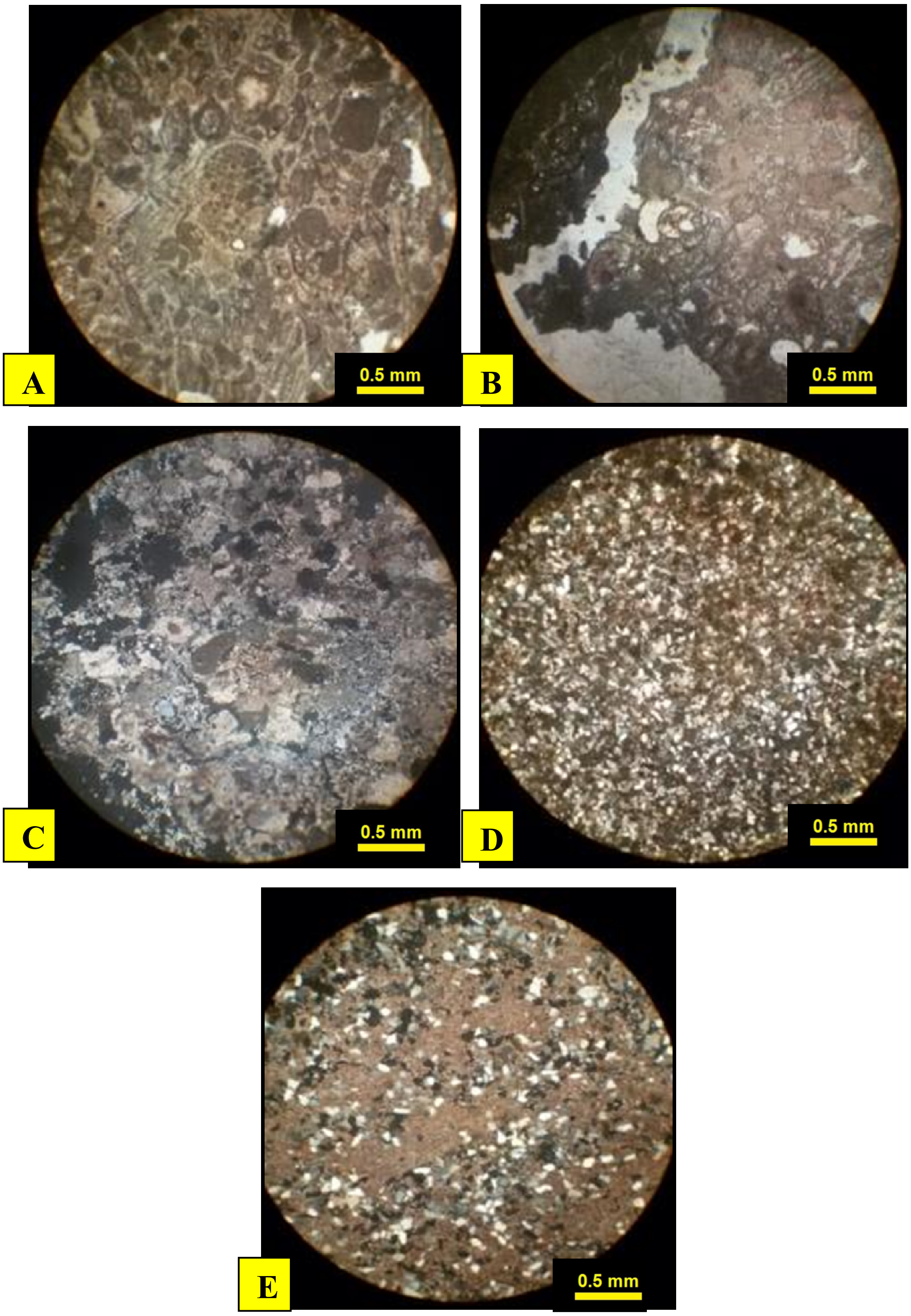
(A) Crinoids and bioturbation in dolomitized laminated wackstone submicrofacies (C2-3) XPL.
(B) A transverse view to echinoids in dolomitized bioclastic wackstone submicrofacies (C2-5) XPL.
(C) Many biomolds of uniserial foraminifera in dolomitized bioclastic wackstone submicrofacies (G1-14) PPL.
(D) and (E) Many biomolds of fossils in dolomitized bioclastic wackstone submicrofacies (C2-4 and C2-13) PPL.
F Dolomitized peloidal packstone submicrofacies (G2-2) PPL.

Plate 4



A and B Dolomitized peloidal oolitic packstone submicrofacies(D1-6, G1-4) PPL.
C and D Dolomitized oolitic peloidal/ grainstone submicrofacies(C2-8) PPL.
E and F Dolomitized algal boundstone microfacies(D1-20 and 20b) XPL.

Plate 5



A and B Dolomitized algal bounstone microfacies as respectively (D1-20, 20b) PPL
C Calcarenite microfacies (G1-12) XPL
D and E Basal conglomerat of sandstone microfacies (G2-7 and 4) XPL

Table (1) shows details of facies analysis.

Facies Code	Facies	Depositional Environments				Facies Subenvironments
		Land	Supratidal	Intertidal	Subtidal-Lagoon	
B	Basal Conglomerates of Sandstone Microfacies	■	■	■		Coastal dunes and tidal channels
VM	Dolomitized Homogenous Lime Mudstone with Vanished Evaporite Submicrofacies		■	■		tidal ponds of supratidal and shallowing intertidal
LM/W	Dolomitized Laminated Lime Mudstone/Wackstone with Fenestral Porosity Submicrofacies		■	■		Supratidal-Intertidal
C	Calcarenite Microfacies		■	■		Tidal flats and probably beaches
PG	Dolomitized Oolitic Packstone/ Grainstone Submicrofacies			■		Tidal Chunnels
LM	Dolomitized Laminated Lime Mudstone Submicrofacies			■		Intertidal
LW	Dolomitized Laminated Wackstone Submicrofacies			■	■	Intertidal to Subtidal of Inner Shelf
A	Dolomitized Algal Boundstone Microfacies			■	■	Intertidal to Subtidal of Shallow shelf
BM	Dolomitized Bioclastic Lime Mudstone Submicrofacies				■	Subtidal or/and Lagoon
BW	Dolomitized Bioclastic Wackstone Submicrofacies				■	Subtidal Lagoon in Protected Inner Shelf
PP	Dolomitized Peloidal Packstone Submicrofacies				■	Shallow Lagoon affecting by periodic marine storms
POP	Dolomitized Peloidal Oolitic Packstone Submicrofacies				■	Subtidal areas or more deep muddy Shelf Lagoon areas.
ML	Marl Lithofacies				■	Deep Subtidal- Lagoon

5. Depositional Environment

High and low tide, wave base and storm wave base are used as basic boundaries in the classification of the major shallow-marine environments (Flugel, 2010). These criteria, as well as salinity, agitation and clastic grains input have contributed to determine the depositional environments of the Mulussa Formation. By field description and microfacies analysis of the formation compared with modern and ancient tidal deposits (Flugel, 1982 and 1910). In the present study, it is believed that the depositional environment of the Mulussa Formation represents shallow inner shelf extending from the coast to peritidal and lagoon.

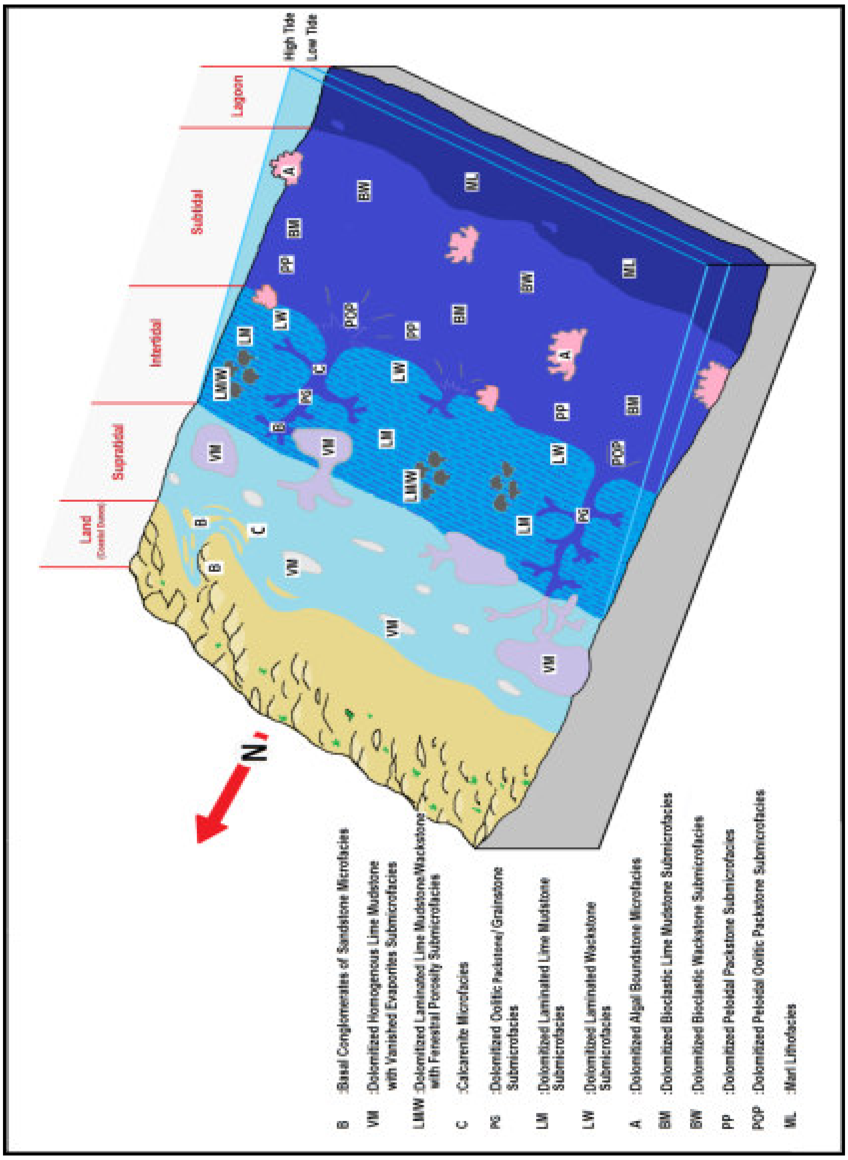
The start of deposition of the Mulussa Formation generally comprises the basal beds of the lower part. It is characterized by high admixtures of clay, sand and gravel (occasionally conglomerates). The gravel is usually reworked sandstone and ferruginous extraclasts from the terrestrial deposits of Ga'ara Formation during the transgression of Mulussa's sea (Tamar-Agha, 1986 and 1993). This microfacies represents these deposits. It consists of sequence between terrestrial grains (from land) and carbonate by periodic high tides of marine storms within shallow inner shelf. Also, it is characterized by cross-bedding, lenticular bedding, wavy bedding, flaser bedding and cross lamination.

Eight microfacies and submicrofacies show many significant sedimentary features that reflect particular environmental conditions. These environmental conditions are represented by variable energy, shallow depth and poor circulation as evidenced from the fine-grained nature of their sediments and the type. Also, very low diversity of the fauna with presence of silt and sand-sized quartz grains, crystals of gypsum and some of them are partially filled molds by authigenic pyrite. Further the presence of stromatolites, lamination with fenestral porosity and bird's eye. Together facies associations relatively represents wide zone in the study area as sabkhas or salt ponds and tidal flats i. e. supratidal and intertidal environments.

The semi-restricted inner shelf is the next depositional environments. It represents a wide zone in the study area and it is characterized by yellow-pale grey to grey color, tough, cross-bedding and mostly thin-bedded and occasionally thick. Some of microfacies are once laminated (faint) indicates proximity of wave base of low tide and/or within range of fair tide, and it is unlaminated in the second time indicating to below the wave base (lagoon). Some of microfacies and submicrofacies are characterized by well diversity of fauna as well as bioturbation especially rhizocorallium and zoophycus with nearly absence of quartz grains (distant from the coast) i. e. good circulation and low to moderate energy. Also, these depositional environments include microfacies characterized by discontinuous, limited location, branching structure with well diverse of skeletal fragments (as crinoids, gastropods and echinoderms) and rarely quartz grains representing reef patches. On other hand, Marl lithofacies represent the deep muddy lagoon sub-environment. It repeats in several beds alternatively with dolostone beds in the top of upper part and most of the lower part.

Comparing those arrangements of facies associations with modern and ancient environments, the deposition took place in deep to shallow shelf, tidal channels, tidal flats, tidal ponds and coast to near coast. All these sub-environments represent shallow inner shelf environments in arid to semi-arid climate i. e. peritidal, lagoon environments with some continental influence in some places (Fig.2).

Figure 2: The depositional model of Mulussa Formation showing the distribution of lithofacies and microfacies within their sub-environments.



6. Conclusions

Three main lithofacies are recognized in this study (using polarizing microscope) namely: dolomite, marl and dolomitic sandstone. By facies analysis, it can be deduced that the deposition took place in coastal dunes, tidal ponds, tidal flats, tidal channels and lagoon. It generally represents deposition in inner shelf environments with hot, arid to semi-arid climate as well as some continental influence.

Acknowledgments
The authors wish to thank the Iraqi Geological Survey for all the information, scientific and technical documents that helped to complete this study.

References:

1. Alsharhan, A.S. and Kendall, C. G. St. C., 2002, Holocene carbonates/ evaporites of Abu Dhabi, and their Jurassic ancient analogs. In: Barth, H.J., Bore, B.B. (Eds.), Sabkha Ecosystems. Kluwer Academic Publisher, Netherlands, pp. 187-202.
2. Alwosabi, M. and Alaydrus, A., 2011, Microfacies Analysis and Depositional Environments of Tertiary Carbonate Sequences in Socotra Island, Yemen, Geological Bulletin of Turkey, Vol. 54, No.1-2, pp. 57-80.
2. Amirshahkarami, M., 2013, Microfacies correlation analysis of the Oligocene-Miocene Asmari Formation, in the central part of the Rag-e-Safid anticlinal oil field, Zagros Basin, south-west Iran. Turkish Journal of Earth Science 22, pp.204-219.
3. Bellen, R. C. Van, Dunnington, H. V., Wetzel, R. and Morton, D., 1959. Lexique Stratigraphique Internal Asie. Iraq. Intern. Geol. Conger. Comm. Stratigr, 3, Fasc. lOa, 333p.
4. Buday, T. and Hak, J., 1980. Report on the geological survey of the western part of the western desert, Iraq. Polytechna, Prague, Manuscript Report. No. 1000, GEOSURV, Baghdad, 265p.
5. Buday, T. and Jassim, S. Z., 1987. The Regional Geology of Iraq, Vol.2: Tectonism, Magmatism and Metamorphism. Publication of GEOSURV, Baghdad, 352p.
6. Dubertret, B., 1966, Liban, Syrie et bordure des pays voisins. Notes and Memoires Meyen Orient, Vol. VIII, Paris.
7. Dunham, R.J., 1962, Classification of carbonate rocks according to depositional texture: American Association of Petroleum Geologists Memoir, 1, 108-121.
8. Flügel, E., 1982, Microfacies analysis of limestones: Berlin - Heidelberg, New York, Springer, 633pp.
9. Flugel, E., 2010, Microfacies of Carbonate Rocks, 2nd Ed. Springer Verlag Berlin, Germany. 976p.
10. Grabau, A.W., 1903, Paleozoic coral reefs. Geological Society of America Bulletin. vol. 14, pp. 337-352.
11. Hussein, S. A., 1989, Facies and Sedimentary Environments of the Mulussa and Zorhauran Formations (Upper Triassic) in Selected Boreholes Western Desert-Iraq: Unpublished M.Sc. Thesis, University of Mosul, Iraq. (*In Arabic*), 107p.
12. Jassim, S. Z., & Goff,J. C., 2006.Geology of Iraq.Brno,Czech Republic:Dolin, Prague and Moravian Museum.341p.
13. Land L. S. and Moore C. H., 1980, Lithification, micritization and syndepositional diagenesis of biolithites on the Jamaican island slope. J. Sed. Petrol. 50, pp. 357-70.
14. Nasser M. E., M. and AL-Itbi N. T., 2013, The Microfacies Analysis of Mishrif Formation in Gharraf Oil Field, Iraqi Journal of Science, Vol. 54, Supplement No.4, pp.1129-1135.
15. Rasser, M.W., Scheibner, C. and Mutti, M., 2005, A paleoenvironmental standard section for Early Ilerdian tropical carbonate factories (Corbieres, France; Pyrenees, Spain). Facies 51, pp. 217-232.
16. Scholle, P. A., Debou, D. G. and Moore, C. H., 1983. Carbonate Deposition Environments, AAPG. Memoir 33. Okla. P.708.
17. Scholle, P. A. and D. S. Ulmer-Scholle, 2003, A Color Guide to the Petrography of Carbonate Rocks: Grains, Textures, Porosity, and Diagenesis: AAPG Memoir 77.
18. Shinn, E., 1983, Tidal flats, *in* Scholle, P.A., Bebout, D. G., Moore, C.H. (eds.), Carbonate Depositional Environments: American Association of Petroleum Geologists Memoir, Vol. 33, pp.171–210
19. Tamar-Agha, M Y., 1986, Detailed Geological Mapping of the Southern Rim of Ga'ara Depression. Unpublished Report, GEOSURV Library No. 1779, Baghdad, 195p.
20. Tamar-Agha, M Y., 1993, Exploration and Prospecting in the Ga'ara Depression 1986-1990. Part 1, General Geology, Unpublished Report GEOSURV Library, No. 1899, Baghdad, 183p.
21. Till, R., 1978, Arid Shorelines and Evaporites. In H. G. Reading (ed.), Sedimentary Environments and Facies, Blackwell Scientific Publications, pp. 178-206.
22. Vaziri-Moghaddam, H., Seyrafian, A., Taheri, A., Motiei, H., 2010. OligoceneeMiocene ramp system (Asmari Formation) in the NW of the Zagros basin, Iran: microfacies, paleoenvironmental and depositional sequence. Revista Mexicana de Ciencias Geológicas 27 (1), pp. 56-71.
23. Wilson, J.L., 1975. Carbonate Facies in Geological History. Springer, Berline Heidelberg, New York, p. 471.