SEDIMENTOLOGY AND LITHOSTRATIGRAPHY OF QAMCHUQA FORMATION FROM KURDISTAN REGION, NE−IRAQ

A THESIS

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بسم الله الرحمن الرحيم

خَلَقَ اللَّهُ السَّمَاوَاتِ وَالْأَرْضَ بِالْحَقِّ إِنَّ فِي ذَلِكَ لَآيَةً لِّلْمُؤْمِنِينَ {44}

العنكبوت

Allah created the heavens and the earth with truth; most surely there is a sign in this for the believers.

Supervisor Certification

I certify that this thesis has been prepared under my supervision in the Department of Geology of the University of Sulaimani. In fulfillment of the requirement for the degree of Doctor of philosophy in Geology.

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Dedicated:

To
My Wife
My Daughter
And
My Two Sons

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Abstract

The studied area located at the Kurdistan region in the Sulaimanyia and Arbil Governorates, northeastern Iraq, near the border with Iran and directly to the southwest of the main Zagros Thrust Fault. In this area, the Qamchuqa Formation (Aptian−Cenomanian) is exposed in the High Folded and Imbricates Zones of northeastern Iraq. The formation has the thickness about 600m and constitutes the main unit of Arabian Platform during Early Cretaceous. It generally composed, in the study area, of alternation of thick to massive beds of limestones dolostones. The limestone beds are mainly located at the lower part of the formation, which consist mostly of light grey to milky fine grain limestones with occasional occurrence of highly fossiliferous and stromatolitic layers. The dolostones are mainly located at the upper part of the formation. Four sections are sampled and correlated, which are: Yakhsamar, Halladin, in addition to Qamchuqa Gorge, and Kewa Rash Mountain sections.

It was inferred that in all sections, the upper contacts, with Kometan or Dokan Formations are conformable and neither conglomerate nor erosional surfaces or other indicators of unconformities are observed. Therefore, the previously unconformable contacts are amended to gradational boundary with more or less thick transitional zones. The formation is underlain conformably by Sarmord Formation.

The Qamchuqa Formation is divided into eight units, based on the lithology and fossils content. The prevailing facies are lime mudstones, wackstones and dolostone. The new facies that was found in the formation were Ooid packstones to grainstones, stromatolites and rudists bearing facies, oncoids–bioclasts facies, branching coral bearing facies. Among these facies, lime mudstone and lime wackestone are deposited in low energy while the high-energy facies, represent by a packstone and grainstone of ooids and pelloids.

For the first time the microbialites are described in Iraq which represent by several types of laminated (stromatolite) and clotted (thrombolite), which

deposited by microorganism (microbes) such as cynobacteria and algae in addition to fungi. Eight types of the stromatolites are distinguished: stratiform, wavy, vertical, flat, convolute, blistered , oncoidal and flat pebbles stromatolites.

The facies analysis showed that the Qamchuqa Formation was mainly deposited in a barrier reef with the possibility of the existence of atoll type of reefal environment. In this environment, the mudstone, miliolid–bioclast wackstones and planar stromatolite are deposited in the lagoon while the branched coral, oncoid, wavy and vertical stromatolites, thrombolite and bacinela are deposited in the reef core. The coquina (bioclast packstone), Radiolid rudists and orbitulina bearing lithofaices are deposited in the fore reef. The ooids and some bioclast packstone and dolostones are deposited in the sand flats that is located directly at the backreef. The planktonic Formainifera bearing mudstone are deposited in the forereef–slope transition. Generally the environments of the formation characterized by relatively low energy, which was of normal marine water during Aptian while toward Cenomanian, the salinity and temperature were increased which reflected by deposition dolomite or high mg- calcite.

The burrows are very common in the lower part in all sections. In the field and thin section studies, it appears that the bioturbation has enhanced selective dolomitization in the limestone units while pervasive is common in dolostone units. The most suitable paleogeographical setting, for Qamchuqa Formation, is a wide carbonate platform, which occasionally transformed to isolate platform due to surrounding by deep water from nearly all sides. The platform includes several subenvironments such as barrier reefs (with possible patchy reefs) lagoon, forereef, forereef–slope transition which represented by Balambo Formation. These environments repeated several times through the whole sequence of the formation, which attributed to cyclic sea level change due to eustasy and forebulge subsidences and uplifts.

Tectonic and depositional history, show that the deposition of the formation had occurred on the Arabian platform (on passive Arabian Margin) during collision (converging) of Arabian and Iranian plates. During Aptian, in the trench huge pile of sediments (as accretionary prism of the radiolarite and ophiolite) accumulated by deposition and scraping off the ocean floor. Due to excessive load of this accumulation and horizontal stress, the Arabian plate is deflected (flexed) elastically to form a broad submerged paleohigh high (forebulge or Arabian platform) at the studied area and similar areas of same elongation in the Zagros Belt. The uplift and relaxation with the effect of eustatic sea level had changed the facies and environments of the platform are repeated several times during Aptian−Cenomanian. After the exhausting of the oceanic crust and southwest advance of Iranian plate in the Turonian, the studied area (the previous platform) is subsided (drowned) and Kometan formation had deposited.

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CHAPTER ONE

INTRODUCTION

1.1. Preface

Bellen et al, (1959) mentioned that the Qamchuqa Formation was first described by Wetzel 1950 in unpublished report and Henson 1954 referred to it as Qamchuqa limestone. It consists of about 650 meters of alternation of well-bedded, grey colored, dolomite and light grey limestone or dolomitic limestone. He mentioned that in the very early reports of the Iraqi Petroleum Company, the Qamchuqa Formation was called the Judea Formation due to overlook correlation with the Judea Formation of Cenomanian age, in Lebanon and Palestine. The name of Qamchuqa Formation is derived from the name of Qamchuqa village, which is located directly to the southwest of the type section, about 45 Km northwest of Sulaimani city in the High Folded Zone (Figs.1.1 and 1.2).

According to Furst (1970 in Buday, 1980), the Upper and the Lower Qamchuqa Formations have been renamed Maudud and Shuaiba Formations, respectively in the middle and southern part of Iraq. The same author mentioned that, in Iran, the correlative formations are Dariyan (Aptian) and the Albian part of Sarvak Formation of the East Zagros Mountains.

1.2. Location and Geomorphology of the Study Area

The studied area is located within Sulaimani and Arbil governorates in northeastern Iraq, bounded by latitude (35^{0} 51^{-} $12^{=}$ and 36^{0} 31^{-} $51^{=}$) N and longitude (44^{0} 45^{-} $49^{=}$ and 45^{0} 12^{-} $25^{=}$) E. The studied area constitutes part of Zagros mountain belt, where the high mountain chains are in northwest–southeast direction. The outcrops of the formation are mostly along the summit and sides of many mountains such as Piramagroon, Sara, Asingaran, Zhelwan, Kosrat, Safeen, Kewa Rash, Karokh and Makok (Fig.1.1). In the same direction and between these mountains there are narrow or wide subsequent (strike) valleys, most of which coincide with synclines, while few of them are developed along the axes of anticlines by erosion of their core. The main erosional valleys are Ranyia, Sarmord, Kani Maran, Marga and Zewe valleys (Fig1.1). Moreover, the mountain chains are dissected by many large or small consequent valleys, the largest ones are those in which the Lesser Zab and Greater Zab Rivers flow. The area contains three large plains(: Bitueen, Marga and Peshdar) which are located to the west, east and north of Dokan Lake.

1.3. Geological and Structural Setting

The studied area is located in the Western Zagros Fold-Thrust Belt, directly to the southwest of the main Zagros Suture Zone (Buday and Jassim 1987; Mc Quarrie 2004 and Jassim and Goff, (2006). Structurally, the area is located within the High Folded and Imbricated Zones (Buday, 1980 , Buday Jassim, 1987 and Al-Kadhimi et al.,1996) Fig. (1.3). The area mainly consists of sub parallel high amplitude anticlines and synclines, many of the anticlines are asymmetrical with the southwestern limbs steeper than the northeastern ones.

The strata suffered from intense deformations especially those that are located within the axis of synclines due to imposed stress of Iranian Plate. The stresses generated many thrust faults and transverse in the area. Most of the gorges are developed along transversal normal and strike slip faults, such as Qamchuqa, Smaqully, and Sargalu, Ranyia and Tabeen. Due to this stress, the northern boundary of the area is characterized by obscured anticlines and synclines. These phenomena are very clear in the Imbricated Zone, especially those located in the transition Zone between Qamchuqa and Balambo Formations, along the line that connects between Sulaimani city and Ranyia town. The main depression (plain) in the area is the area below and around the Dokan reservoir, which most possibly represent a graben.

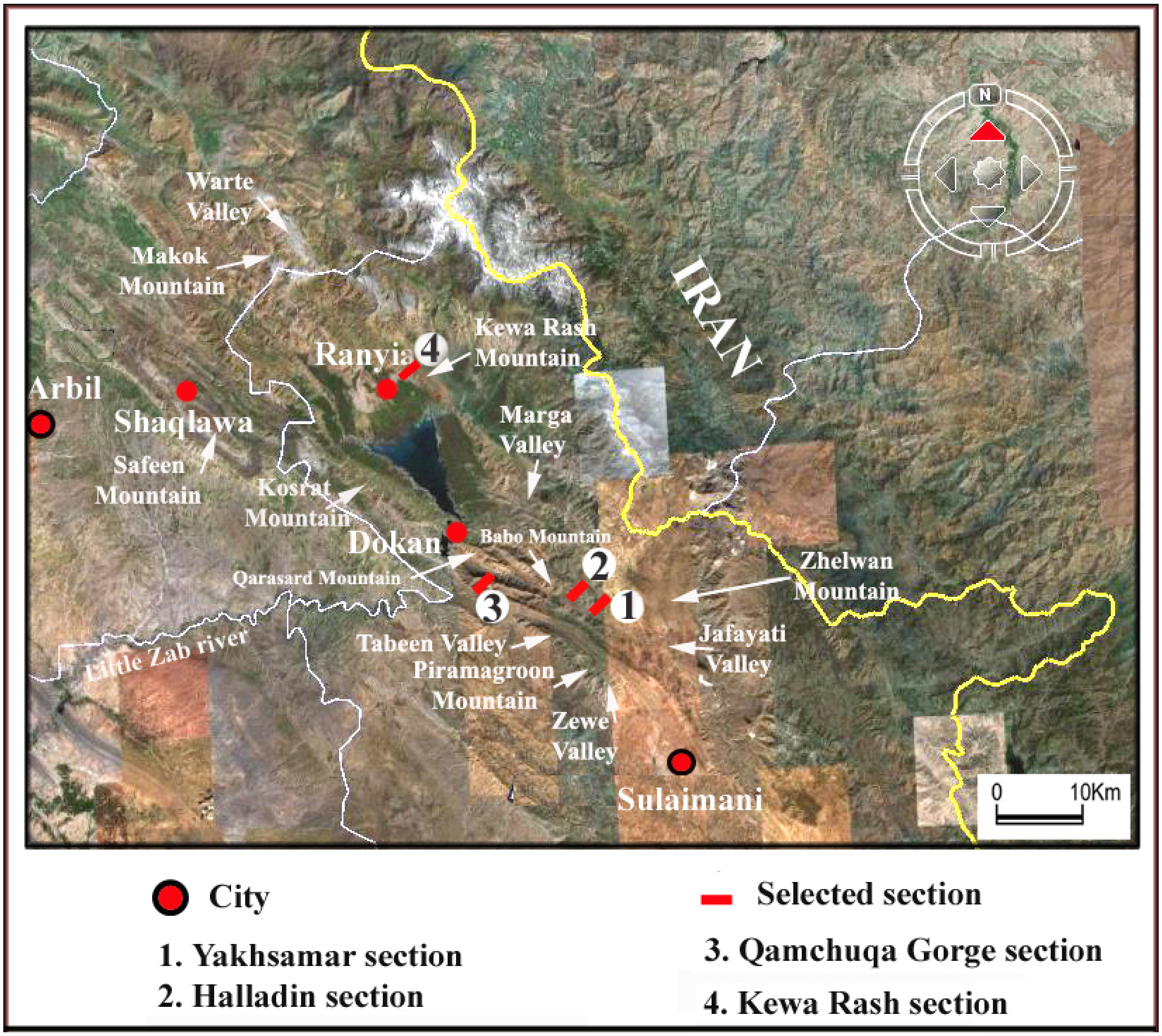

Fig. (1.1) Satellite image, from Google Earth, 2007, showing the selected sections in the studied area.

However, nowadays, apparently, this graben resembles a large syncline in which, the dissected (by normal faults) anticlines are so modified that appears as plunging anticlines beneath the plain. In these areas, the anticlines have been stacked together as very thick packages, which are mostly overturned toward southwest. Most of the outcrops of the Qamchuqa Formation are located in the High Folded Zone such as those exposed along the of the Safeen, Kosrat, Daban and Sara anticlines while those of Kewa Rash, Karokh, Makok, Asingaran and Zhelwan are located in the Imbricated Zone (Figs.1.1 and 1. 2).

In all studied sections, the Qamchuqa Formation is underlained by Sarmord Formation (or it's equivalent). Kometan Formation are overlying the Qamchuqa Formation in the Sulaimani and Arbil Governorates, respectively (Fig. 1.4). The Tanjero Formation pinches out toward the northwest of the studied area (to the west of the Dokan Dam) and most probably changes to Shiranish Formation(Figs.1.2 and 1.4).

1.4. Studied sections

Four sections (Yakhsamar, Halladin, Qamchuqa Gorge and Kewa Rash) are chosen and sampled around Sulaimani and Arbil Governorates, for detailed study. In addition to the four studied sections, many other locality are visited for study the Qamchuqa Formation like : Peramagroon mountain, Zewe valley, Tabeen vally, Sargalu village, Qarasard mountain, Dokan dam, Smaqully valley, Safeen mountain, Kosrat mountain, Shawre valley, Makok mountain, Marga valley, Bardashan village, Zhelwan mountain, Asigaran mountain(Fig.1.1 and 1.2)

In the study area 350 samples are collected in all studied sections with visited localities. The selection of these sections is based on the maximum obtainable information (facies change) and degree of the differences with that of the type section of Qamchuqa Formation. In the assortment, the distribution of the sections is considered so that they include the entire studied area. However, the process of the selection has suffered from three constraints. The first is that the formation, in many places, form vertical erosional and fault scarp, which cannot be sampled and even inspected. The second is that, due to high thickness, the lower boundary and even thick intervals of the lower part is not exposed some time in the studied area. The third is that the formation is affected by many thrust and reverse faults, especially in the Imbricated Zone, which most possibly have caused repetition of some intervals.

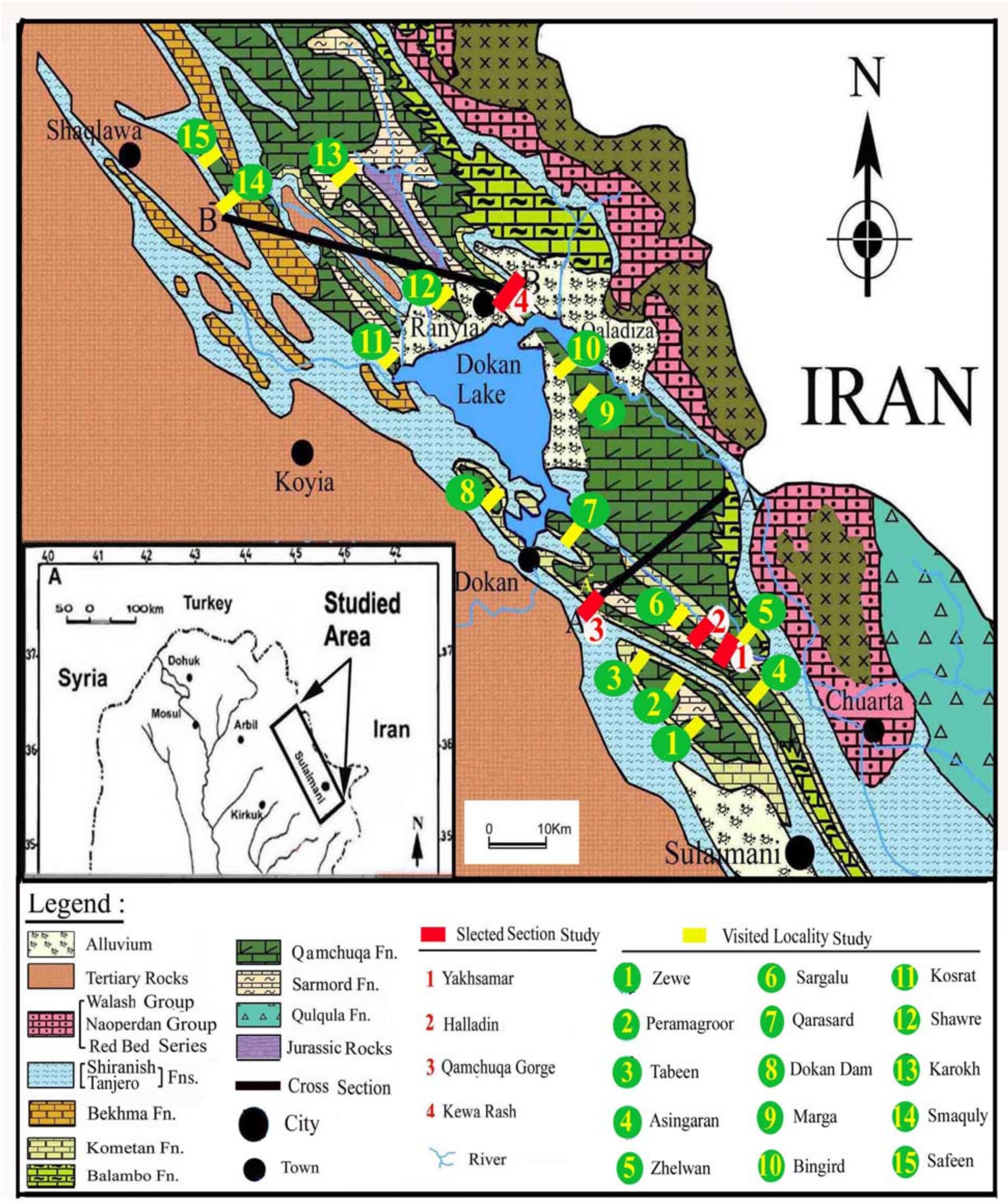

Fig.(1-2): Geological map of northern Iraq (from Sissakian, 2000), showing location of the studied sections and visited locality.

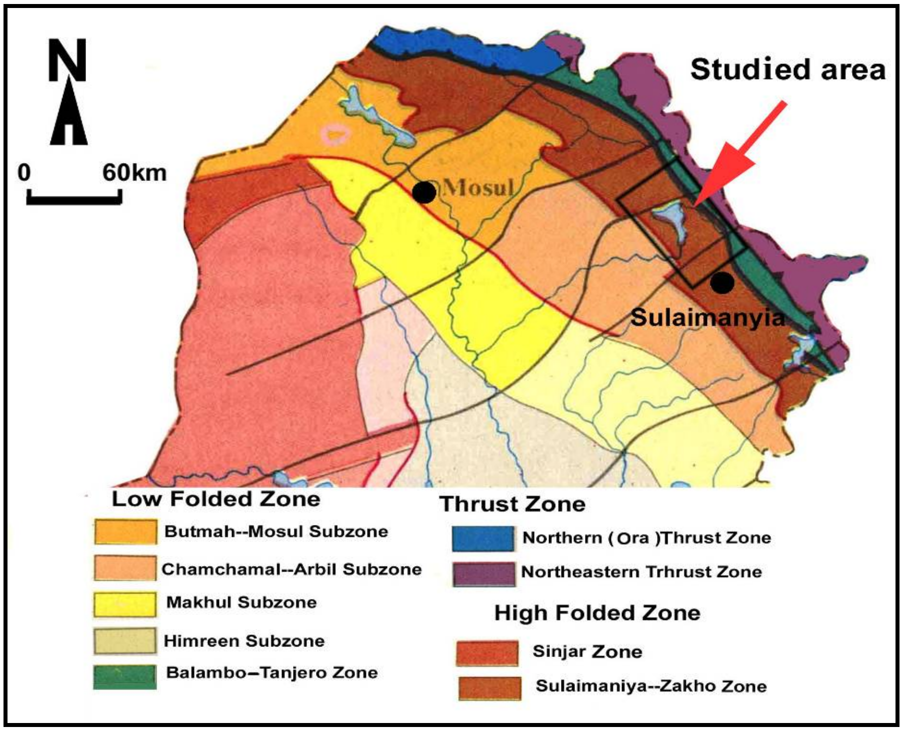

Fig. (1-3) Tectonic map of the northern Iraq (Simplified from Al-Kadhimi et al.,1996).

The formation is inspected accurately in all available continuous and isolated outcrops. Most of the outcrops, when topography has permitted, are stepped on continuously along the dip and strike to see vertical and lateral facies changes. In opposite to other formations, the facies change is so rapid, in some places, that when stepping on, several different facies could be recognized .The sampled sections (Fig.1.1 and 1.2) are :

1-Yakhsamar Section

Located at the intersection of latitude and longitude 35^{0} 51^{-} $12^{=}$ N, 45^{0} 12^{-} $25^{=}$ E directly to the northeast of Yakhsamar Village in Jafayati valley about 25 km to the east of Dokan Town .

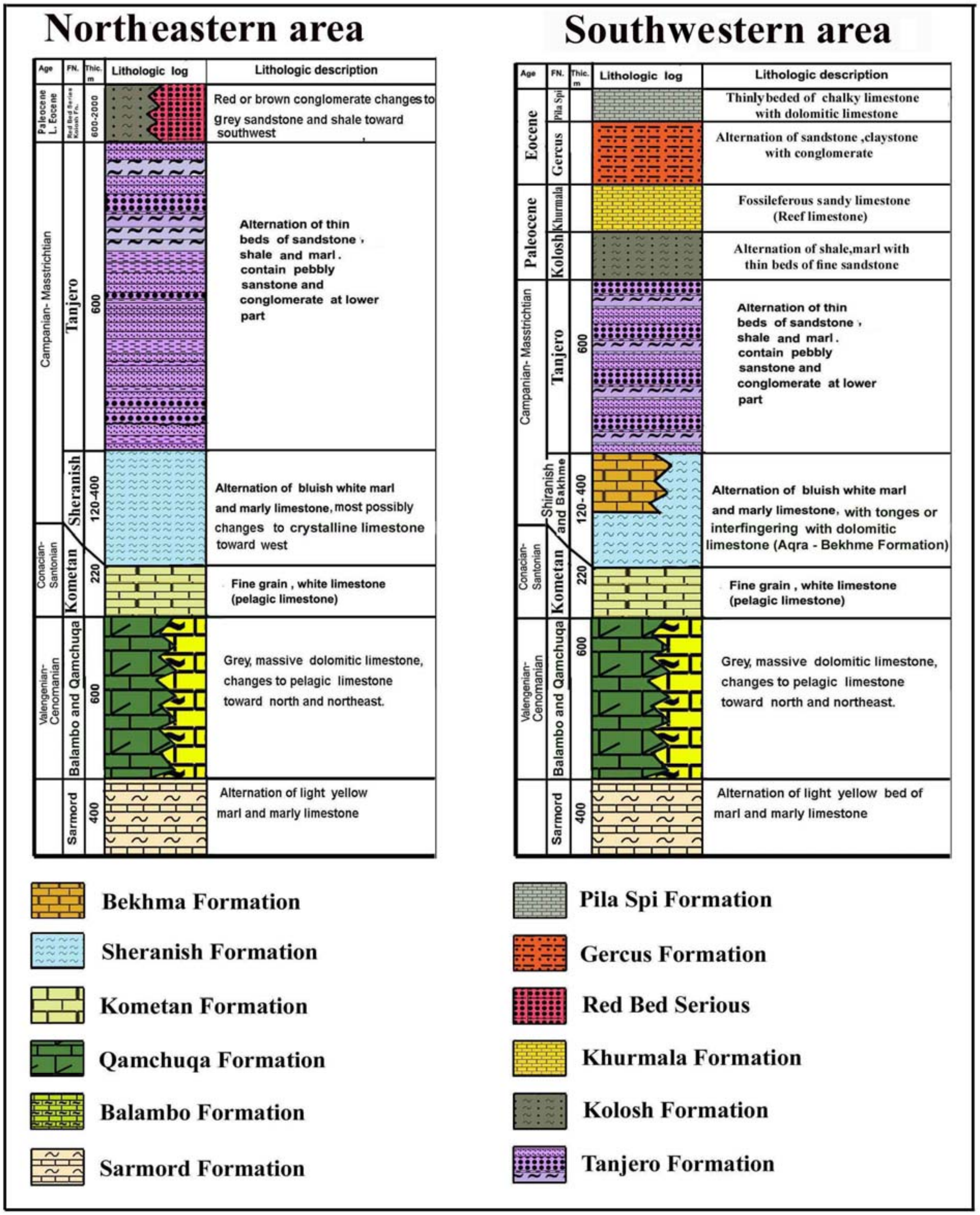

Fig.(1-4) General stratigraphic column of the studied area (not to scale).

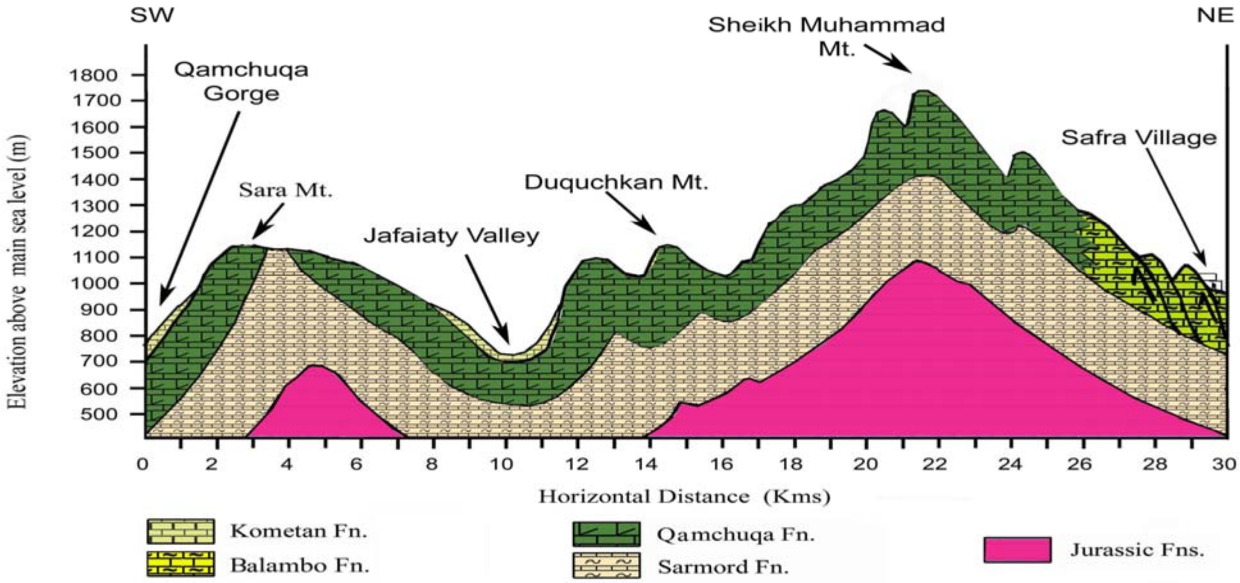

Fig. (1–5) Geologic cross section between Safra Village, from the northeast, and Qamchuqa Gorge from southwest.

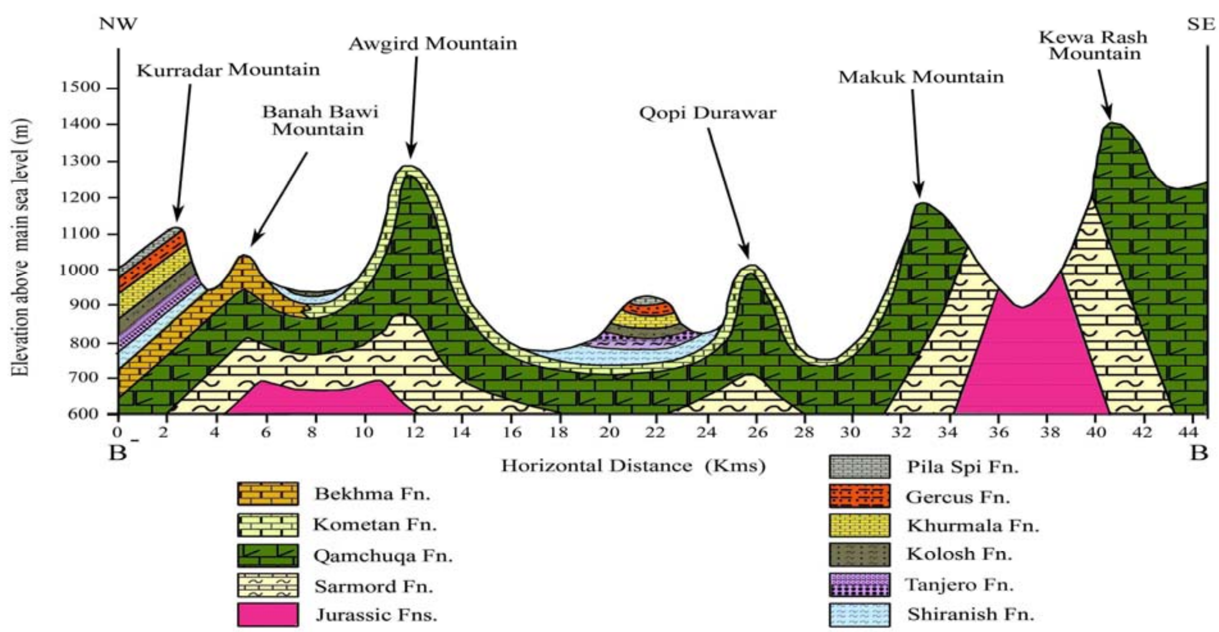

Fig.(1-6)Geologic cross-section of the studied area passing through Raniya (Kewa Rash) and Smaqully Valley.

2-Halladin Section

Located at the intersection of latitude and longitude 36^{0} 31^{-} $51^{=}$ N, 44^{0} 45^{-} $5149^{=}$ E about 4km to the northeast of Halladin Village in Jafayati valley about 20 km to the east of Dokan Town. The section consists of southwestern sides of Babo Mountain .

3-Type Section (Qamchuqa Gorge Section)

Located at the intersection of latitude and longitude 35^{0} 53^{-} $53^{=}$ N, 45^{0} 00^{-} $53^{=}$ E about 10 kms to the southeast of Dokan Town, directly to the east of the ruins of Qamchuqa village, which is now transferred to near Dokan town .

4-Kewa Rash Section

This section is located directly to the northwest of Ranyia Town and about 10km to the west of Darband Ranyia Gorge. It begins from the base and ends at the top of the scarp slope of the mountain at the intersection of latitude 36^{0} 15^{-} $37^{=}$ and longitude 44^{0} 54^{-} $38^{=}$.

1.5. Previous studies

According to Bellen, et al., (1959), the formation was first described by Wetzel (1950), from the Qamchuqa Gorge in northern Iraq. He divided the formation into six alternating dolomite and limestone units as follows; Upper dolomite unit, Upper limestone unit, Middle dolomite unit, Middle limestone unit, Lower dolomite unit and Lower limestone unit. He mentioned that the total thickness of the formation in the Qamchuqa and Bekhme Gorges is 650 and 799 meters respectively. Also he cited Hauterivian to Albian age.

Hudson (1954, in Al-Sadooni,1978) studied the Qamchuqa Formation in Bekhme gorge which is located 30 Km east of Aqra city .He divided the section, based on age, into seven units, from Valanginian to Albian; Upper dolostone Unit, Albian Unit, Lower dolostone Unit, Lower Aptian Unit, Barremian Unit, Hauterivian Unit and Valanginian Unit. He recorded the thickness of 804 meters for the formation in the gorge.

Dunnington (1958) constructed the isopach facies map of the Qamchuqa Formation during the Valanginian−Aptian and Albian−Cenomanian (Fig.1.7).

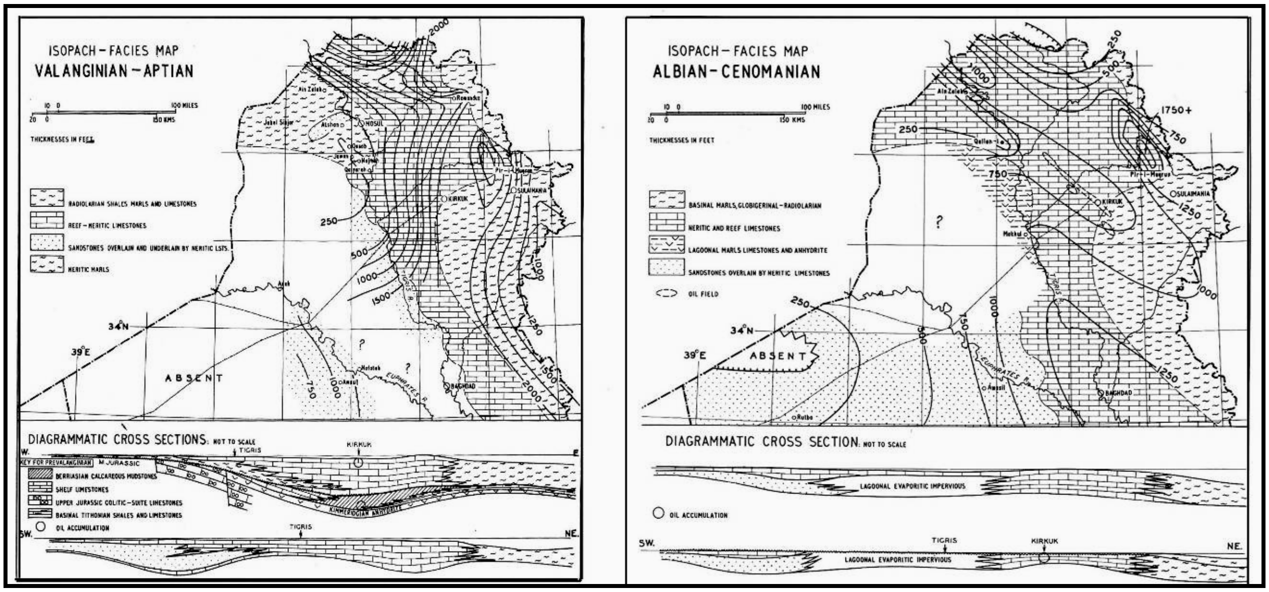

Fig.(1-7) Isopach facies map of Valanginian-Aptian and Albian-Cenomanian (Dunnington, 1958)

Al-Naqib (1959, in Al-Sadooni, 1978) divided the Qamchuqa carbonates, based on faunal content, into an upper and lower parts .The Lower Qamchuqa (Aptian-Barremian/Hauterivian) consists of neritic shoal limestone and dolomites with occasional tongue of the Middle Sarmord Formation. The Upper Qamchuqa (Albian) is similar in lithology to the lower part, but it normally contains the Upper Sarmord tongue. Chatton and Hart (1960) divided the Qamchuqa rocks according to the faunal content into a Lower Unit of pre –Albian age and an Upper Unit of Albian age. They considered the Shuaiba and Maudud Formations as extensive individualized tongues of the Lower and Upper Qamchuqa Formations, respectively.

Al-Shakiry (1977), studied the depositional and diagenetic aspects of the Qamchuqa carbonates in the Jambur structure, which includes the Lower part of the Upper Qamchuqa Formation, and the upper and middle parts of the Lower

Qamchuqa Formation. He concluded that, depositionally, the studied rocks lie within two basic facies; a high-energy shelf margin facies (as Upper Qamchuqa shoal banks and Lower Qamchuqa reefs) and a relatively low to moderate energy shelf facies (as Upper Qamchuqa and Lower Qamchuqa formations).

Al-Sadooni (1978), studied the sedimentology and petroleum prospects of the Qamchuqa Group from Kirkuk, Bai Hassan and Jambur Oil Fields. He compared the stratigraphy with the outcrops at Safeen-Dagh and Geli Ali Beg, and inferred that the deposition of the Qamchuqa Group is a rudist- algal-hydrozoans bank (not a reef). He also mentioned that the contact between Mauddud Formation (equivalent of Upper Qamchuqa Formation) and the overlying Dokan Formation is unconformable. There is a conglomeratic limestone bed 5–7.5 cm in thickness, composed of irregular, cracked pebbles of *Oligosteginal* limestone, and the pebbles contacts are stylolitic .The majority of these pebbles are from the Dokan Formation, although some may be derived from the Qamchuqa Formation itself. He also mentioned, that this conglomeratic limestone indicates the presence of an intra-Cenomanian tectonic movement.

Sissakian and Youkhana (1984) studied the uppermost part of Qamchuqa Formation in the vicinity of Shaqlawa. They mentioned that the contact between Qamchuqa and Bekhme Formations is unconformable but without observing conglomerate or erosional surface between the two formations. They found a new lithologic unit, which is consisted of soft facies (marl and marly limestone). Sahar (1987), studied the Upper Qamchuqa Formation in four sub-surface sections in wells such as Kirkuk-130, Chamchamal-2, Butma and Tell Hajer-1. His study showed that the lithology is prevalently dolomitized with few parts, or partially non-dolomitized. He also mentioned that the formation was deposited either in a quite shallow marine environment (represented in mudstone and wackstone facies) or some times in high-energy conditions, especially in the upper part (represented in packstone and grainstone facies).

Al-Peryadi, (2002), studied the Upper Qamchuqa and Jawan Formations in Bai-Hassan Oil Field. This study deals with the sedimentological and reservoir aspects of the Upper Qamchuqa/ Jawan succession in five subsurface sections for determination of the effective porosity in Bai-Hassan Oil Field. He divided the Upper Qamchuqa succession into four lithological units and two units for the Jawan Formation.

1.6. Aim of the study

The main aim of this study is to interpret the environment and basin development during deposition of Lower Cretaceous successions. This is based on the available and the inferred evidences. The study included the following:

1. Description and analyzing of different constituents and lithofacies of the Qamchuqa Formation in order to establish the depositional environment, to interpret different depositional processes with stratigraphy and sedimentological history of these sediments.

2.To establish the relation ship between Qamchuqa Formation with both underlying and overlying formations, in addition to laterally facial changes.

3- Study of the tectonic development and depositional history of the Qamchuqa Formation.

1.7. Methodology

To achieve the aims of this study, the following work is conducted:

1- Detailed field study of the outcrops to get the general view of the distribution, description of the sections and lithological changes in addition to vertical (stratigraphic) and geographic (lateral) lithofacial changes. Indication of most suitable sections for sampling.

2- More than 300 thin sections studded under binocular and polarizer microscopes for differentiation of the constituents and photographing the most useful samples.

3-Calculating percentage of the constituents (for identification of facies and rocks type) by using point counter. The method of Flugel, (2004, in: Betzer, *et al*. 2005) is used for point counting in which void with in particles are counted as constituent of the particles. In the slides and samples that contain few allochems the visual estimation by using the charts prepared by Folk et al., (1970) and Tucker (1989).

4- Studying of the selected samples by scanning electron microscope (Philips SEM, Quanta, 400).

CHAPTER TWO

LITHOLOGY AND STRATIGRAPHY

2.1. Preface

This chapter deals with the detailed study of stratigraphy and lithology of the studied sections. The field and thin section studies are used to subdivide and correlate the rocks of the sections. The relation of the Qamchuqa Formation with underlying and overlying formations is deciphered by extensive field and lab studies. The formation consists mainly of thick alternation of limestone and dolomite successions. Generally, the dolomite horizons are more abundant within the upper part than the lower (Fig.1.7).

Several new types of grains (allochems) are found in the rock of the formation, which are explained latter in term of facies (see chapter four) and depositional environments. During this study, the author had faced at least two main problems. The first is the intense dolomitization of the rocks; at least, half of the thickness of the sections is intensity dolomitized. The second is the original shape and size of the rock constituents are modified by either tectonic or lithostatic stresses in addition to recrystallization. This modification (deformation) is clearly seen in the oncoids, all types of mollusk and stromatolites. Some intervals of the dolomite are completely changed to breccias.

2.2. Lithology of the studied Sections

The four studied sections are described lithologically, based on field inspection and petrographic study under polarized and stereoscopic microscopes. The study started from the base to the top of each section. The description began with the most informative sections, and to eliminate repetition through the study, only the details of the difference of the later sections are stated.

In this study and based on the lithology and fossils content, the Qamchuqa Formation is divided into eight units.

1. Lower Limestone Unit (L 1)

The lower part of this unit consists of thin beds of light grey limestone while changes to massive limestone in its middle and upper parts, which is (25−70 m) thick. The unit commonly consist of light grey limestone, with oncoids, branching coral, stromatolites, pelecypods and gastropods, with fair bioturbation. These are the most common carbonate grains, which can be seen in hand specimens. These are generally embedded in fine matrix. Towards the south, as in Qamchuqa type section, the thickness and fossil content decrease, In Halladin section, it contains an interval of about 7m thick, and at the upper part, that consists of oolitic limestone near the middle(Figs.2.16, 2.18 and 2.21).

2- Lower Dolomite Unit (D 1)

This unit consists of very coarsely crystalline dolomite with both massive and finely laminated intervals. In some cases, the veins and fractures are filled by white coarsely crystalline secondary dolomite, which give spotty appearance to the rocks. This unit is composed of calcitic dolomite in Kewa Rash section. The thickness of this unit ranges between 5 and 20m, the minimum thickness occurs in Yakhsamar and Halladin sections, while the maximum thickness is present in Qamchuqa Gorge sections(Figs.2.16, 2.18 and 2.21).

3- Middle Limestone Unit (L 2)

This unit consists of monotonous white, light grey, well-bedded limestone with few beds of marly limestone. All beds consist of fine crystalline fractured limestones and contain thin-shelled pelecypods at the base in Qamchuqa section, while the macro fossils (gastropods, rudist and pelecypods) content increases in other sections. The thickness of this unit is more than 130m (Figs.2.16 and 2.18).

4- Middle Dolomite Unit (D2)

This unit consists of very thick succession of massive and coarse crystalline dolomite. It is very similar to unit (D1) in characteristics, but with more thickness .The dolomite is dark grey to brown color, intensely breeciated and leached, locally laminated. White, coarse crystalline, secondary dolomite more or less present in some intervals. This unit forms the middle part of the formation. Thickness of this unit is more than 200m (Figs.2.16, 2.18 and 2.21).

5- Upper limestone Unit (L 3)

This unit resembles generally Unit (L2), but with less thickness and thinner beds. It occasionally contains laminated beds and very sparse macrofossils. The thickness ranges between (10–70) m (Figs.2.16, 2.18 and 2.21).

6- Upper Dolomite Unit (D 3)

This unit consists of very coarse crystalline dolomite. It also contains white coarse crystalline secondary dolomite, with veins and laminae. Some beds are stylolitic and others are containing the stromatolite. The thickness of this unit ranges between 20 and 60m, the minimum thickness is shown in Yakhsamar section, while the maximum thickness is present in Halladin sections(Figs.2.16, 2.18 and 2.21).

7- Upper Most limestone Unit (L 4)

This unit consists of well-bedded limestone, which alternates with marly limestone. It contains few limestone beds rich in rudists and pelecypods with at least one bed with large benthonic Foraminifera (Orbitolina). At the top a stromatolitic and brecciated beds occur. The thickness of this unit ranges between (10- 50)m(Figs.2.16, 2.18 and 2.21).

8- Upper Most Dolomite Unit (D 4)

This unite consists of dolomite and dolomitic limestone, which gradually changes to Kometan Formation. The unit is extremely fractured and brecciated and contains stromatolite in some beds. The thickness ranges between (40—140) m, some interval of this unit is covered by soil in most sections(Figs.2.16, 2.18 and 2.21).

2.2.1. Description of the sections

The four studied sections are described here in details

2.2.1.1.Yakhsamar Section

It is located in the intersection of latitude and longitude N: 35^0 51^- $12^=$, E: 45^0 12^- $25^=$ respectively , directly northeast of Yakhsamar Village in Jafayati Valley, 25 km to the east of Dokan Town (Figs.1.1, and 1.2). In this section 45 samples are chosen for the study. The Unit (L1) consists, near the base, of pelletal and bioclastic limestone (wackstone) with few large benthonic Foraminifera. Towards the middle and the top, the thickness of the beds increases and high rudists content and intense bioturbation appear. The rudists are cylindrical and either fixed vertically on the bedding plane (elevator type) or the lying parallel to the bedding plane, as in situ recumbent type and are associated with medium grained bioclasts. After Unit (L1) the Unit (D1) is relatively thin (about 5m thick) and massive, which shows intensive weathering and brecciation with no indication of fossils and sedimentary structures. The Unit (L2) is similar to Unit (L1), but with more thickness (155m) ,contains more rudist bearing layers and bioturbation. It contains, in the middle part, few laminated beds (most possibly belong to badly developed flat stromatolite) and three beds of marly limestone. In these two units, selective dolomitization can be seen clearly as spots, which affected the burrows that appear as grey and coarse-grained elongated spots.

The Unit (D2) is very thick (200m) and massive and intensively fractured in some intervals brecciated. The fractures are filled with white coarse crystalline dolomite. Some intervals show pale ghost of fossils, which appear uncertainly as a rudist and gastropods, other intervals contain both clear and crude lamination, the lamination consists of alternation of couplets of white and dark grey thin bands. Also, Unit (D2) consist of white, coarse, secondary dolomite (spary dolomite) and dark colored saccaroidal dolomite, respectively. The Unit (L3) is similar to Unit (L2) in pelecypod skeletons content but with less thickness and with some dolomitic limestones in Yakhsumar ,Halladin and Qamchuqa Gorge sections(Fig.2.3 ,2.5 and 2.8).

Unit (D3) consists of a very coarse crystalline dolomite, with white coarse crystalline secondary dolomite veins and laminae. Some beds are stylolitic, and others are presented the stromatolite. The thickness of this unit ranges between (20-60)m, the minimum thickness is shown in Yakhsamar, while the maximum is present in Halladin sections. Unit (L4) consists of well-bedded limestone, which alternates with marly limestone. It contains few limestone beds rich in rudists and pelecypods with at least one bed with large benthonic Foraminifera (Orbitolina).
At it’s top, a stromatolitic and brecciated beds occur. The thickness of this unit ranges between (10-50) m. The Unit (D4) consists of dolomite and dolomitic limestone, which gradually changes to Kometan Formation. It is extremely fractured and brecciated and contains stromatolite in some beds. Its thickness ranges between (40-140 m), some interval of this unit is covered by soil in most sections.

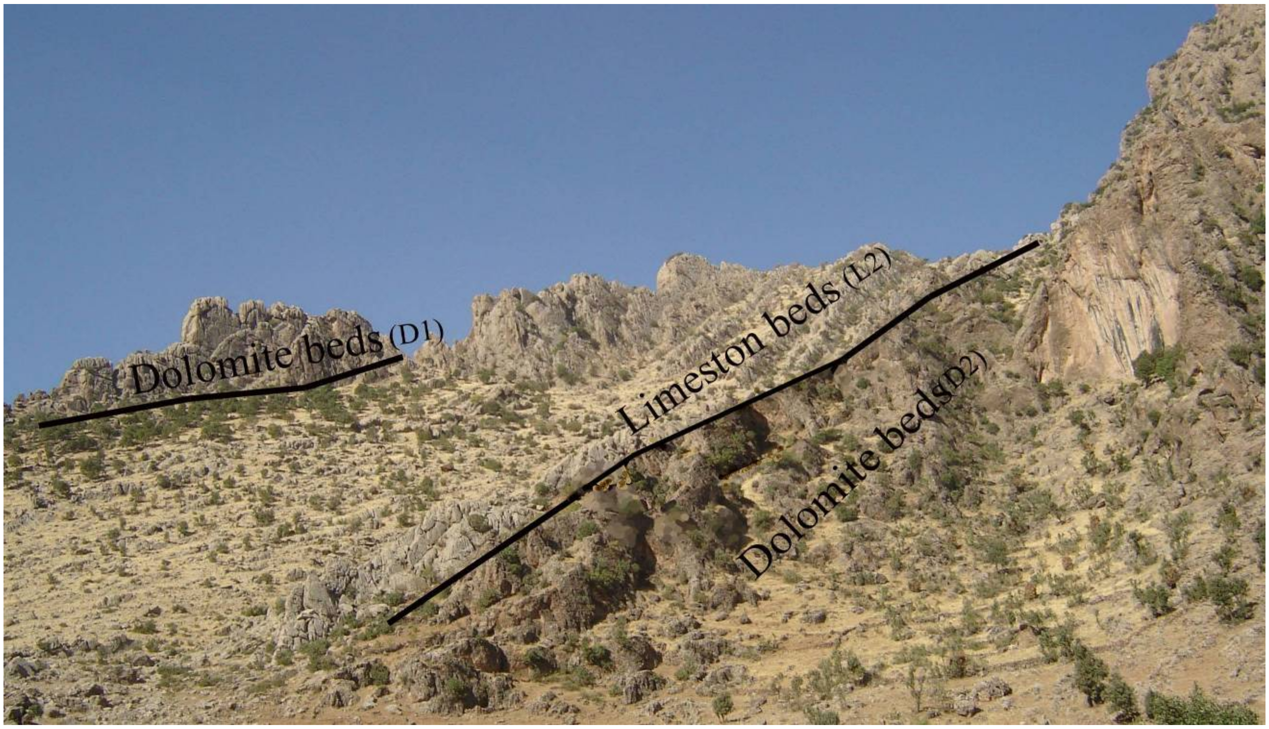

Fig. (2-1): Dolomite and limestone successions in the Yakhsamar section

Fig. (2-2): Dolomite and limestone successions in Halladin section.

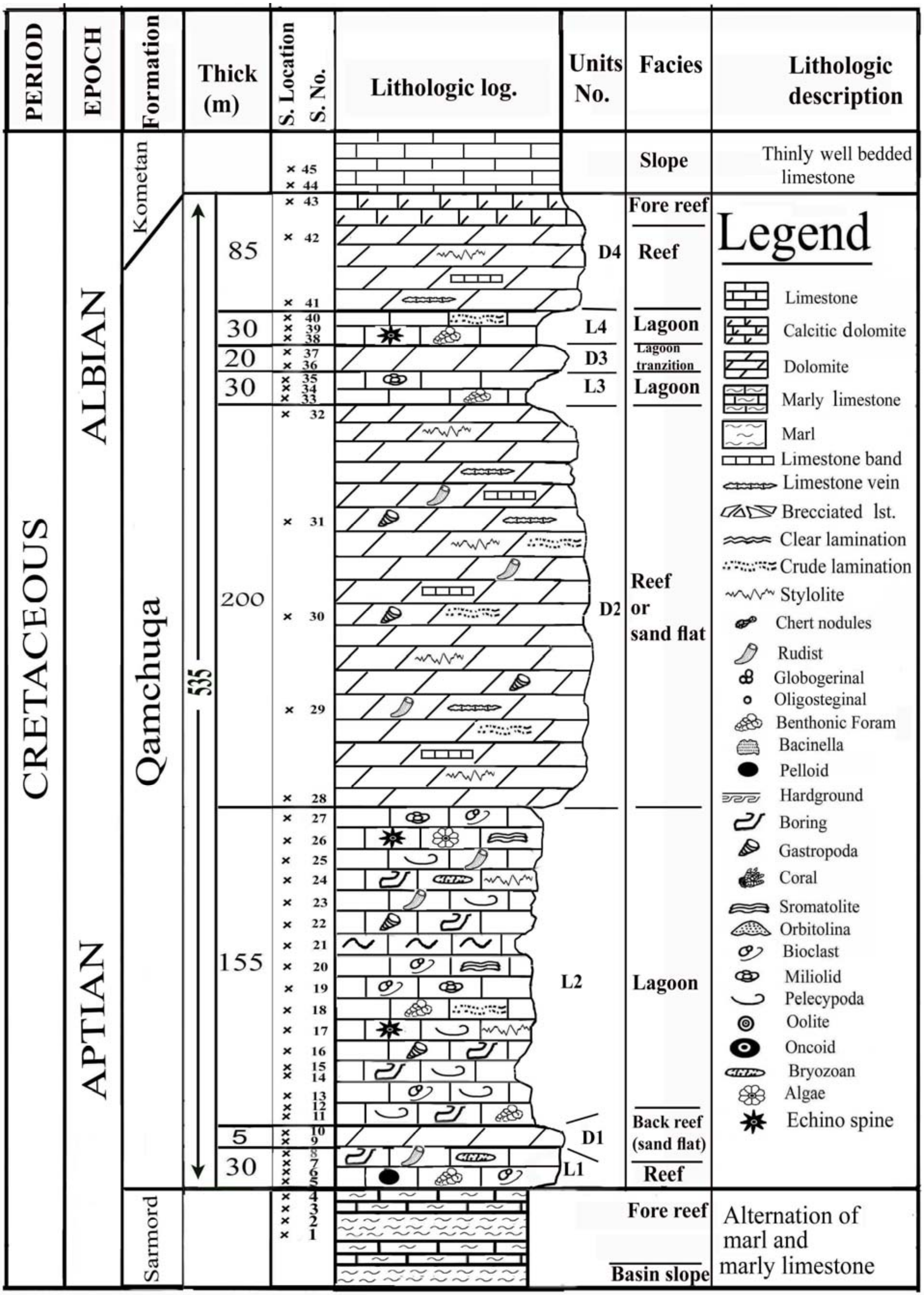

Fig. (2.3) Stratigraphic column of Yakhsamar section, (not to scale).

2.2.1.2. Halladin Section

It is located in the intersection of latitude and longitude N: 36^{0} 31^{-} $51^{=}$, and E: 44^{0} 45^{-} $5149^{=}$, respectively, 4km to the west of Halladin section and northeast of Halladin Village in Jafayati Valley , 20 km to the east of Dokan Town (Figs.1.1,and 1.2). In this section 36 samples are chosen for the study. This section contains the most well developed reefal limestone constituents, such as oncoids, branching coral, stromatolites, green algae, pelloids and ooids. The stages, facies and structures of reef succession (Walker and James, 1992) can be identified (Fig.2.4). The Unit (L1) is thicker than other sections; it consists of 70m of reefal limestone. At the base, consists of pelloidal and bioclastic limestones with bed thickness of 0.5–3 ms. Toward the middle of this unit, bedding thickness increases and changes to massive with gradual increase of oncoids, stromatolites, branching corals, gastropod, rudist and green algae, while red algae and large forams are not observed in this section. Toward the top, the bedding thickness decreases again and the grey sound oncoidal limestone changes to relatively beds of yellow to pale brown oolitic limestone, with some marly limestone interbeds(Fig. 2 .5).

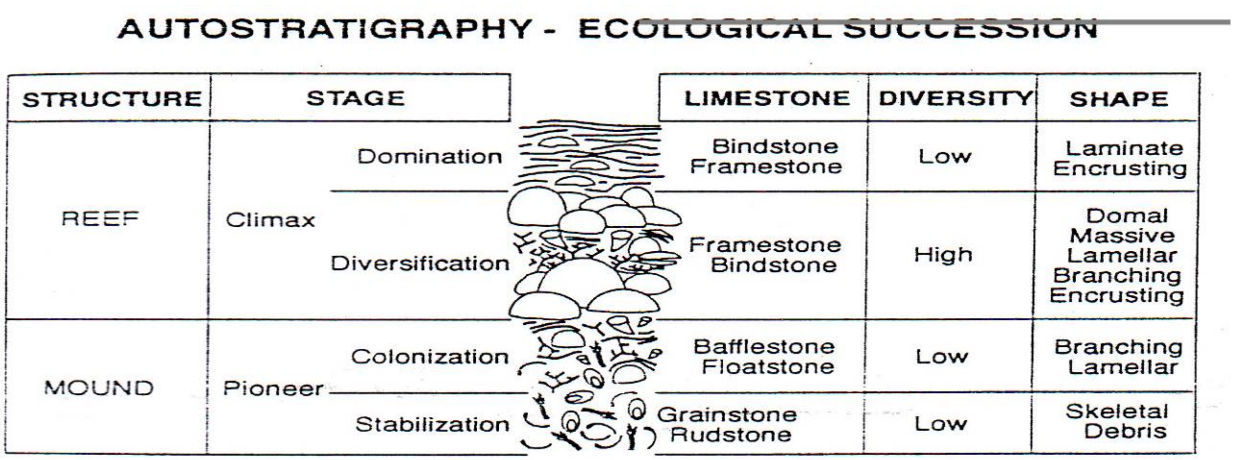

Fig.(2-4): A sketch of the four divisions of the core facies that can be generated by ecological succession of the reef builders(after Walker and James,1992)

The reef aspects of this section change laterally toward northeast and southwest to limestone succession, similar to those of Yakhsamar and Halladin sections

(Fig. 2 .1 and 2.2). The Unit (D1) is relatively thin (2-10m thick) in some case laterally (along the strike) disappears, changes to bioturbated limestone while along dip direction it is un known if it continues or disappears, due to luck of outcrops in dip direction. The Units L2, D2, L3, D3, L4 and D4 are all nearly similar to those of Yakhsamar section.

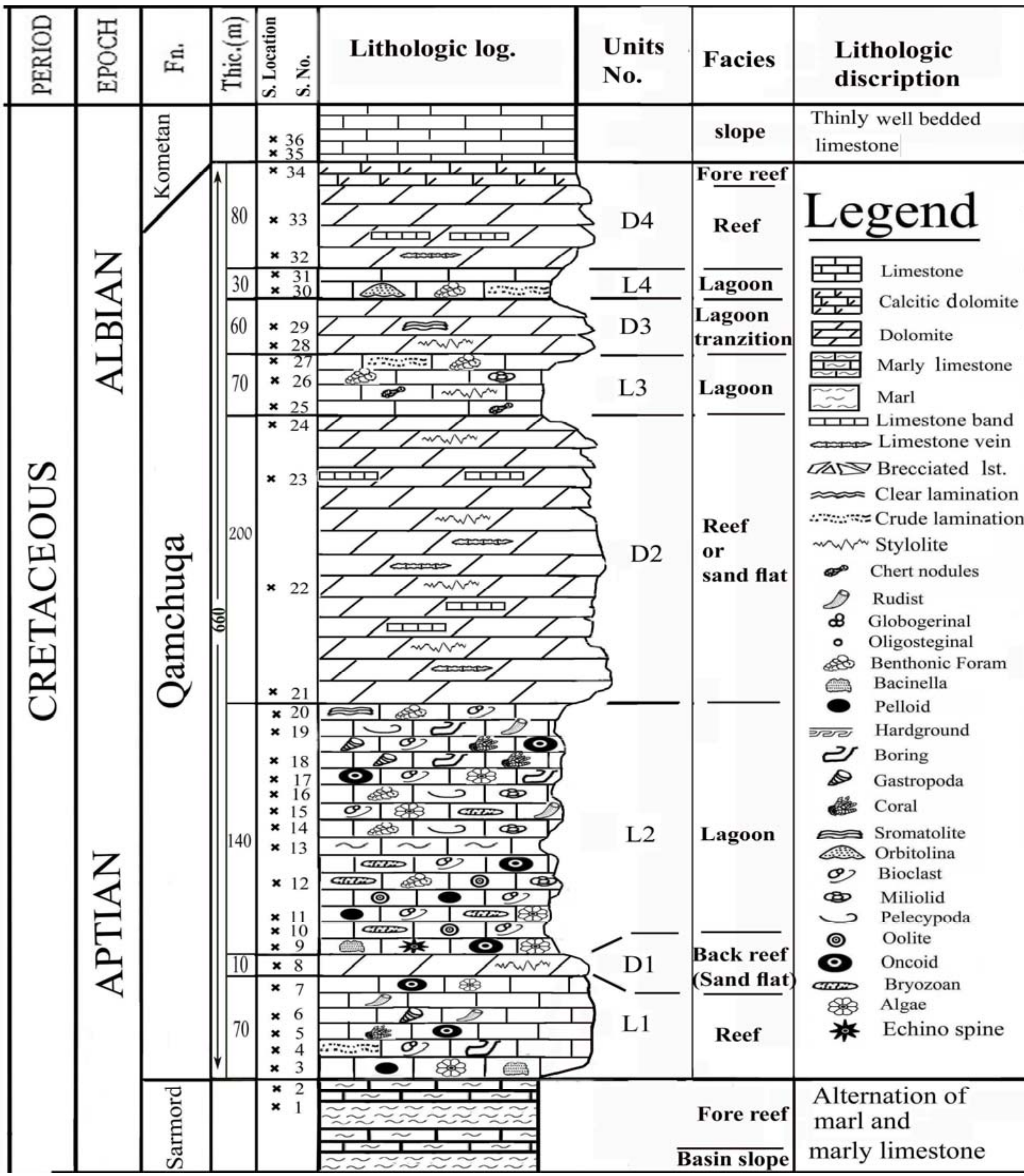

Fig. (2-5): Stratigraphic column of Halladin section,(not to scale).

2.2.1.3. Type Section (Qamchuqa gorge section)

It is located in the intersection of latitude and longitude N: 35^0 53^- $53^=$ and E: 45^0 00^- $53^=$, about 10 kms to the southeast of Dokan Town., (Figs.1.1 and 1.2). In this section 34 samples are chosen for the study. The limestone beds of this section did not show any signs of typical reefal stages and structures that are given by Walker and James (1992) in the figure (2.4). Most limestone beds have characteristics of lagoonal limestone, while the thick and massive dolostone beds have suffered from recrystalization and brecciation, therefore the original constituent can not be seen clearly. However, it is possible that the thick dolostone beds of units (D2 and D3) may represent (more or less) some parts of a reefs such as reef mound or back reef sand flat or forereef debris.

The only well observable structure is the well-developed lamination that can be seen in the dolostone successions, with some large gastropods and pelecypods ghost, in other successions. The well-developed lamination and large fossils, most possibly represent sand flat, behind the reef.

The Unit (L1) is about 70m thick and consists of light grey, fine grain limestone (mudstone or wackstone), with bedding thickness of (0.2–2) m. Near the base, it contains branching coral debris about 30cm thick (Fig.2.9B). Near the middle part, it contains two horizons of thin-shelled gastropods and bioturbation. Near the top, three horizons rich in chert nodules can be seen. The Unit (D1) is about 20m thick and similar to the Unit (D1 and D2) of the Yakhsamar section. The Unit (L2) is well-developed limestone succession, about 140m thick and contains few beds of dolomitic limestones. The micro and macrofossils are relatively sparse, which include small and thin-shelled pelecypods. Between the limestone beds, occasionally, there are marly limestone interbeds with one glauconitic thin bed, near the middle part of the unit. Generally, Unit (L2) is nearly similar to L2 in the Yakhsamar section, but without rudists bearing beds. The Units (D2, L3, D3 and L4) are nearly similar to those of Yakhsamar section, except for their thicknesses, which are shown in the (Fig. 2.3 and 2.8). The Unit (D4) is thick and contains different successions of competent and incompetent layers. The competent beds consist of massive dolomite, while the incompetent beds consist of dolomitic limestone and contain few beds of stromatolitic and brecciated rocks, with one fossiliferous bed, which contains either pelecypod or rudist, this is unknown due to the diagenesis.

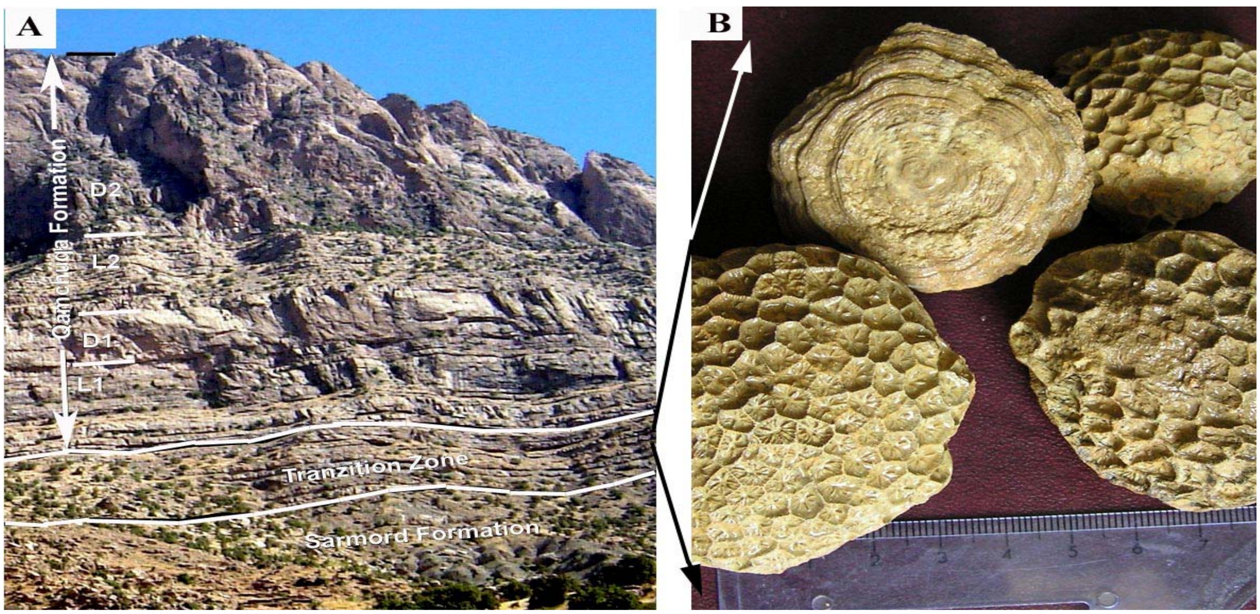

Fig. (2.6) A. Qamchuqa section (lower and middle parts) B. the single colony coral colonies of the transition zone with Sarmord Formation.

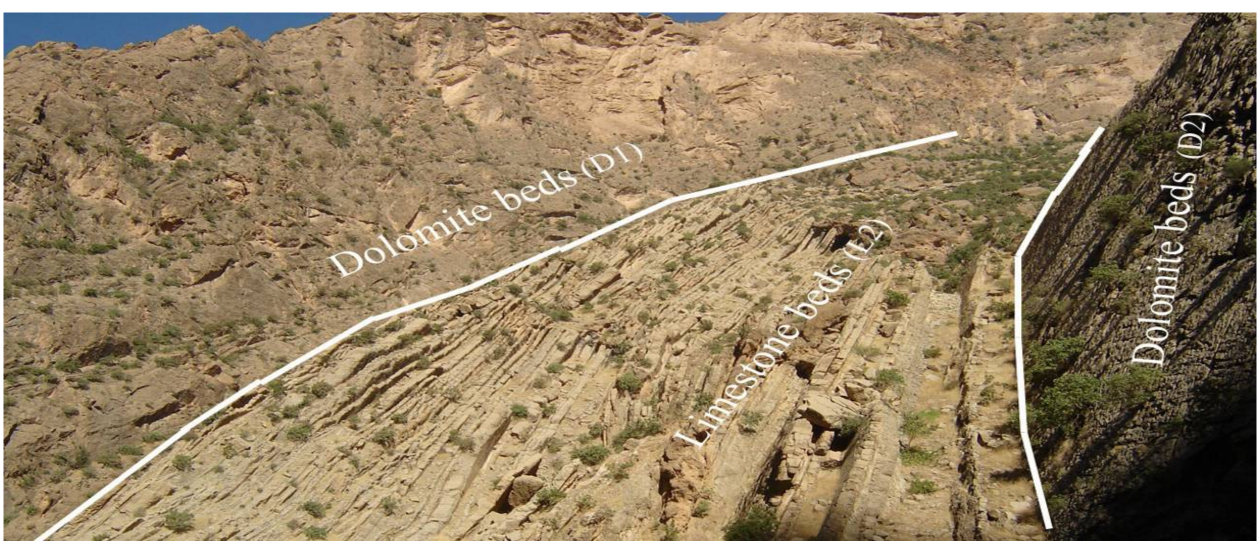

Fig. (2.7) The Unit L2 is sandwiched between Units D1 and D2 at the in Qamchuqa Gorge section.

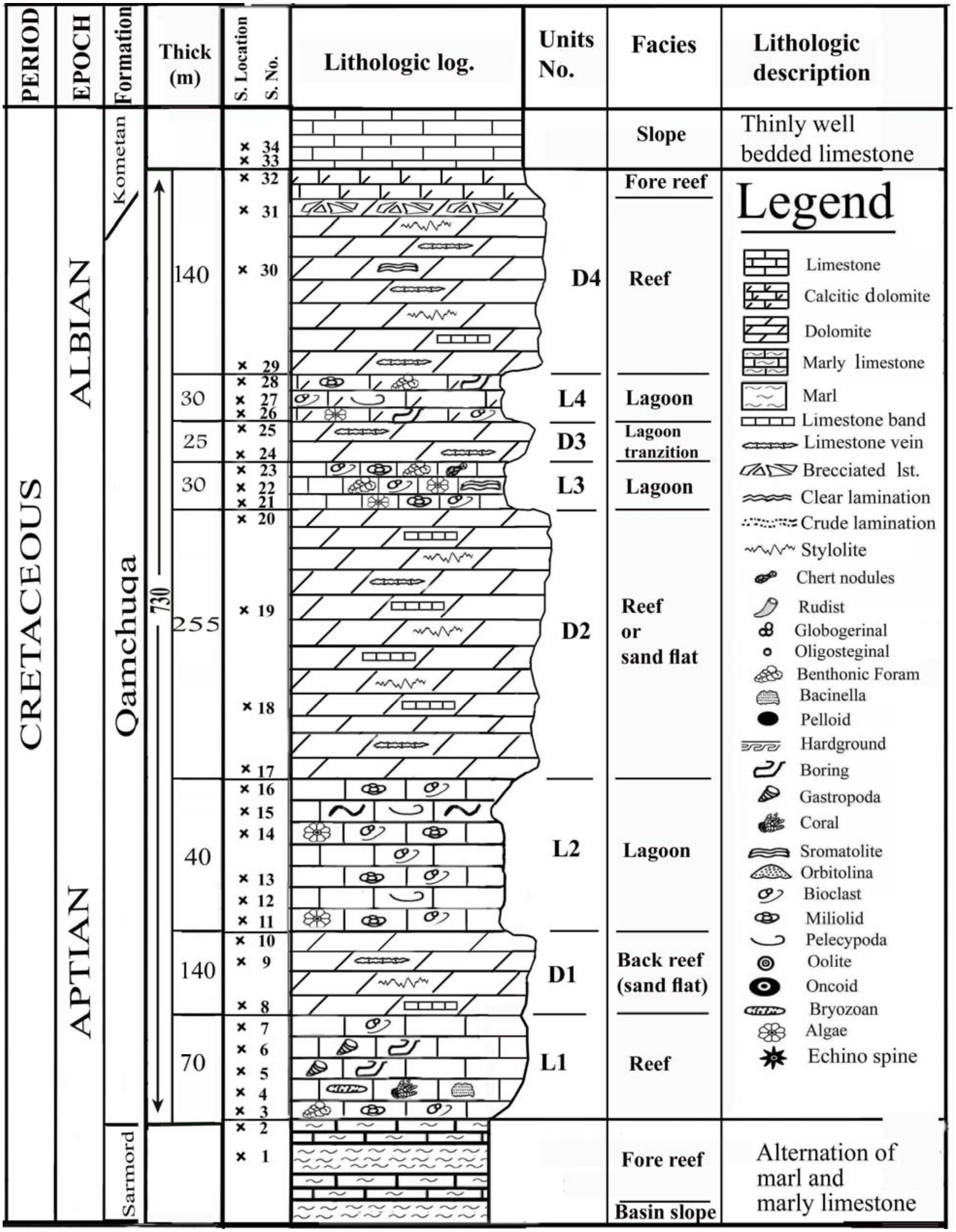

Fig. (2-8) Stratigraphic column of Qamchuqa Gorge section (not to scale).

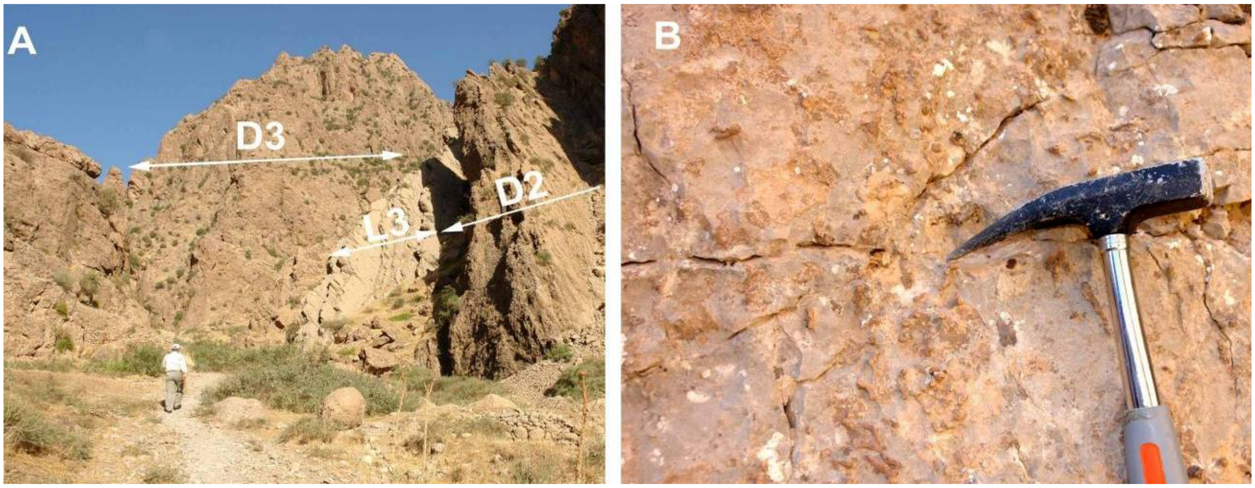

Fig. (2.9) A: Units D2, L3 and D3 of the Qamchuqa Gorge section. B: Branching coral debris near the base of the Unit L1.

2.2.1.4. Kewa Rash Section

The base of the section is located in the intersection of latitude and longitude N: 36^0 15^- $37^=$ and E: 44^0 54^- $38^=$, respectively, directly to the north of the Ranyia town (Figs.1.1, and 2.2). In this section 33 samples are chosen for the study.The limestone and dolomite units have different thicknesses and some of them disappear suddenly both along dip and strike. This is most possibly attributed to repetition or omission of some intervals, due to thrusting and reverse faulting. The rocks in this section differ from other sections by the following aspects:

. Generally, the thickness is less than other sections, it is about 535 m.

. The Units D2 and D3 consist of dolomitic limestone Fig.(2.11).

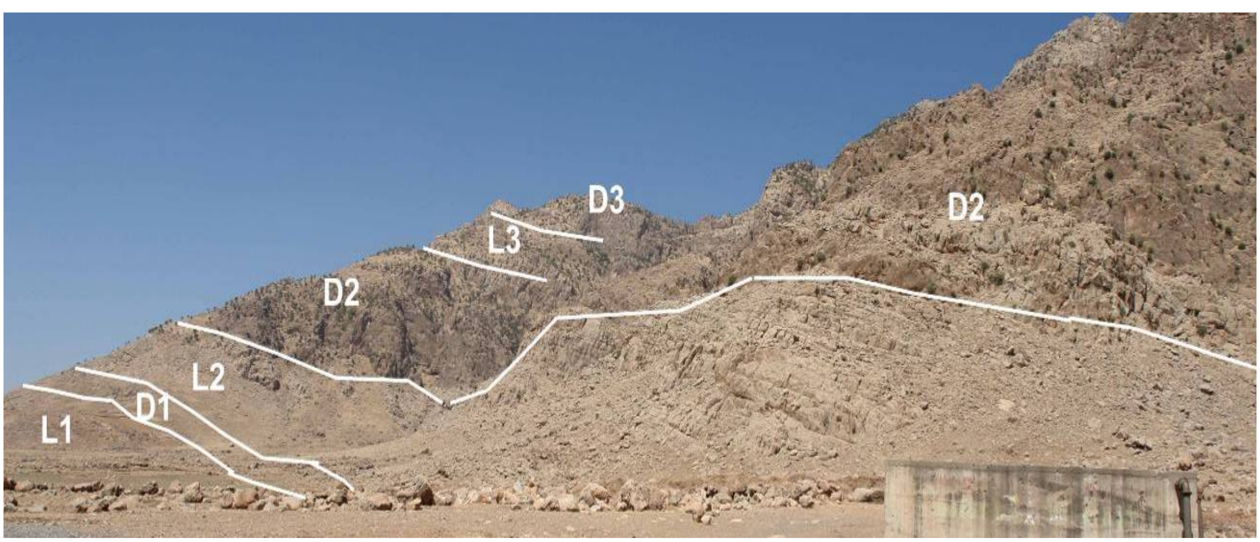

Fig. (2.10) Kewa Rash section directly north of Ranyia town

. Generally, the section is more or less similar to that of the type section (Qamchuqa section).

.The bioturbations are very common in this section.

. A bout 15 m of the lower and 30 m of upper contact are covered Fig.(2.11).

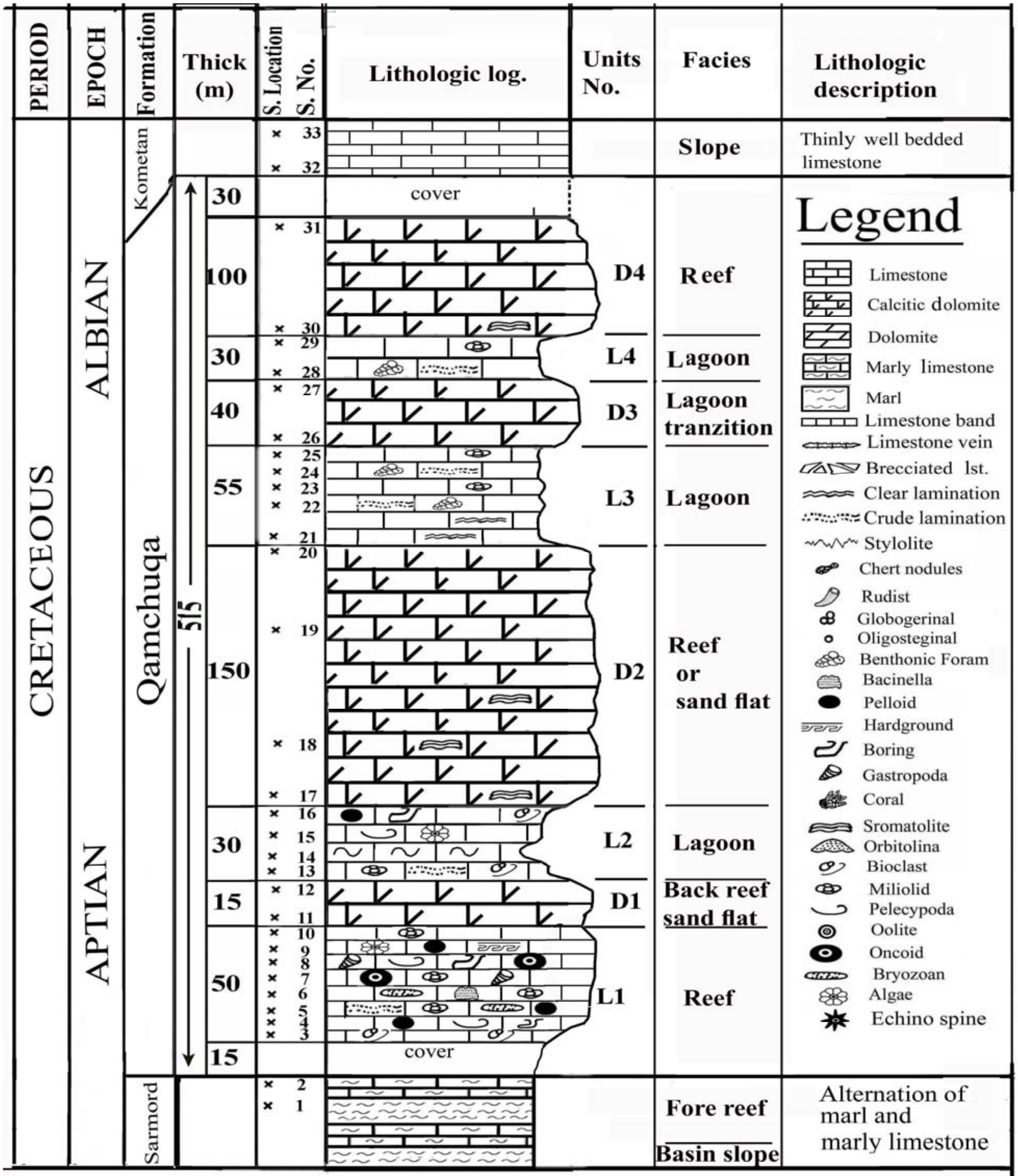

Fig. (2 .11) Stratigraphic column of Kewa Rash section (not to scale*).*

The Warte valley also studied It is located in the intersection of latitude and longitude N: 36^{0} 31^{-} $51^{=}$ and E: 44^{0} 45^{-} $49^{=}$, respectively, 40 km northeast of Raniya City (Fig.1.1, and 1.2) because of nearness to the typical outcrop of the Qamchuqa Formation and the rocks of this section have the bedding and color characteristic which are intermediate between Qamchuqa and Balambo Formations. Large content of microfossils in this section is abnormal, which is most probably attributed to nearness of the location of this section to nutrient rich reefal environment. According to Wilson (1975), the uni-chamber foraminifera (Oligosteginas) are associated with Globigeraina and represent an environment, which is characterized by transitional environment between deep and shallow. **.** No any large fossils of lagoonal or reefal limestone are found in the rocks. Moreover, in thin sections (under microscope) the whole section consists of Oligosteginal and Globigerinal ooze (Fig.4.5). No bioturbation or trace fossil are observed in the rocks of this section, while it is very abundant in rocks of other sections.

Besides, the glauconite, which is associated with Oligostegina in the Qamchuqa Formation, is also another indicator for this environment mentioned by (Cloud, 1955) that glauconite requires a normal salinity with moderates depth to neritic. According to Adams et al. (1967), the calcispheres are common in transitional belt, separating the Orbitolina neritic limestone (Fig. 4-4), and the pelagic radiolarian mudstone. This facies is abundant in the whole Warte section (Fig. 2.25) which is important evidence for transitional environment to the Balambo Formation(Fig. 2.27).

2.3. Contacts of the Qamchuqa Formation

Qamchuqa Formation, in the studied area, is underlain by Sarmord Formation and overlain by Kometan and or Dokan Formations. The study of these contacts is important for envisaging and connecting of tectonic and environment setting of the formation with the geologic history of the entire Cretaceous Period. The study of the contacts let the geologist to put the formation and neighboring units either in a one basin or in several basins by appling Walther Law as cited in Blatt *et al* (1980).This is also useful for tectonic consideration of the formation and it's depositional basin during Late Cretaceous.

The study of the boundaries is as follows:

2.3.1. Lower Contact with the Sarmord Formation

Bellen et al. (1959, p. 231) mentioned that the contact between Qamchuqa and Sarmord Formations is conformable in the type section. Jassim and Goff (2006, P. 130) mentioned that the lower contact is conformable, except in the western parts of the Northern Thrust Zone near Banik where the Qamchuqa Formation unconformably overlies the Garagu Formation. Al-Sadooni (1978, p. 32) mentioned that the contact between the Lower Qamchuqa and what was considered as Upper Sarmord (nowadays Nahr Umr) in Kirkuk, Bai Hassan and Jambur Oil Fields is unconformable, but the break is of short span. He added that it was connected with the uplift in the end of the Aptian and correlated with the unconformity at the northwestern part of the country. Qaradaghi (2007) studied the upper contact of the Sarmord Formation with Qamchuqa Formation in Zewe, Sargelu and Raniya area, and he referred to the conformable nature.

This study also revealed that the contact between the Qamchuqa and Sarmord Formations is gradational, which is manifested by alternation of well bedded,

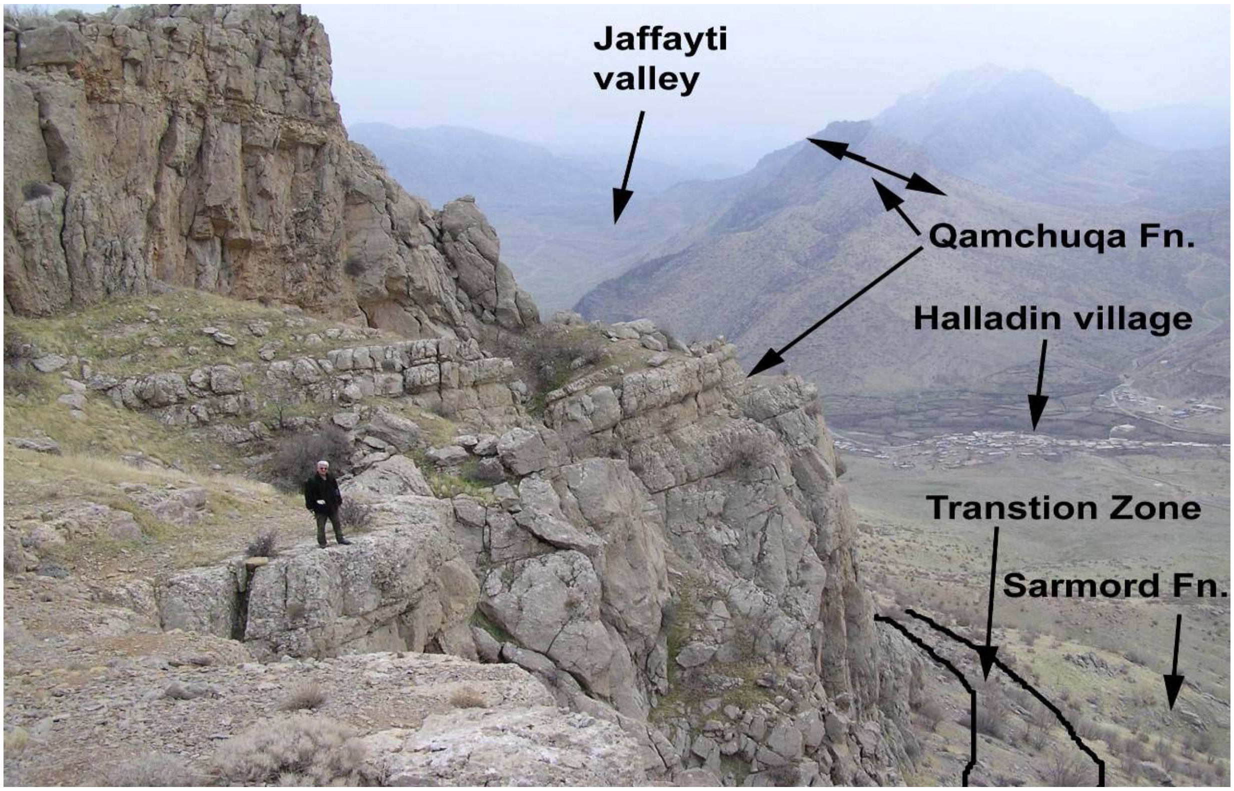

Fig. (2.12): Conformable contact between Sarmord and Qamchuqa Formations, represented by a transition zone of thin, bedded succession of pelletal limestone at the base of Halladin section.

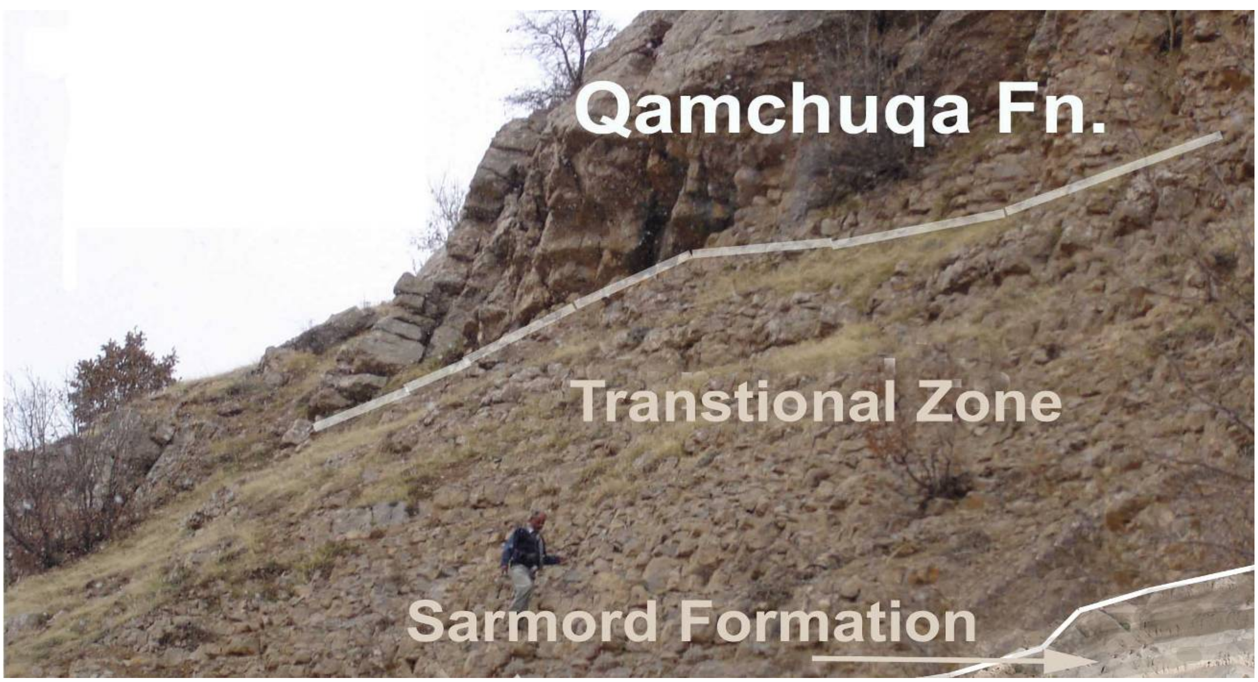

Fig.(2.13)Transitional Zone between Qamchuqa and Sarmord Formations of Halladin section, which consisted of alternation of pelletal limestone and marly limestone.

sandy marl with bioclastic or benthonic Foraminifera(mainly Orbitolina) bearing limestone. This interval is assumed as transitional zone in this study, it has thickness of 10-30m and changes upwards to massive bed of Qamchuqa Formation and downward to marl and marly limestone of Sarmord Formation (Fig.2.6). The bioclastic beds, in the transitional zone, contain pelecypods, gastropods and single colony coral (scleractinia corals, fig.2.5). This type of contact can be seen in the northeast of Bingird (north of Bardashan Village) and northeastern end of Qamchuqa gorge (Fig. 2.6). In the Halladin section the marl of Sarmord Formation changes to alternation of thin beds of pelletal limestone and interbeds of marly limestone laminae (Fig.2.12).

2-3-2. Upper Contact with the Kometan Formation

Bellen, et al. (1959, P. 231), Sadooni and Al-Sharhan, (2003) mentioned that the contact between Qamchuqa and Kometan Formations is considered as an erosional unconformity throughout the area of the occurrence, but without an angular discordance in the type section. Bellen et al. (1959) mentioned that at Dokan, Hajiawa, Sarchinar and Qamchuqa Gorge, an *Oligosteginal* unit occurs, intermittently between the eroded top of the Qamchuqa and the base of the Kometan Formations. The same author mentioned, that the break between *Oligosteginal* Dokan and Qamchuqa Formations at Dokan area, might be a result of intra-Cenomanian emergence or near-emergence. They added that the Qamchuqa sedimentation might have continued into early Cenomanian prior to regression, but not eroded remnants of any such sediment which are known to be attributed to the Qamchuqa Formation. Jassim and Goff, (2006) mentioned, that the upper contact is marked by a break and is either non-sequential or unconformable.In this study, according to the detailed field observations and thin section study, the upper contact between Kometan and / or Dokan Formations is considered most probably conformable, of gradational contact. This is proved by the following evidences: The **first** is that in the field and in all studied five sections, no erosional surface or any indications of unconformity such as paleo-karstrification, paleosol, conglomerate and sedimentary breccias are observed in the studied sections (Fig.2.14). Therefore, no any sub aerial erosions are observed in all studied sections, probably sub marine erosional or non sedimentation events tacked place. Moreover, in studied area of Qamchqa Formation, no sediments equivalent to this supposed erosion episode was found although extensive field works were carried out. The **second** is that Bellen et al. (1959) mentioned the occurrence of Oligosteginal limestone (Dokan Limestone) above Qamchuqa Formation at Dokan area. They ascribed these foraminifera to Cenomanian age. Most recently, the palynological study of Sarraj (2006) aged the Dokan Formation as Late Albian--Cenomanian. Moreover, Bellen et al. (1959) mentioned that the environment of Dokan Limestone is shallower than Kometan Formation. In our envisaging, the above citation and conclusions are indirectly explains the absence of unconformity due to continuous of sedimentation during Cenomanian in which the transition zone between the two formations is deposited. This transition zone is most probably represented by Dokan Formation, which is mentioned by Bellen et al. (1959) to be shallower than Kometan Formation (intermediate between the two formations). The **third** is that we observed, in all the five sections, that the Qamchuqa Formation gradually changes upwards to either Dokan or Kometan Formation. This change occurs through clear transition zone of well-bedded dolomitic limestone that has intermediate characteristics between Kometan and Qamchuqa Formations (Fig.2.14). According to Adams et al. (1967), the calcispheres are common in transitional belt separating the Orbitolina bearing neritic limestone and the pelagic radiolarian mudstone. In our opinion, the position of calcispheres (now called Oligostegina) between the shallow and deep environment is similar to that of Dokan Formation. The **fourth** one is that Buday, (1980, P. 157) mentioned that, in Chamchemal well, the base of Dokan Formation is glauconitic but no unconformity between the Upper Qamchuqa and Dokan Formations had been observed there. In this study, glauconite also is observed in the upper contact of Qamchuqa Formation outside the area of occurrence of Dokan Formation. The glauconite bearing bed, most possibly belongs to the Dokan Formation. In all recent studies concerned with sequence stratigraphy the glauconite is not related to unconformity but it is evidence of deepening and maximum flooding (Vail, et al.1977, and Haq, et al. 1987).

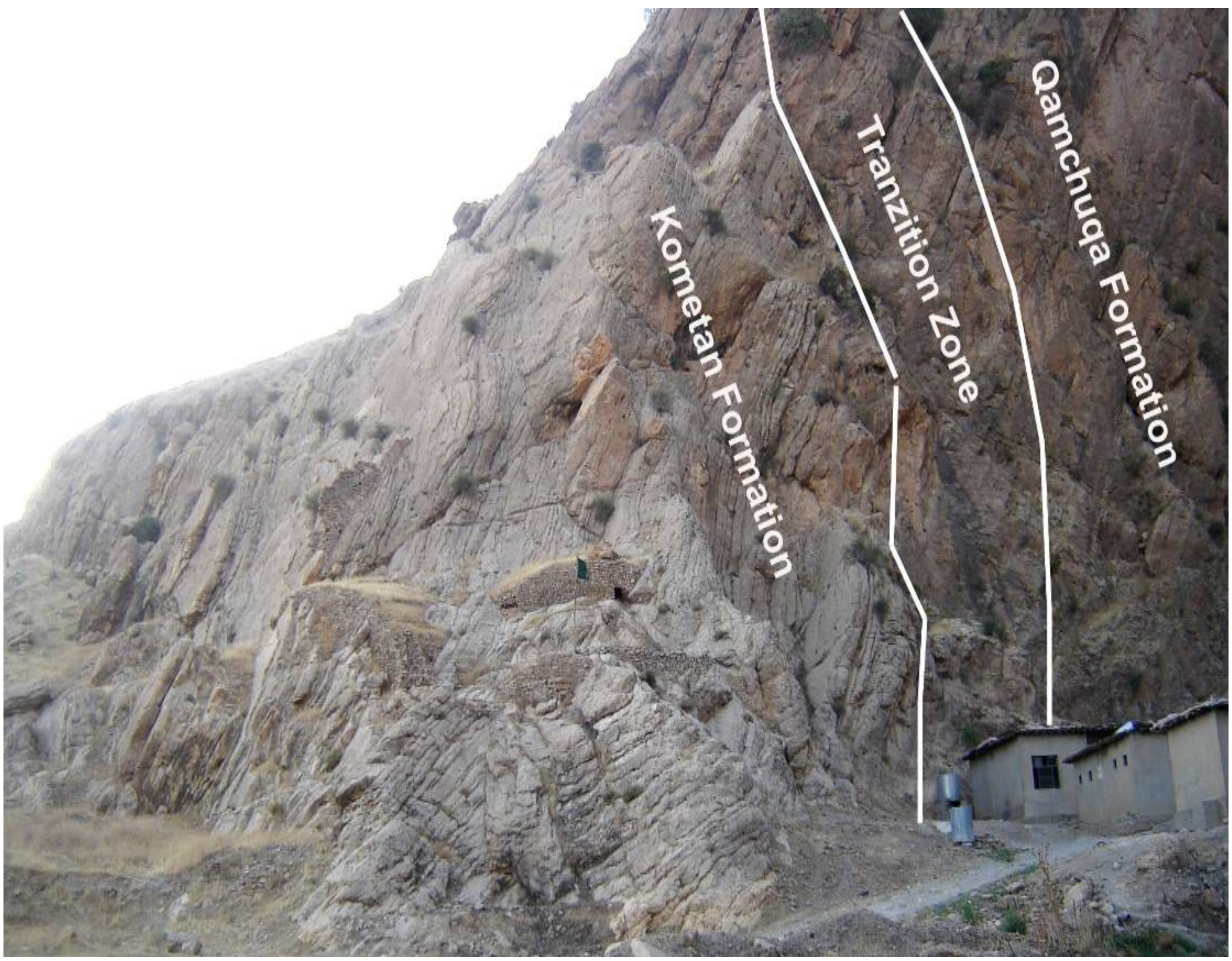

Fig (2.14) Upper conformable contact between Qamchuqa and Kometan Formations, Qamchuqa Gorge section.

2.3.3. Stratigraphic position of the boundary between Lower and Upper Qamchuqa Formation

In all studied sections, the clear evidence of the lower and upper Qamchuqa Formation is not obvious as the whole succession consists of limestone and dolomite units without clastic intervals to separate the formation into two parts. The Formation cannot be divided into upper and lower Qamchuqa Formation in the studied area. However, there are some signals of the equivalent of Upper Sarmord Formation, which separate the formation in south and middle Iraq into lower and Upper Qamchuqa Formation (Shuaba and Maudud Formations respectively). These signals exist in L2, which contain some signals of deepening demonstrated by thin beds of marl and thick bed of marly limestone(Fig.2.14). The stratigraphic position of this unit is located nearly in the same position of the Upper Sarmord Formation. According to these, it is possible that the L2 represents the equivalent of Upper Sarmord Formation of Bellen et al.(1959) and Buday (1980).

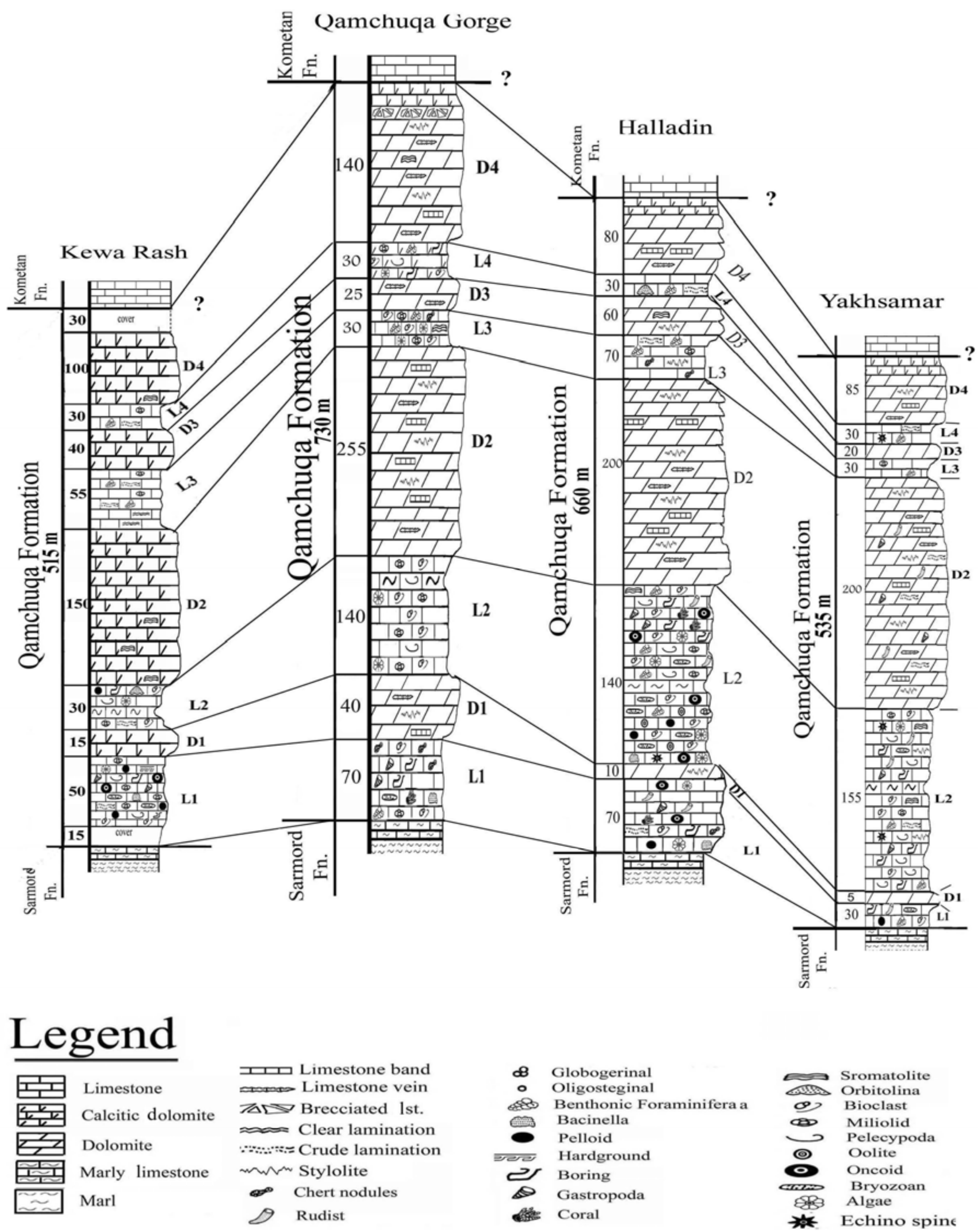

Fig.(2.15) Lithofacies correlation of the studied sections

CHAPTER THREE

MICROBIALITE

3.1. Preface

The microbialite is developed by accretion and agglutination of fine sedimentary particles by microorganisms, especially by bacteria, cynobacteria, algae and micro encrusting organism in general, such as foraminifers. They may also form by mineralization on the surface of some organisms and by biomineralization inside the organic test when the organism is still living. The microbialite have played a major role in the formation of carbonate deposits at geological scale, during the Precambrian and the Phanerozoic, in marine, marginal marine and non-marine environment. The microbialites, together with the fossil organisms provide indications on the paleoenvironment, including factors such as light, energy and water depth, salinity and climatic change (Immenhauser, et al. 2005).

Leinfelder et al., (1996) studied the microbialite in the Late Jurassic, and they said that the low-energy reefs may have excellently preserved framework and pronounced relief whenever microbialite crusts provided stabilization, and also they said that the reefs in steepened slope setting are generally rich in microbalites because of bypass possibilities for allochthonous sediment.

Three questions could be imagined when stepping the outcrops of the carbonate rock of Qamchuqa Formation, which is more than 600 m thick. The first is "what is the origin of the huge thickness of calcium carbonate". The second is "what is the nutrient for survival of all organisms that were living in the basin of Qamchuqa during Early Cretaceous". The third is "why do so much bioturbation exist in the beds of the formation". Especially, most parts of the formation apparently consist of massive grey or milky fine crystalline mudstone or micritic limestone.

These questions have triggered deep thinking and extensive fieldwork for answering them. The starting point for answering the questions is finding extensive oncoids (small spherical stromatolite) in thick successions and some planar, vertical or wavy stromatolites. Thin section and scanning electronic microscope investigation showed that they are attributed to microbes (cyanobacteria and algae). Therefore, we can say that the nutrient for organisms in the formation was bacterial and algae colonies or cultures, which were forming stromatolites.

Therefore, the answers of the three questions are all related mainly to the bacteria, which were forming extensive bindstones and nearly most organisms (Gastropods pelecypods and rudists) were living on them. Moreover, the extensive (bioturbation) burrows were made by pelecypods and gastropods mainly for search for bacterial and algal cultures and colonies. The fine lime mudstones are most probably the products of the disintegration of biogenetically deposited bacterial carbonate and algae.The grazing animals such as gastropods and pelecypods have the main role in disintegration in addition to wave and currents. In addition to destruction, the wave and current were responsible transported the excessive lime muds to surrounding and forereef and deep basin to be deposited as Balambo Formation.

In literature, the science that explains the role of microbes in geology and classifies them is called microbalite. This term is introduced by Burne and Moore, (1987). Therefore the science of microbalites is a new science, which is very useful for studying of carbonate of Iraq, especially it is found in the other formations such as Avroman (Karim, 2007). Salae (2001) has studied stromatolite in Barsarine Formation and attributed them to green algae.

3.2. Definition of microbalites

The hereinafter-mentioned definition of microbalite is compiled from several authors such as ,Burne and Moore (1987) Ridding (1991) Kenter *et al*. (2005) and Daood, (2006) According to these authors, Microbalite is defined as “carbonate sedimentary rocks that are deposited due to activities of microorganisms (microbial community) such as, cyanobacteria, hetetrotophic bacteria, algae and fungi. The cultures of these organisms generated a biofilms in which carbonate precipitate by accretion, metabolism and extra cellular polymeric matter. The biofilms bind sediments by agglutination of fine sedimentary particles. The microbalites mainly depend on photosynthesis for food generation especially that formed by cyanobacteria, but microbialite formation is not necessarily light dependent and can apparently take place without cyanobacteria.

3.3. Classification of microbolites

Leinfelder and Schmid (1996, in Daood, 2006) proposed a refined classification and nomenclature of microbialites, based on a combination of both microstructure (e.g. peloidal crusts) and macrostructure (e.g. thrombolites). In macroscopical scale, three types of microbialites can be distinguished: Thrombolites, stromatolites and leiolites (Braga *et al.* 1995), the lieolites being characterized by a dense structureless mass of microbal origin carbonate. In earlier literature, some confusion occurred by mixing up structures of different dimensions and using them both for classification often involving growth forms such as oncoids (e.g. Burne and Moore, 1987). In mesoscopic scale, various growth forms do occur, ranging from massive, columnar microbialites to dendroid or reticulate forms as well as spheroidal forms (oncoids).

Growth forms depend mainly on sedimentation rate and water energy; for example, microbialites develop dendroid forms as a reaction to slightly elevated rate of the sedimentation at low-energy conditions (Schmid, 1996). Thus, characterizing a microbialite-rich reef can be done by considering the microstructure, macrostructure, morphology and growth form. Microbialites play a paramount role in reef building. Whereas, previously microbialites were mostly considered as secondary, merely binding organisms within the reef build (Fagerstrom, 1987). They are acknowledged by now also as genuine constructors, especially in Late Jurassic reefs, are frequently responsible for large parts, if not the entire primary reef that Late Jurassic reef corals favor. According to Kempe and Mierc (1994), the wide spread of microbialite in certain age, may be resulted by a slightly elevated seawater.

The microbialites have played a major role in the formation of carbonate deposits at geological scale, during the Precambrian and the Phanerozoic Era, in marine, marginal marine and non-marine environments. Even today, microbialites are important products in fluvial environments, springs, cavities and soil. In the same time, they play an important role in the lithification of reef deposits. Within the reefs, the interland the intraclast cavities are filled with microbialites associated with micro encrusting organisms, such as *Bacinella irregularies, Tubiphytes obscures, Lithocodium aggregatum* and encrusting foraminifera. Mineralization under marine microbial environments is more obvious in the reef and intertidal areas. In non-marine environments is more in the areas where CO_2 release is a faster process, such as springs and waterfalls, or where evaporation is more intense such as lagoons.

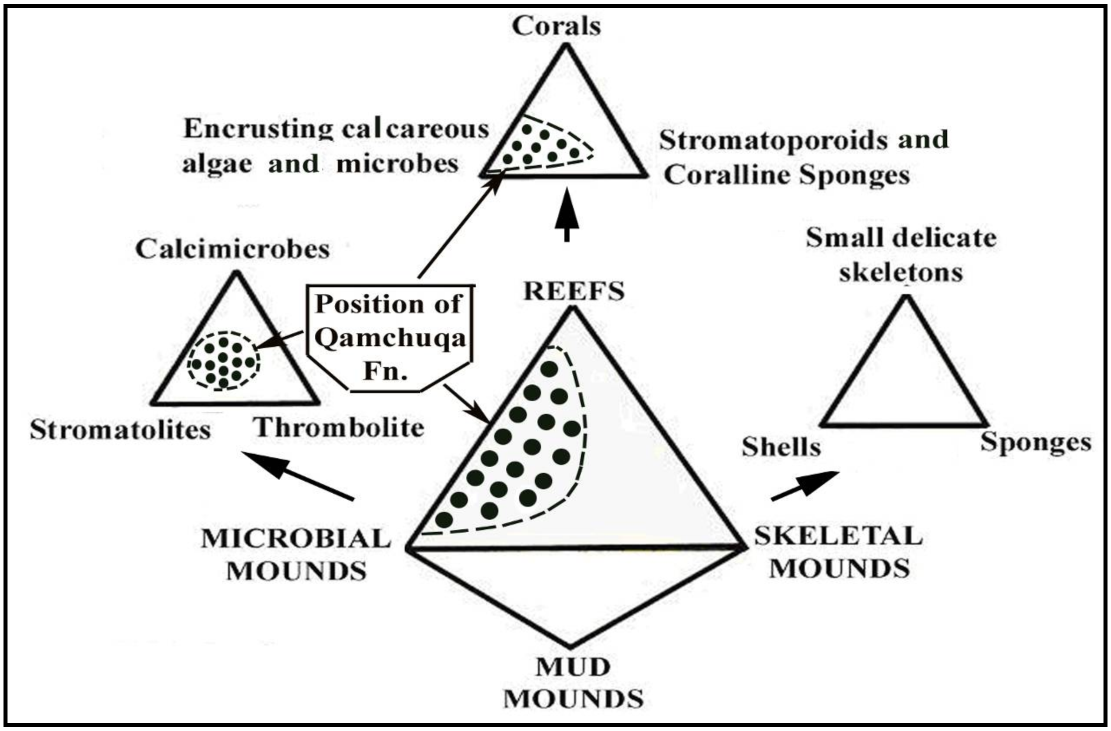

Fig. (3.1): A conceptual classification of reefs and mounds (After Walker and James, 1992) in which the position of Qamchuqa Formation is indicated on the basis of the fact that microbes can form mound.

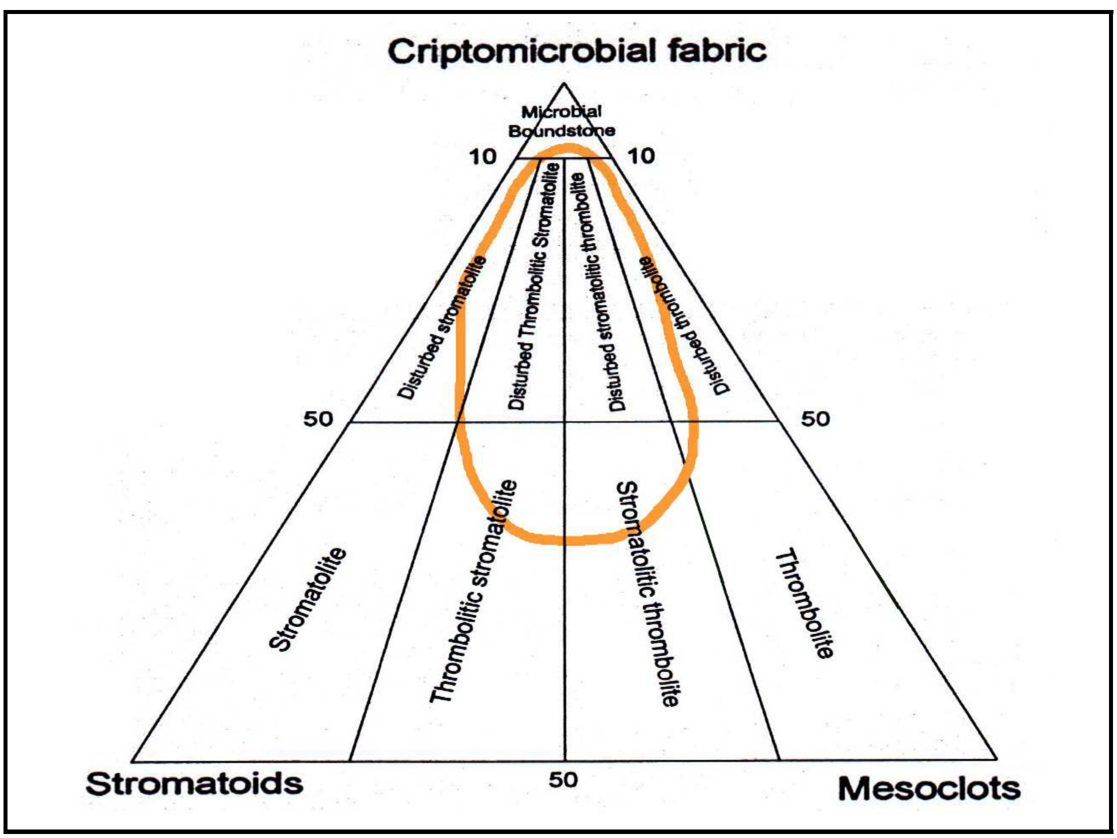

Fig.(3.2) Position of Qamchuqa Formation (Gray circle) within microbialite classification of Schmid (1996).

3.4. Types of structures

The microbolites show great macro and microscopic morphological variety due to their complex biological, chemical and physical functions. Shapiro (2000) defined three structural scales for the microbialites represented by:

1. Megastructures

They are those microbialitic structures, which have domal or which are domes in shape of microbial limestones of metric sizes such as bioherms or biostroms. Dome type of structure is not found in the Qamchuqa Formation, which may be attributed to abundances of grazing animals that disturb structures of microbialites. However in some sections, such as Buko Zawa valley, northwest of Dokan town, a one meter thick bed with lamination of 5 to 15 mm thickness in dolomite of upper part of the formation could be seen, which can be regarded as mega structure but has no dome shape.

2. Macrostuctures

These types of microbialites are referring to dome or columnar bodies with diameters typically in the cm-m range meso-structures (internal textures of the macrostructures visible by naked eye at the scale of the outcrop, such as lamination, clotted or dendritic fabrics). This type has been found in several sections in both the L1 and D4 such as Halladin, Kewa Rash, and Zhelwan Mountain (Fig. 3.7)

3. Microstructures

They are those microbialitic structures, which are identifiable by optical or electronic microscope. Kennard and James (1998) introduced a classification of the two distinctive types of microbialites represented by thrombolites and stromatolites. This classification scheme is based on the relative abundance of the two main components:

a. Stromatoids

Are laminated stromatolites formed by accretion by cynobacteria filaments, which exist in the Qamchuqa Formation (Fig. 3.16 and 3.18).

b. Microbial glomerules

This type of microbial features belong to the thrombolites which is primarily consists of colonial communities of calcified coccoids. This feature has been seen under electron and ordinary microscopes (Fig.3.18).

In this study, the main types of microbialites, which are present in Qamchuqa Formation are:

3.4.1. Stromatolites

Most of the stromatolites have an exclusive carbonate nature, but some of them may have siliceous or evaporitic origin (Blatt et al., 1980). Stromatolites can be defined as laminated organosedimentary structures formed by sediment trapping, binding and or precipitation because of the growth and metabolic activity of microorganisms, principally cynophytes (Walter, 1976). Stromatolites are laminated microbial deposits, where the principal organisms involved are probably bacteria and algae, such as diatoms and chlorophytes (Riding, 1993). Stromatolites grow in various subtidal marine environments, such as lagoons, reefs, shelves… etc. (Walter, 1975). Hoffman (1974) described the stromatolites from the Precambrian of the United States, ranging from platform-shoal to basin floor environment. Grotzinger et al.(2000), and Johnson and Grotzinger (2006) studied the stromatolite growth and morphology in Nama Group at Namibia, and they mentioned that the stromatolite may directly affect reef growth.

The stromatolites reached a high abundance and diversity by Mid and Late Precambrian (2000 million years) and then declined towards the onset of the Phanerozoic, and from this time the stromatolites have persisted within restricted environment until today. The abundance of the stromatolite in Precambrian is attributed to absence of grazing animals such as gastropods and peleypods.

In the Qamchuqa Formation, the laminae of the stromatolite are very clear in hand specimen and under microscopes. Under microscope, two general types can be distinguished. The first type is that in which the laminae show no internal microscopic structure. This type consists of dark and light colored laminae without ghosts of filament and cysts of the microbal colonies (Fig.3.10). The second type shows microbial sheath of the colony (or microbial culture). The sheath resembles elongated tube-like closed bodies arranged normal to the horizontal plane of the laminae. The sheath are covered by very thin black micritic laminae and internally filled with spary calcite.

When the classification of the Feldmann and McKenzie (1998) is used, the studied stromatolites belong to eukaryotic stromatolites, which comprised of microbially induced micritic layers alternating with detrital layers accumulated, bound, and cemented by eukaryotic algae. The alternating laminae reflect growth of the microbial mat organic layer followed by sedimentation; trapping and binding of the sediment grow through, to form a new-organic layer at the surface once more. According to (Tucker, 1991), in old stromatolites the laminae are usually consists of alterations of dense micrite, perhaps dolomitized, and grains such as pellets and fine skeletal debris

The morphological variation of stromatolites largely depends on environmental factors such as water depth, tidal and wave energy, frequency of exposure and sedimentation rate. Large stromatolite columns (almost reefs) grows in shallow, high energy tidal channels. Logan *et al.* (1964) classified stromatolites (microbial mat) on the basis of their sites of growth relative to sea level. It was a geometric term (hemispheroidal and spheroids) from which stromatolites and oncolites are built.

Eight Types of stromatolites were distinguished in the Qamchuqa Formation, these are:

3.4.1.1. Flat stromatolite

This type of stromatolite very common in the Qamchuqa Formation; it consists of flat and thinly laminated light gray to milky limestone with dark colored laminae. The laminae are continuous for several meters and exist in limestone Units of L2 , D2 and D4 and containing fenestrae, which are filled by sparry calcite or dolomite which may represent primary voids due to loose growth of the mat (Fig.3.3 and 3.4).

According to Hoffman (1974), these types are formed wherever the current action is very weak; the mat is continuous, without any structure relief. They usually form in protected areas.

Fig. (3.3) Flat stromatolite in the Yakhsamar section

3.4.1.2. Wavy (bulbous) stromatolites

This type of stromatolites is found in the Halladin section, 7–30 cm thick and 11–50 cm long. They constitute of broadly and laterally-linked hemispheroids (LL-- H). They end by ragged (irregular) boundary and have not enveloping bands and have irregular boundaries (Figs. 3.10, 3.11and 3.12 B, C). According to Walker and James (1992), this type is grown to resist water roughness.

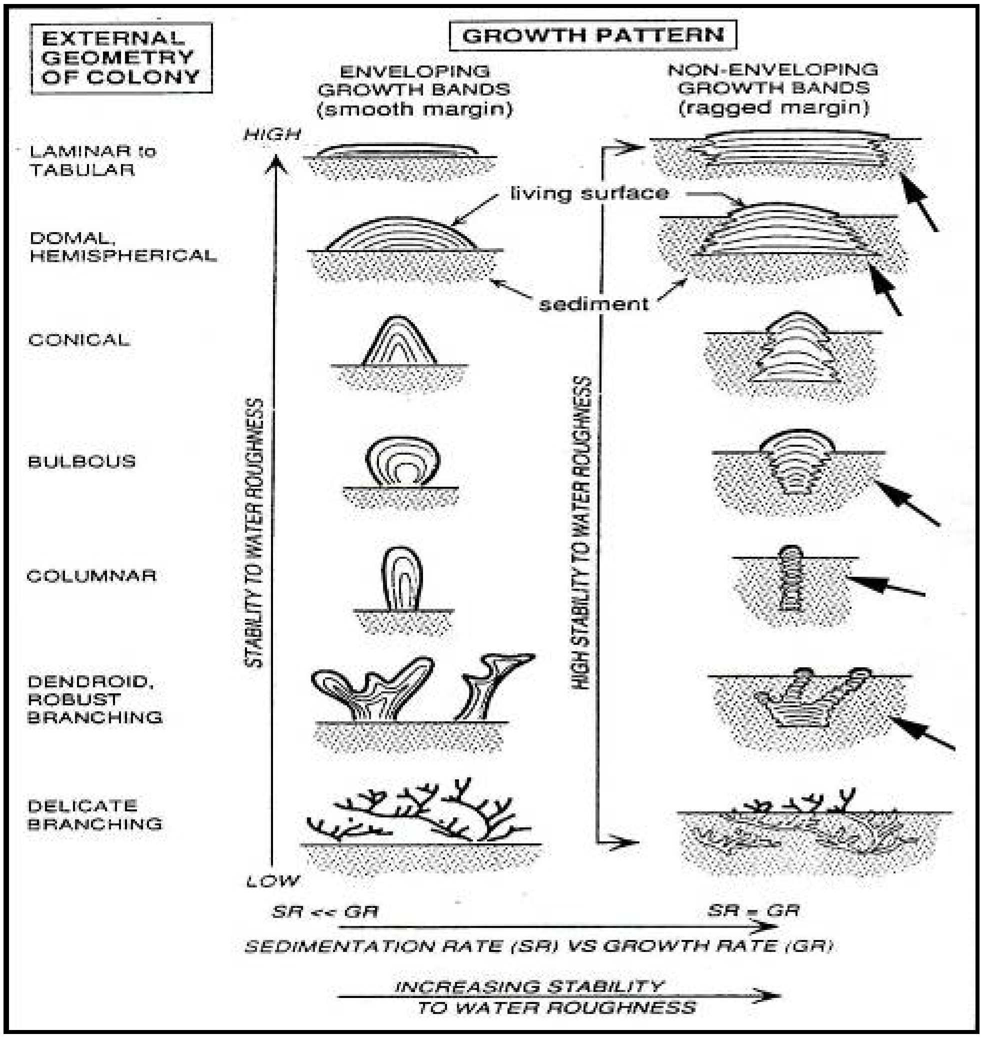

Fig. (3.5): Control of water roughness and sedimentation rate on resulting external and internal geometry of fossil metazoan colonies (Walker and James, 1992). The types that are indicated by solid arrow are found in the Qamchuqa Formation .

3.4.1.3. Blistered stromatolite

This type of stromatolites is small-scale, closely spaced growth proturbation (Fig.3.11). Blistered stromatolites are largely scoured by wave action; it can be distinguished from flat and stratiform stromatolite. The more irregular blisters are very comparable to convoluted algae that are described by Logan (1964).The ancient blistered stromatolites are described by (Leeder, 1975) from Nothumberland basin. All blistered stromatolite are associated with dolomite crystals at Qamchuqa Formation.

3.4.1.4. Oncoid stromatolite (spheroidal stromatolite)

The second type of stratitform stromatolite is oncoid stromatolite that is found only in the Lower Limestone Units (L1) in all sections. Oncoids are biogenic grains more than 2mm in diameter, which consist of concentric laminae arranged around a nucleus. The nucleus may be shell fragment, sand grain and / or earlier oncoid around which the laminae are deposited. The deposition is attributed to the processes of trapping and binding of sediment by microbial organism, such as primitive blue green algae (Cynaobacteria or blue-green bacteria) and fungi with the aid of direct precipitation of carbonate minerals (Hoffman, 1976; Pettijohn, 1975; Blat *et al.,* 1980 and Selley, 1988). In this study, the small fragments of the oncoids are examined (for structures) under scanning electron microscope to indicate the origin of the depositions. Under microscope, aggregate of globular bodies each about one micron in diameter are shown (Fig.3.17). In literature, these bodies are ascribed to calcified cysts of cynobacterias (Krumbein and Cohenl, 1977).

The comparison of the oncoids, in literature, with that of the present study showed that the oncoids of the present study have nearly the same characteristics of those cited in literature. This is because they have nearly spherical shape and the laminae are more concentric and continuous with occurrence of composite oncoids (Figs.3.6 and 3.10). The shapes of the oncoids are spherical, oval or elongated; this depends on nuclei, so that wherever the nuclei are elongated, then oncoids maintain nearly the same form. Occasionally, composite oncoids are formed and consist of several smaller bodies, grown together and enveloped by lamina of later growth. Moreover, their size ranges from gravel to coarse sand (2 mm–4 cm) (Figs.3.6 and 3.10). According to Lehrmann *et al*. (1998), oncoids indicate occasional wave agitation, probably near wave base, while Gunatilaka (1977) mentioned that oncoids are very likely a morphological and ecological adaptation of the mate forming communities to specific energy conditions.

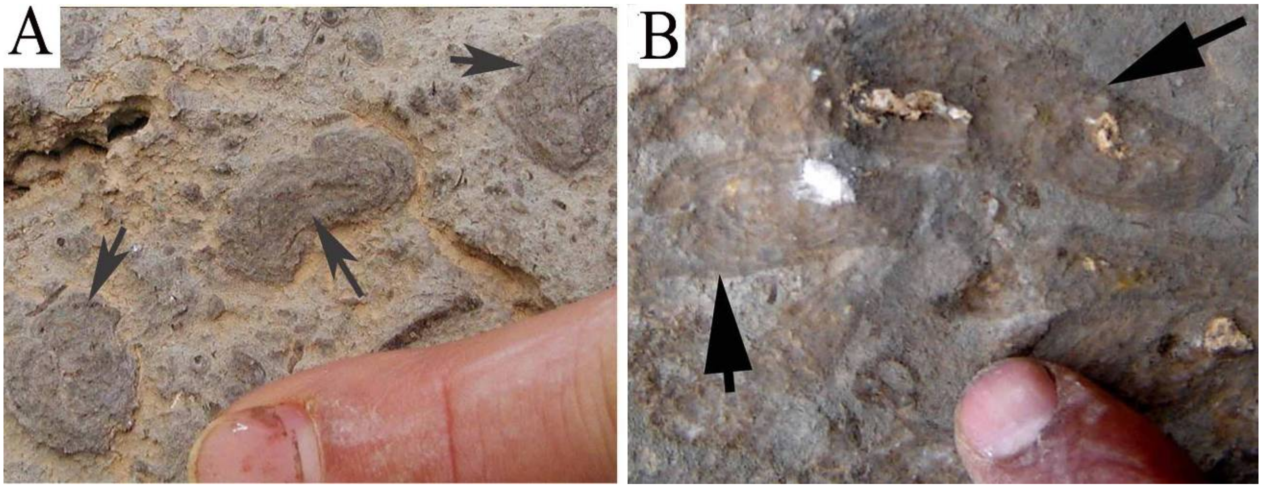

Fig. (3.6) A: Most oncoids in Qamchuqa Formation are deformed and have faint, laminae , lower limestone (L1) beds of Piramagroon anticline. B: rare oncoids have well developed laminae, Halladin section.

3.4.1.5. Vertical stromatolite:

This type of stromatolites is found in the Halladin section, they are 2 – 5 cm thick and 6 – 15 cm high. They are ended by planar stromatolite, at the top frequently, branched and have irregular boundaries (Figs.3.7 and 3.10). According to Walker and James (1992), this type is grown when the rate of sedimentation equals to rate of the growth (Fig. 3.5).

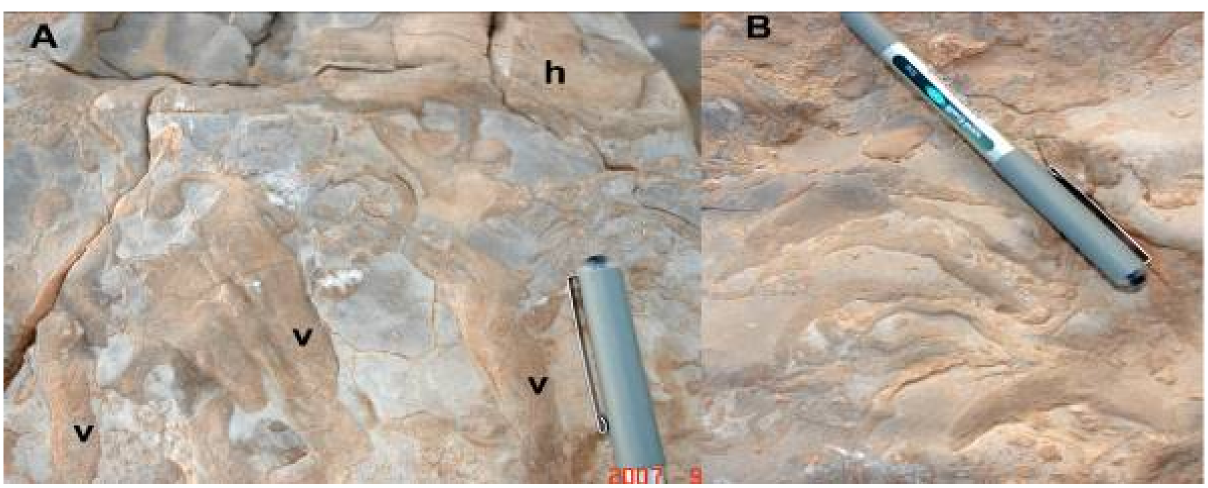

Fig. (3.7) A. Vertical stromatolite (v) with irregular boundaries which are ended by flat ones (h) at the Halladin section. B. dome-like stromatolite in the southwestern limb of Zhelwan anticline.

3.4.1.6. Cryptalgal stromatolite

The cryptalgal stromatolite believed to originate through the sediment-binding and/ or carbonate precipitating activites of non skeletal algae. The existence of sediments, with distinctive style of more or less planar lamination is due to sediment binding activity of algae; it is suggested that the cryptalgal laminate structure can be designated as mode “planer”(Aitken,1967).

In the Qamchuqa Formation, the cryptoalgal stromatolites are often confined to thick dolomites; they displayed crude and discontinuous laminations (Fig.3.10).

3.4.1.7. Ragged stromatolite

This type of stromatolite has ragged boundary shape (Fig.3.10). The growth pattern of stromatolite, as external geometry of colony, is shown in fig. (3.5) represents the sedimentation rate (SR) equal to growth rate (GR), the individual beds are 5 to 25 cm thick. This lithofacies is present in the lower and middle part of Halladin, Qamchuqa Gorge and Kewa Rash sections. This lithofacies is similar or equivalent to the bindstone microfacies classification (Embry and Klovan, 1971)

3.4.1.8. Flat pebbles stromatolite (Flat pebbles conglomerate)

This type of stromatolite is found in the Halladin section, below in the middle part of the L1 Unit, which consists of imbricated flat pebbles (elongated in the sections) which lithologically belong to planner stromatolite (Fig.3.11 A). The clasts consist of angular pebbles and cobble sized grains that show no transportation. They are associated with bioclasts and smaller lithoclasts. The lithology, imbrication and angularity testify the that the pebbles are intra-formation in origin and deposited after suffering of the reef, from striking of severe storm after deposition of the stromatolite. Many authors considered that intraformational flat pebbles are resulted from storm (Jones and Dixon, 1976, Sepkoski,et al.

1991) or from tsunami action (Kazmierczak and Goldring, 1978). Kullberg et al (2001) interpreted the origin of as effects of seismic–shock and gravity sliding.

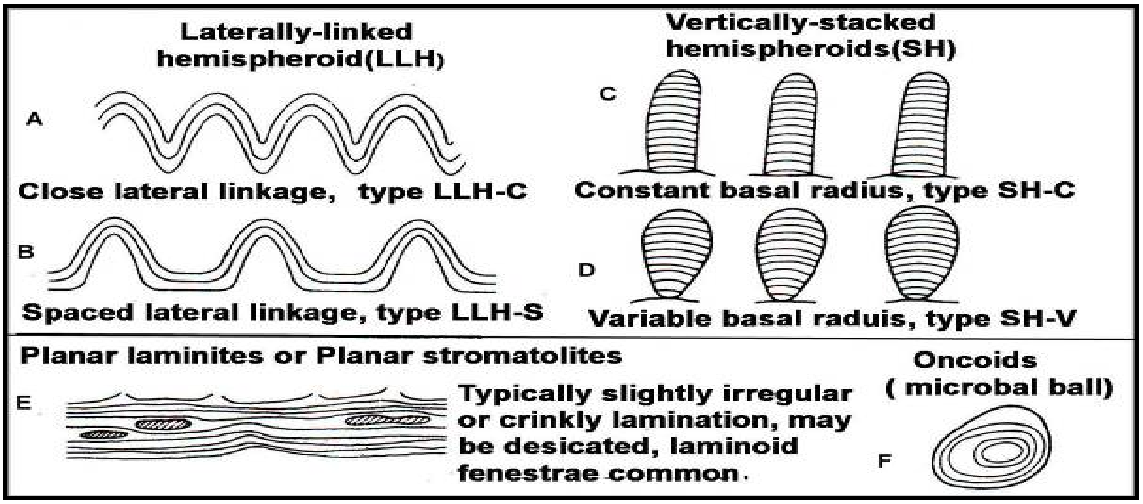

Fig. (3.8) Classification of stromatolite (Logan *et al*. ,1964 in Tucker, 1996). In the present study the A, C, E, and F types are found.

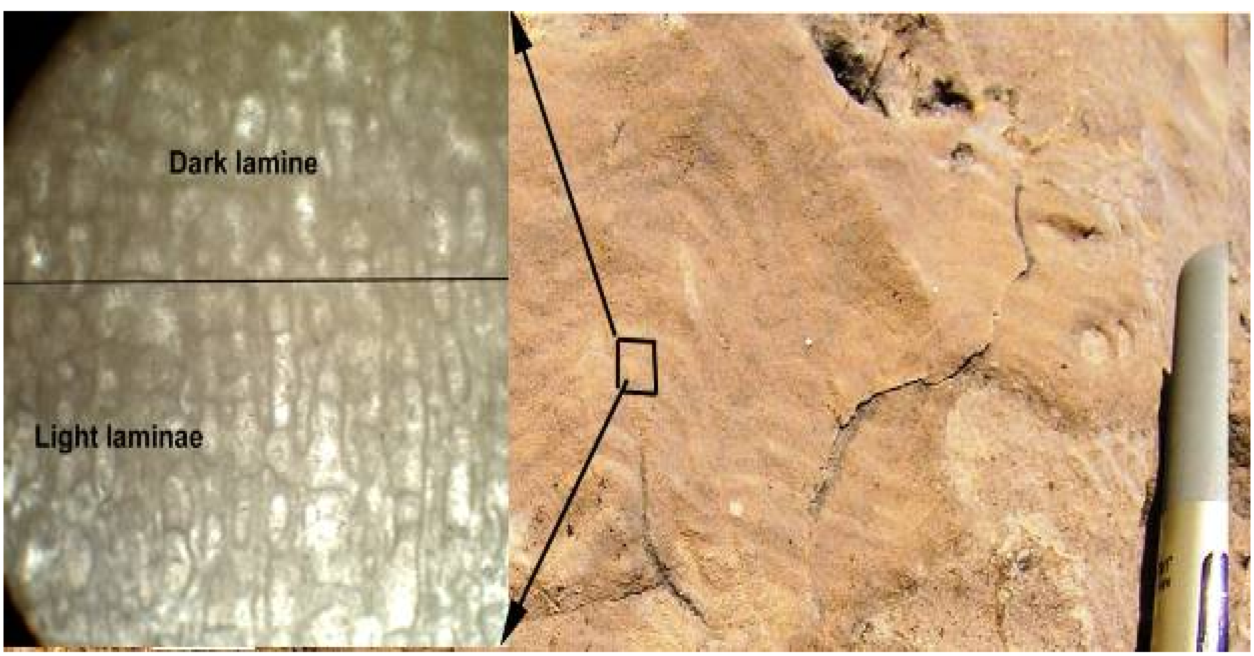

Fig. (3.9) Wavy stromatolite, Halladin section with it's microstuctures, which consist of elongated micritic sheathes (right), most possibly constitute the microbial colonies, Halladin section.

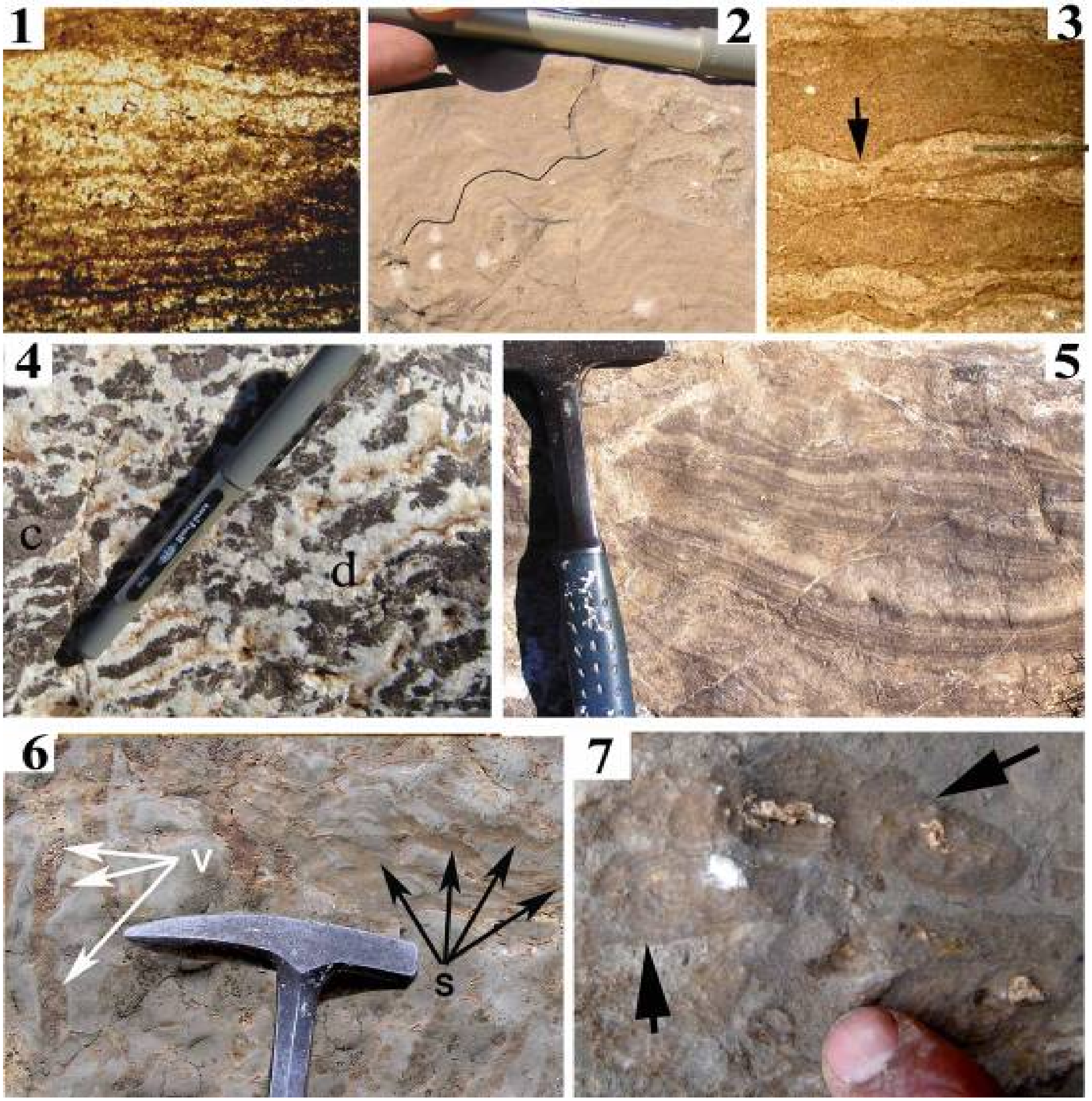

Fig. (3.10):

1- Flat stromatolite, show lamination, Halladin section, X40,P.L.

2- Wavy stratiform stromatolite(wavy back line),Kewa Rash section.

3- Blistered stromatolite, Halladin section,X40,P.P.

4- Cryptoalgal stromatolite, laminated with couplets that are different in color and composition. Thin layer of light color dolomite (d) and dark layer of limestone(c). Yakhsamar section.

5- Ragged stromatolite,Piramagroon Mountain.

6-Columinar (vertical) stromatolite (V white arrow), stratiform stromatolites(S black arrow). Kewa Rash section.

7- Oncoid stromatolite (arrows), Halladin section

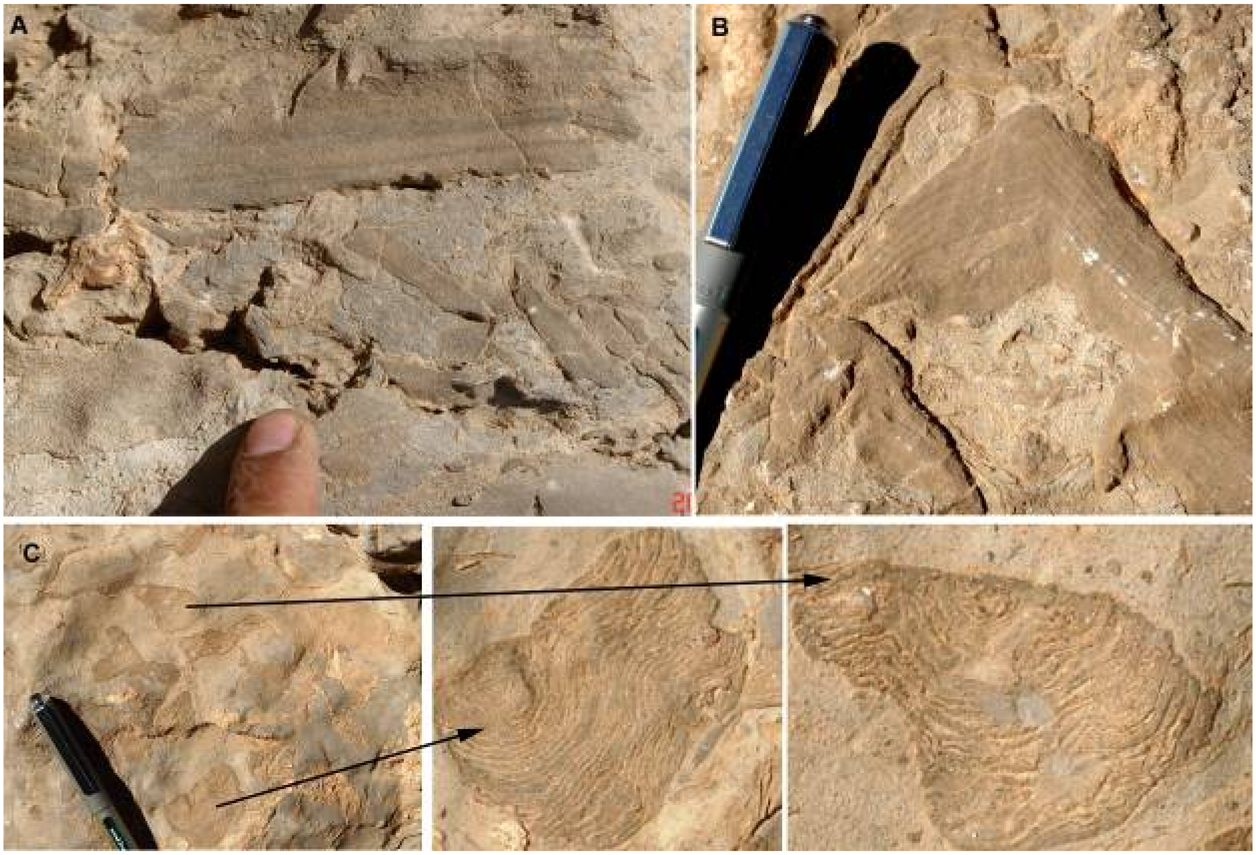

Fig. (3.11) A) Stromatolitic flat pebble showing imbrication of some clasts B) inverted v-shaped stromatolites. C) Isolated patches of stromatolites, two of which are enlarged in the right as indicated by arrows, Halladin section, Unit L2.

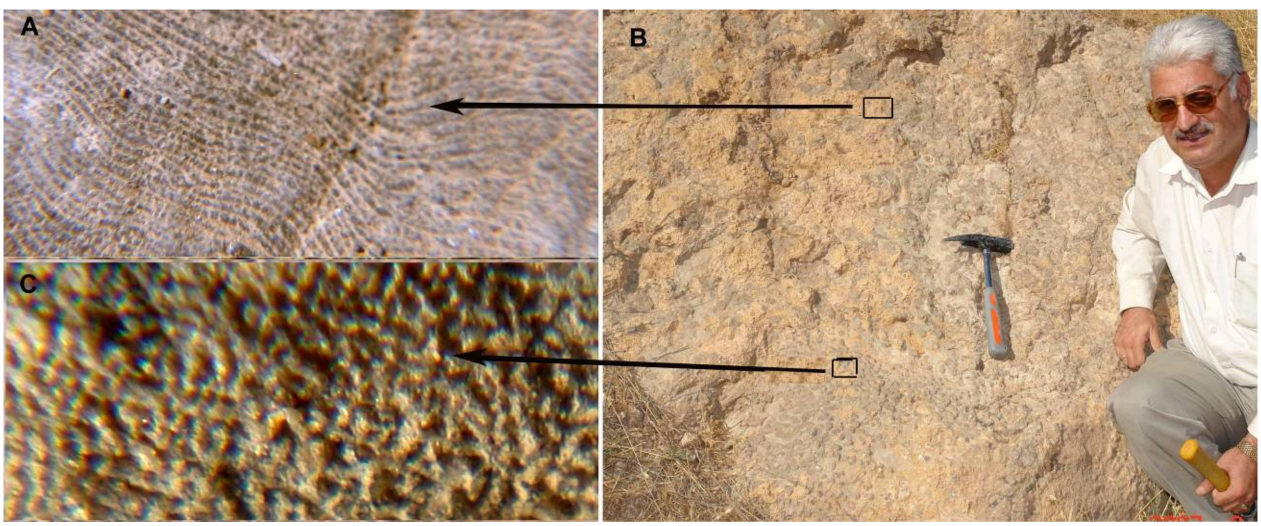

Fig. (3.12) B: Nodular limestone, when inspected under microscope it consisted of very fine wavy stromatolite of cynobactria origin (A) and vertical algal colony, which has reticule structure of green algae origin (C).

3.4.2. Thrombolites

The term of thrombolites has been introduced by Aitkin (1967) for that type of microbolite, which consists of clotted fabric and more or less rounded small bodies with general obscured internal structures (Fig.3.13). The laminations are disturbed and hard to be identified, but they contain a network of small-coated fenestrae and coated grains (Aitkin, 1967 and Shpiro, 2000). It is formed, like stromatolite, by products of trapping and binding of grains (Fig.3.14), by filamentous cynobacteria or they were an extensively burrowed form of stromatolite. Thrombolites are clotted algal or cynobacterial mats, can be found in a range of aquatic environments: fresh water, marine and hypersaline. Feldmann, *et al*.(1998) mentioned that the thrombolites formed by microbes,algae and metazoans,and also mentioned Phanerozoic thrombolites have been interpreted as unlaminated stromatolites constructed by cynobacteria.

Environmental conditions must favor growth of thrombolite to accumulate thickly enough, to be recognized in the fossil record. Such conditions may include a super saturation of calcium carbonate in the water, slow rates of sediment accumulation, or elevated salinity and temperature conditions. Modern thrombolites are found in a variety of environments including hypersaline lagoons, tidal channels and fresh water lakes.

Oliver *et al.*,(2002) mentioned that the microbial crusts, played an important role in the stabilization and grouth of the reef body, which developed on various substrates such as corals,bivalves or bioclassts. Grotzinger *et al*.(2000) and Johnson and Grotzinger (2006) studied the thrombolitic microbiolite growth and morphology in Nama Group at Namibia, and they mentioned that the stromatolite may directly affect reef growth.

The following sentences are cited in the web under the title of Cynobacteria, thrombolite/cyanobactria “The **stromatolites** are produced by the activity of cyanobacteria through precipitation of calcium carbonate over the growing mat of bacterial filaments, which perform photosynthesis by which bacteria deplete carbon dioxide in the surrounding water and initiate precipitation. The minerals, along with grains of sediment, being precipitated from the water, are then trapped within the sticky layer of mucilage that surrounds the bacterial colonies, which then continued to grow upwards through the sediments to form a new layer. As this process occurs repeatedly, the layers of sediments are created. This process still occurs today in *Shark Bay* in Western Australia, which is well known for the stromatolite. In some cases, the stromatolites were infiltrated with a mineral-rich solution, which fossilized the bacteria along with the layers, but more often only the layers are preserved".

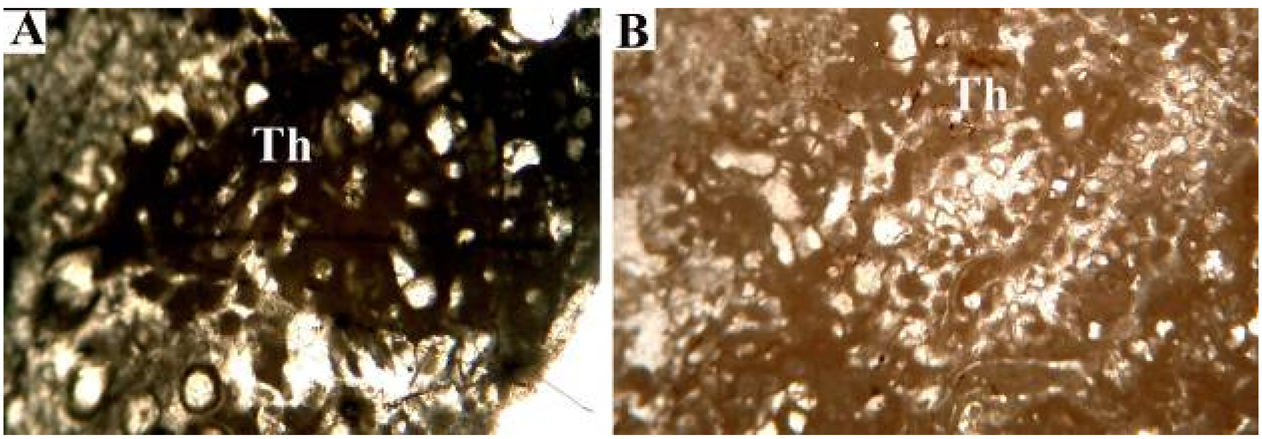

Fig.(3.13) Clotted pelletal stromatolite (thrombolite) in the Yakhsamar section undermicroscope X40 p.p.

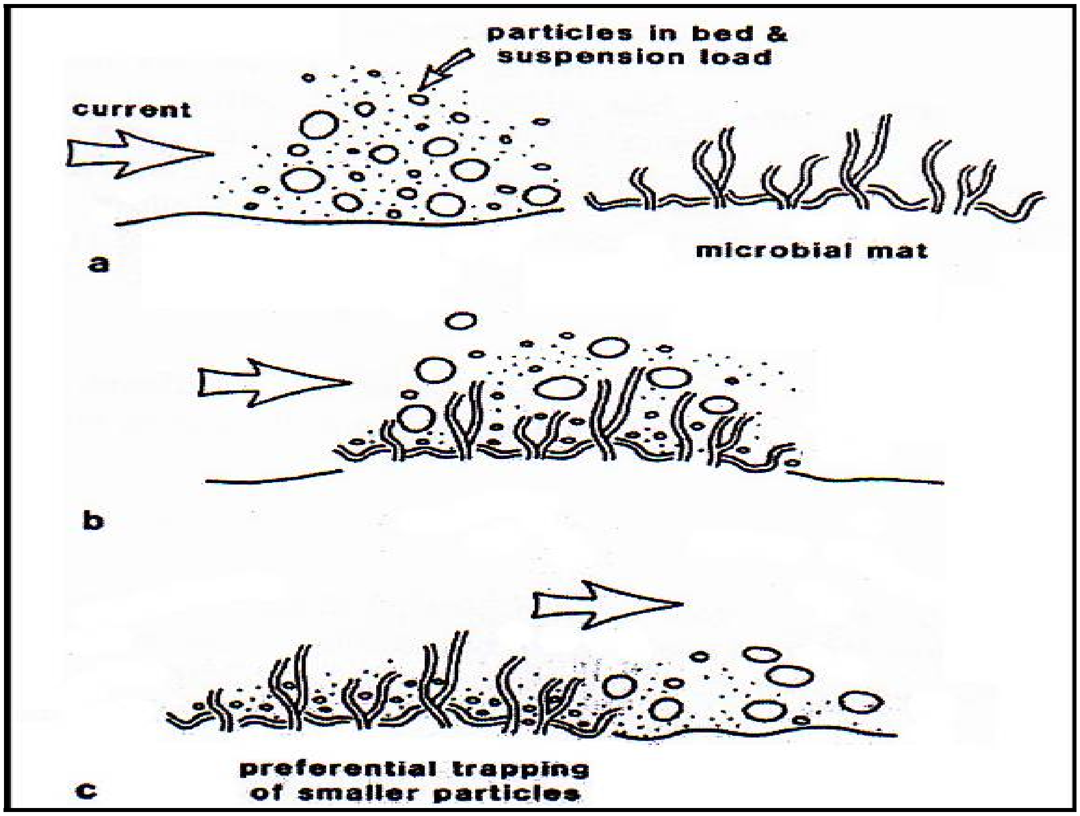

Fig. (3.14) Selective trapping of smaller particles by a benthonic microbial mat community. (Riding, 1991)

Algae and algal carbonates are of interest to geo and bioscientists because of the significant interactions between algal life and environment. Two types of algae were recognized in the Qamchuqa Formation. The following are the most common types:

3-4-2-1. Cyanobactreia (Blue-green algae)

The term Cynobacteria is Greek: Kyanos, means blue with bacteria, also Known as Cynophyta is a phylum of bacteria that obtain the energy through photosynthesis. Cynobecteria is often still referred to as blue-green algae, although it is in fact prokaryotes like bacteria (from web, Wikipedia, cynobacteria). The description is primarily used to reflect their appearance and ecological role rather than their evolutionary lineage. Cynobacteria include unicellular and colonial species. Colonies may form filaments, sheets or even hollow balls. Cynobacteria have an elaborate and highly organized system of internal membranes, which function in photosynthesis. Photosynthesis in cynobacteria generally uses water as an electron donor and produces oxygen as a by-product, though some may also use hydrogen sulfide when occurs among other photosynthetic bacteria. Carbon dioxide is reducing to form carbohydrates (Cribs,1996).

Cynobacteria are considering simple aquatic plants, some of cynobacteria contain small gas bubbles within their cell. These bubbles are allowing them to float at the water surface, or to sink to the bottom, as response to changes in the light regime or nutrition availability. Cynobacteria live as planktonic or benthonic aquatic or subarial epi-and endolithic organisms, in fresh waters, marine and hypersaline environments, but usually preferring alkaline waters, no cynobacteria was identified in waters with pH values below 4.

There are two types of Cynobacteria, the first is coccoid blue green algae, which deposits in summer and the second is filamentous (Fig.3.17) which deposits in winter (Flugel, 1977 p39).Some layered stromatolite are produced by the activity of ancient Cynobacteria. The layers produced as calcium carbonate are precipitated over the growing mat of bacterial filaments (3.15). In some cases, the stromatolites infiltrated with a mineral rich solution, which fossilized the bacteria along with the layers, but more often only the layers are preserved.

Algae and Cynobacteria make a major contribution to limestone by providing skeletal carbonate particles, trapping grains to form laminated sediments and attacking particles and substrates through the boring activates. Although few Cynobacteria are calcified, they have a profound effect on sediments through their boring activities and microbial (algal) mat formation. A large proportion of skeletal fragments in modern and ancient carbonate sediments posses a dark micritic envelope around the grains. The envelope is mostly produced by endolithic cynobacteria, which bore into the skeletal debris and subsequently filled with micrite. Repeated boring and filling result in a dense micrite envelope, which is the altered outer part of the skeletal grain (Tucker, 1991, p120).

Cynobacteria are becoming increasingly prominent on declining reef (Reijmer and Immenhauser, 2005). The cynobacteria are mucilaginous and this together with its filamentous nature, results in the trapping and binding of sedimentary particles to produce a laminated sediment or stromatolite (Riding, 1991) (Fig.3.16).

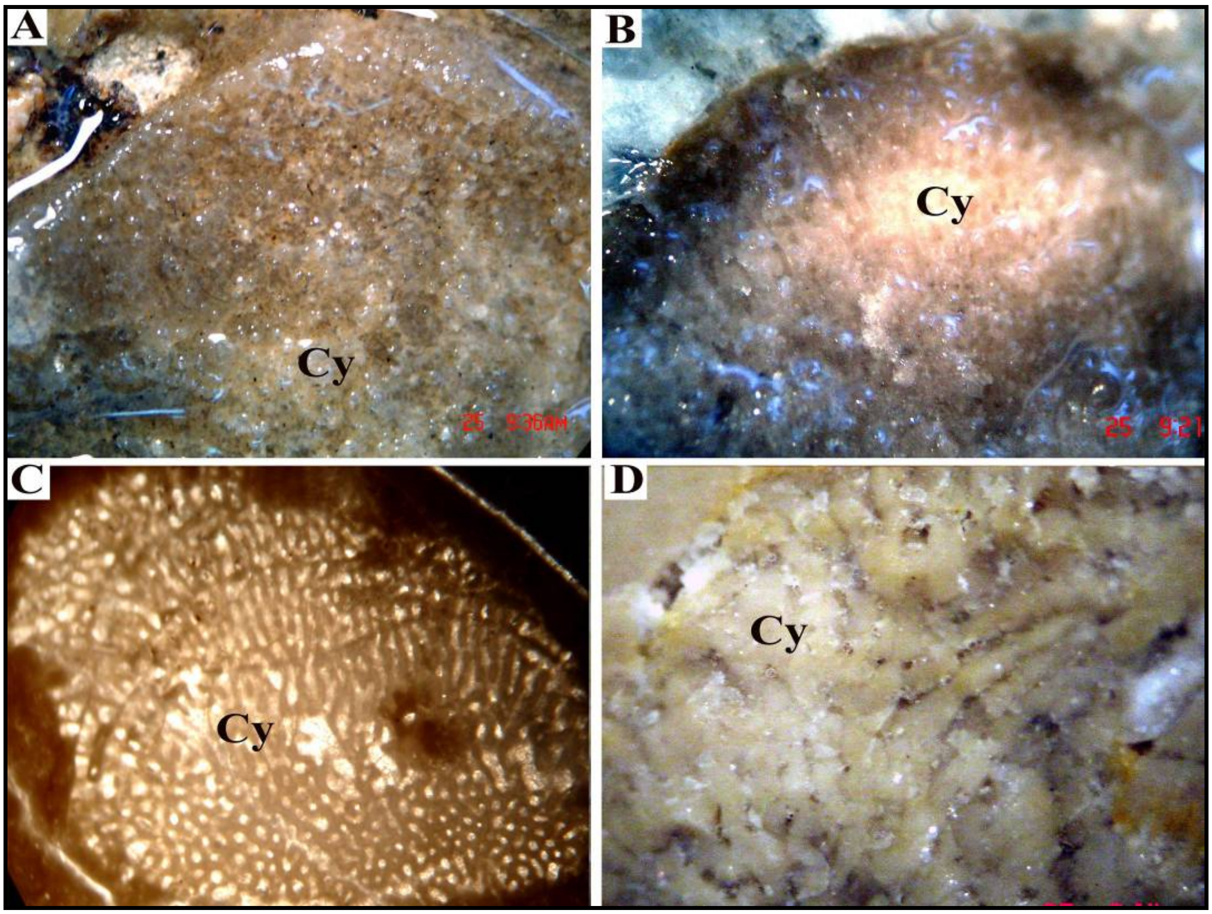

Fig.(3.15): Cynobecteria filaments, slab samples of cynobecteria (A,B,D), and(C) cynobecteria undermicroscope X40 p.p.

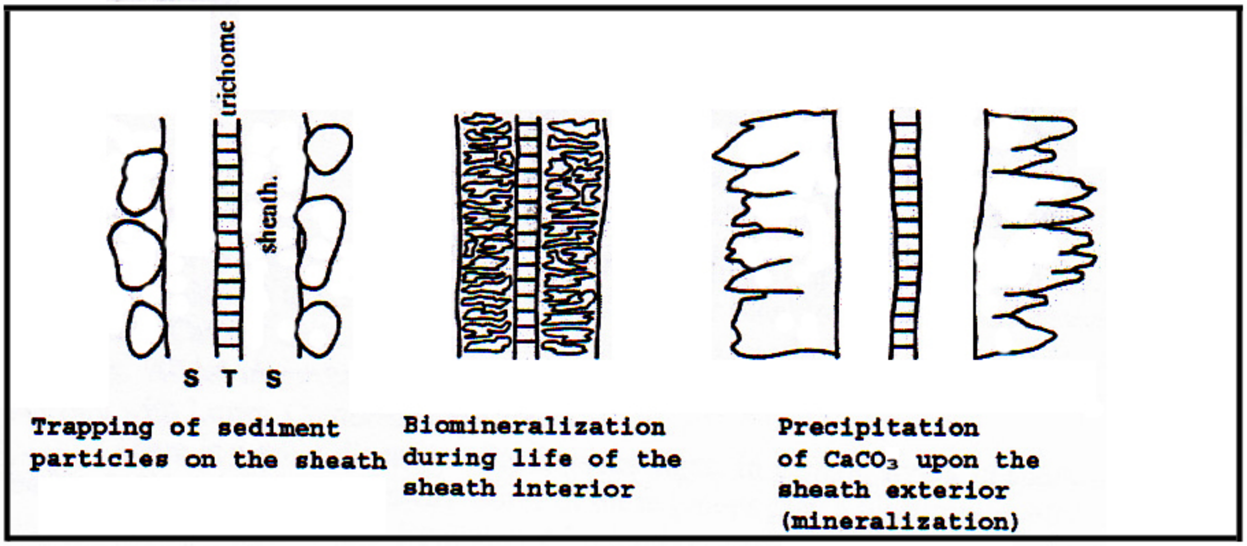

Fig. (3.16) Processes leading to the formation of benthonic microbial carbonates by filamentous of cynobacteria

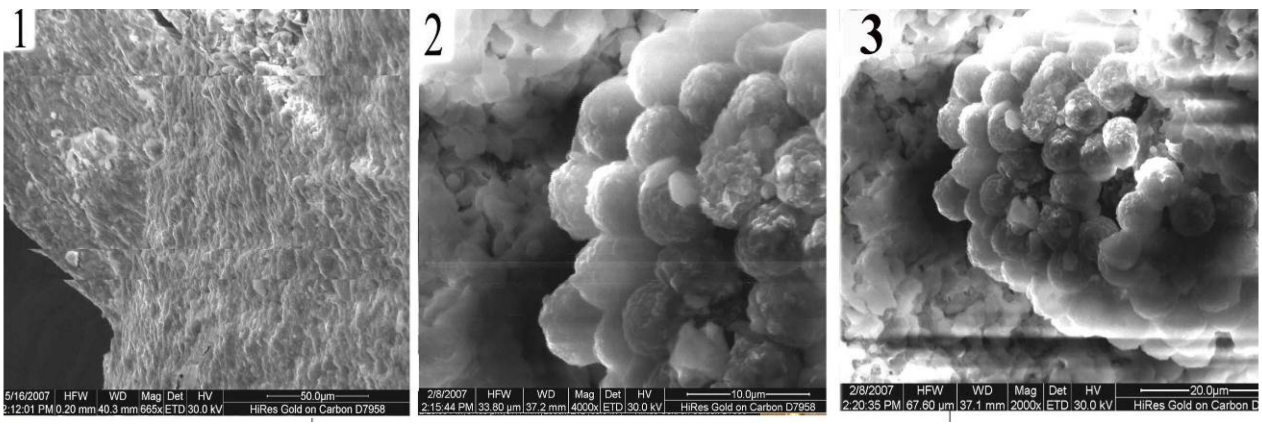

Fig. (3.17)

1) Scanning Electron Microscope (SEM) of Cynobacteria filaments.

2) Scanning Electron Microscope (SEM) of calcified Cynobacteria coccoids
3) Scanning Electron Microscope (SEM) of calcified Cynobacteria coccoids

Algal oncolites are regarded as indicators of shallow water environment, the size of oncolitic forms is often regarded as an indication of turbulence: the bigger the forms the stronger the turbulence assumed. Similar environmental significance is also usually ascribed to foraminiferal –algae oncolites. The well-known example of foramineferal –algal oncolite was ascertained by Johnson (2006) as being composed of intergrown blue-green algae (prostromata) and encrusting foraminifera.

Cynobacteria, which is deposited in shallow water, has a great importance for the study of fossil algal deposits, because it produces oncoidal and stromatolitic structures of different types, which are typical for intertidal deposits and shallow water carbonates (Flugel, 1977).

In this study, both filaments (Fig.3.18-1) and coccoids (Fig.3.17. -2 ,3) are observed in Qamchuqa Formation, in the lower part of Halladin, Qamchuqa and Kewa Rash sections. The presence of Cynobacteria in the lower part of Qamchuqa Formation is also an another important indicator to obtain the idea which improves that the lower part represents shallow water carbonates (According to Flugel, 1977), and declining reef (according to Oliver et al. 2002 and Reijmer and Immenhauser, 2005, p.19)

3.4.2.2. Bacinella (Green algae)

According to Elliot (1958) the green algae is characterized in the Tethys area and especially the Aptian life. It consists of hollow cylindrical or near cylindrical tubes, the walls are thin, dark and amorphous inner layer and thick yellowish outer layer, with innumerable radial and sub parallel line made of calcite. The most common type of green algae in Qamchuqa Formation is Dasycladacean (Fig.4.6.1, 2, 6), which is common in the lower part of all sections (Figs.2.16, 2.18 and2.21).

Bacinella irregularies also is regarded as important kinds of the green algae. Bacinella irregularis is an enigmatic microencruster with an irregular micritic meshwork (thickness of threads is 15-20 mm) that is assumed to represent a cynobacterial structure (Fig.3.18). Irregularies apparently have intruded into the skeletons of corals and stromatoporoids (Shiraishi and Kano, 2004). It commonly occurs as thin micritic layers, which have been interpreted as being parts of stromatoporoid skeleton, also they mentioned that the Bacinella meshwork is filled with both calcite spar and lime-mud .Bacinella is described in Iraq first time by Elliot (1963) when he found it in Piramagroon Mountain in Sulaimani area. Bacinella algae and lithocodiium are common at the lower part of the Shuaiba Formation of the Cretaceous Rudist bearing of the Arabian Gulf (Alsharhan, 1995, P.537). Daood (2006) studied Bacinella Irregularies in the Romania in the Cretaceous rocks; he mentioned that the bacinella played a major role in the sediment accretion and agglutionation, as well as during its lithification, he also mentioned that the bacinella binds the rudist fragments. Koch, et al.,(2002) studied the bacinella irregularies in the Middle Aptian limestone in Sabotin Mountain W-Slovenia, and they mentioned that the bacinella irregularies developed a lithocodiom in a reef mound.

In this study, the Bacinella irregularies are common in Qamchuqa Gorge, Halladin and Kewa Rash Sections, with Piramagroon Mountain. According to Elliot (1968), the maximum abundance of green algae is located from the low tide level to 5-6 meters in depth, and existing down in diminishing order to 10 m. The algal facies are mainly found in the landward part of the basin, lagoonal or semi lagoonal environment (Al–Sadoony 1978, P.124).

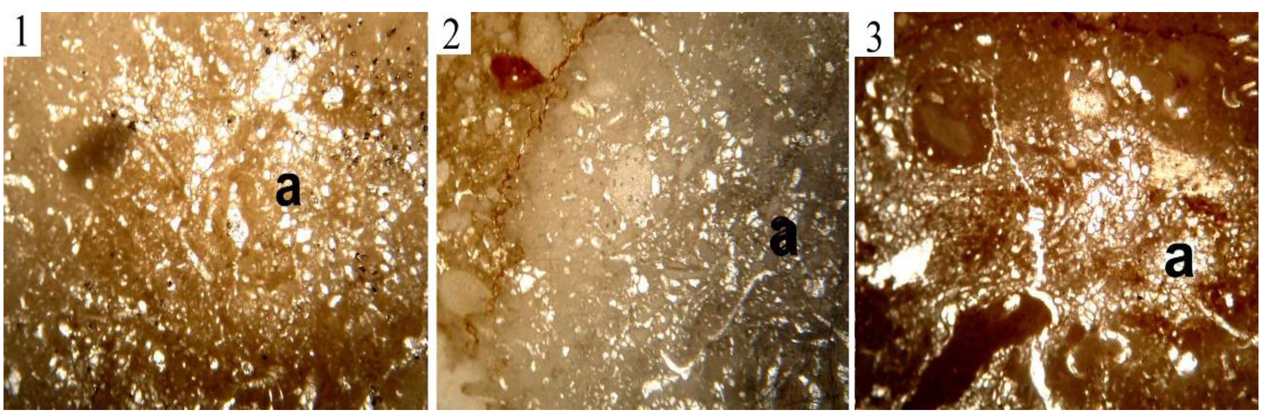

Fig.(3.18)
1) Bacinella Irregularies (a), Piramagroon Mountain, X40, P.P.
2) Bacinella Irregularies (a), Qamchuqa Gorge section, X40, P.P.
3) Bacinella Irregularies (a), Halladin section, X40, P.P.

CHAPTER FOUR

SEDIMENTARY FACIES AND DPOSITIONAL ENVIRONMENT

4.1. Preface

The present study had utilized the classification of Dunham (1962) and its modified version by Embry and Klovan (1971) for studying the carbonate rocks of the formation (Figs 4.1 and 4.2). These authors noticed that Dunham classification did not accommodate details of organic reefal limestone, and there was no size-scale for the different components. The modification was a very important step towards the simplification and generalization of the classification of all carbonate rocks in a single one. This is because the terms rudstone, bafflestone, bindstone and floatstone are most useful and specific in the description of reefal carbonates. Dunham's classification has presented different facies types.

In this study, another classification is used which especially deals with reefal carbonate rocks; it is that of Insalaco (1998). This classification is very useful for classification of reefal limestone, especially that of Qamchuqa Formation. It is depending on shape of growth, which is purely descriptive, not interpretative as that of Dunham or Embrey and Klovan.

The styles of growth fabrics dominant by in growth position of metazoan skeletons are defined by (Op.cit), according to the dominate growth from which constructs the bulk of the growth fabric as follows:

1. Platestone: dominated by platy to tabular skeletons such as tabular stromatolite (Fig. 3.11 and 4.16).

2. Sheetstone: dominated by sheet like skeletons such as stromatolite and slender recumbent rudists, which are found in their living position (Fig. 3.11 and 4.16).

3. Domestone: dominated by domal and irregular massive skeletons, such as domal stromatolite and solitary coral colony (Fig. 3.8 B).

4. Pillarstone (dense and spars): dominated by a vertical component of growth and relatively restricted lateral growth (branching, rod and tabular solitary forms) such as branching coral (Fig.4.17 and 4.19) and in situ growth of radiolitid rudists (Fig.4.9 B and 4.12).

5. Mixstone: not dominated by one growth form and includes a variety of growth forms, such as coexistence of pillarstone and sheetstone as seen in the occurrence of columnar and lamellar stromatolite together (Figs. 3.8 A and 3.11).

In the Qamchuqa Formation, the abovementioned reefal limestone (or facies) exists, but there is a very important type of reefal limestone, which is not mentioned in the classification of Insalaco (1998). This type of limestone is oncoidal limestone (or oncolite). Therefore, another type is added to the abovementioned classification, as the sixth type under the name of Ballstone

6. Ballstone: Dominated by ball-type or globular structures such as oncolite (Figs.. 3.7,3.11 and 4.16)

Table (4.1) Comparison of Dunham (1962) classification (modified by Emery and Klovan, 1971) with that of Insalaco (1998)

Dunham (1962) With Embry and Klovan (1971)	Meaning of the genetic of the term	Insalaco (1998)	meaning of shape or descriptive term
Framestone	Framework constructing	Pillarstone (dens and spars)	The components have vertical growth and restricted lateral growth (branching, rod and tabular solitary forms)
Bafflestone	Collecting and filtering sediment from water		
Bindstone or boundstone	(encrusting and binding original components	1-Platestone	1-dominated by platy to tabular skeletons
		2-Domestone	2-Dominated by domal and irregular massive skeletons.
		3-Sheetstone	3-Sheet like and lamellar skeletons
Bafflestone with Bindstone		Mixstone	not dominate by one growth form and includes a variety of growth forms
Concentric bindstone		Ballstone	Dominated by speroidal skeleton

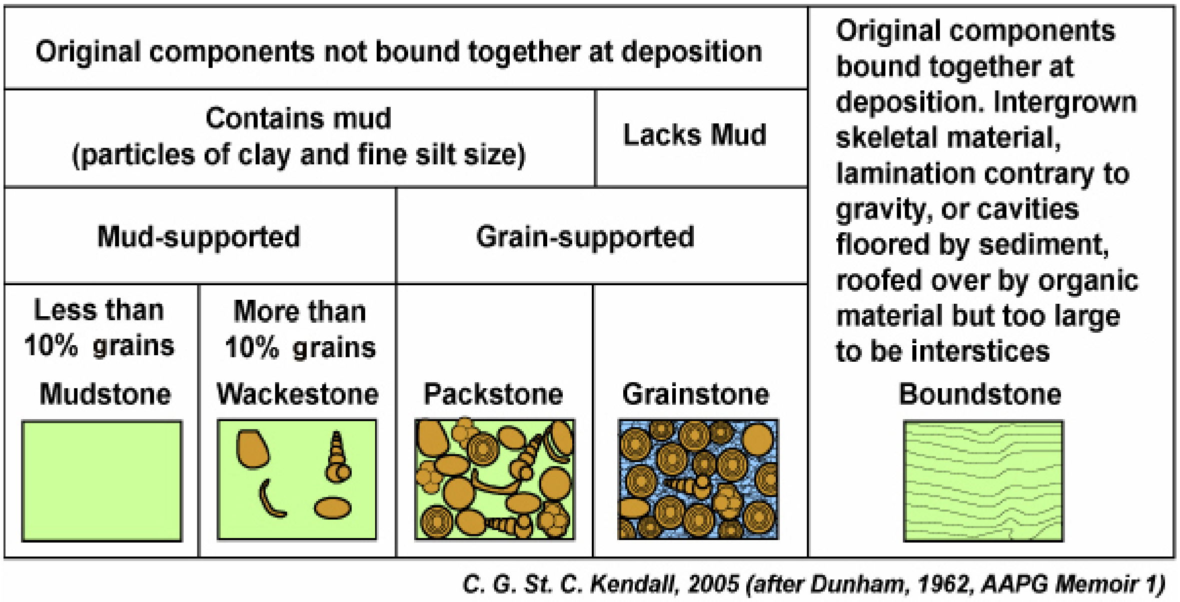

Fig (4-1) Classification of carbonate rocks (Dunham, 1962)

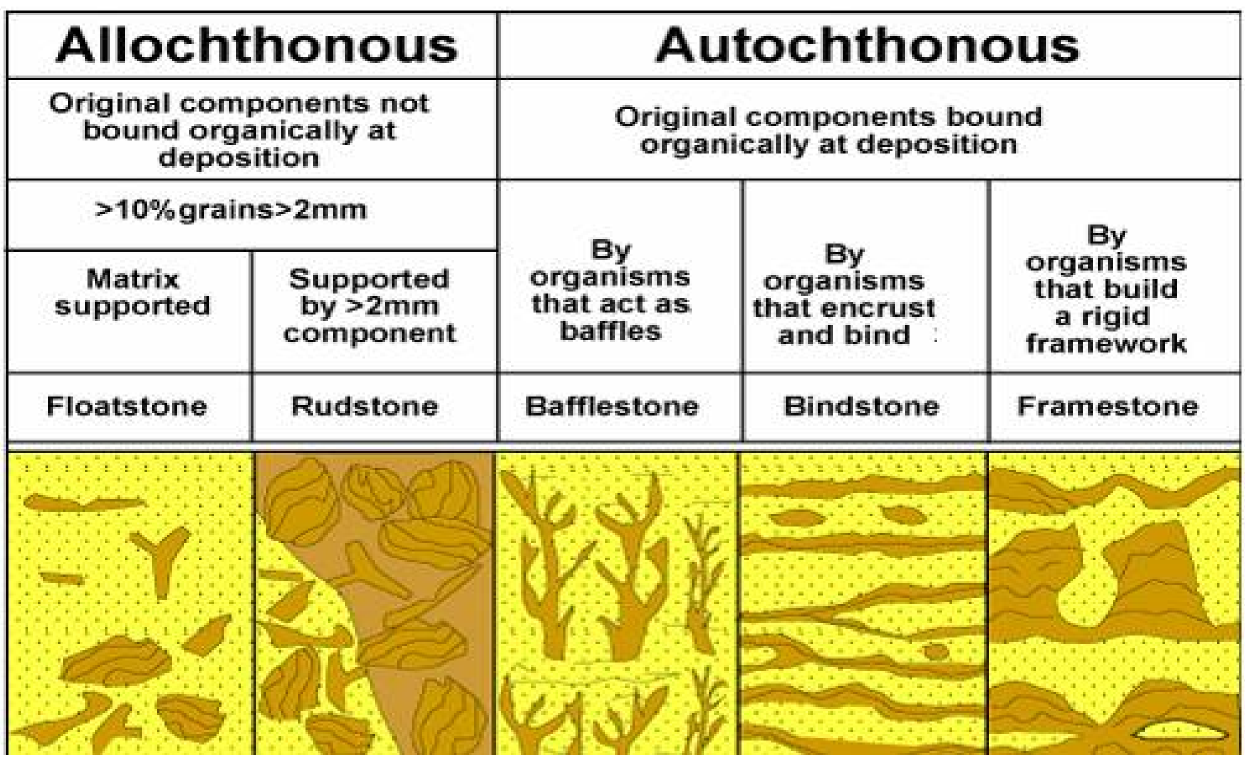

Fig (4.2) Classification of reefal limestone by Emery and Klovan (1971) and James (1984)

4.2. Microfacies in Qamchuqa Formation

The following microfacies are recorded in the Qamchuqa Formation

4.2.1. Lime Mudstone Microfacies

This facies is most common facies after the dolostone facies and constituents more than 60% of the limestone units and about 30% of the total thickness of the formation. It is found in the Units L1, L2 and L4. It contains some silt and sand sized bioclasts and few benthonic forams such as miliolids. This facies consists mainly of micrite, which is slightly effected by recrystallization processes. This microfacies could be subdivided into the following two submicrofacies:

4.2.1.1. Bioclast Lime Mudstone Submicrofacies

It is composed of dark brown micrite containing fine bioclasts with algae. The bioclasts are the main skeletal components of pelecypod and algae (Fig.4.3). This submicrofacies are common, especially in the lower part of the sections, in the L1,. L2 (Figs, 2.3, 2.5 and 2.8). (Wilson, 1975) mentioned that this facies has back reef or sand flat.

4.2.1.2.Globogerinal and Oligosteginal Lime Mudstone Submicrofacies

Calcispheres is the former name of *Oligosteginal*, which is the common allochems in this facies. These allochems are spherical and some have peripheral fringe on the outer margin (Fig.4.5). The identification under microscope is very difficult, and they can be easily mistaken with uni-chamber planktonic foraminifera, Oligostegina is associated with Globogerina. They are found in the Warte section, which is transitional zone between Qamchuqa and Balambo Formations. In the present study, these allochems exist in the transition zone between Qamchuqa and Balambo Formations. They can be observed in the Warte section with some glauconite grains (Fig.4.5). According to Adams *et al.* (1967), the calcispheres are common in transitional belt separating the

Orbitolina neritic limestone and the pelagic radiolarian mudstone. (Wilson, 1975) mentioned that this facies has deep and open marine environment. Kenter, *et al*.(2004) , mentioned that the rare radiolarians and minor skeletal grains are the dominate lithofacies in Toe –of- slope.

4.2.2. Lime Wackestone Microfacies

In this facies, the grains of wackestone usually range between 10 and 15 percent in a micritic matrix. Skeletal grains include; bryozoans, echinoderms and algae. Non-skeletal grains include intraclasts and pelloids. Depending on the type of the grains, this facies in Qamchuqa Formation can be subdivided into the following three submicrofacies.

4.2.2.1. Bioclast Lime Wackestone Submicrofacies

This facies contains clasts of mollusk, bryozoans, algae and with some whole skeletal of *Milliolids*. The matrix consists of micrite (Fig.4.3). This facies is found within the lower part of the sections (Fig, 2.3, 2.5 and 2.8),

4.2.2.2. Orbitolina Lime Wackestone Submicrofacies

This microfacies is characterized by a high content of large benthonic foraminifera (*Orbitolina*), which is found with light color, slightly argillaceous mudstone (marly limestone) (Fig.4.7) and associated with bioclasts pelecypod. This submicrofacies is found in some beds in the upper part of all sections (L4), in addition to transition zone of the type section(Fig.4.4).This submicrofacies is a typical for open marine of circulation conditions (Wilson,1975).

Orbitolina has been described from the undolomitized horizons, in the type locality of the formation by Dunnington (1958), and has been used as a stratigraphic tool. At the same location, Qaradaghy (2007) recorded this fossil in

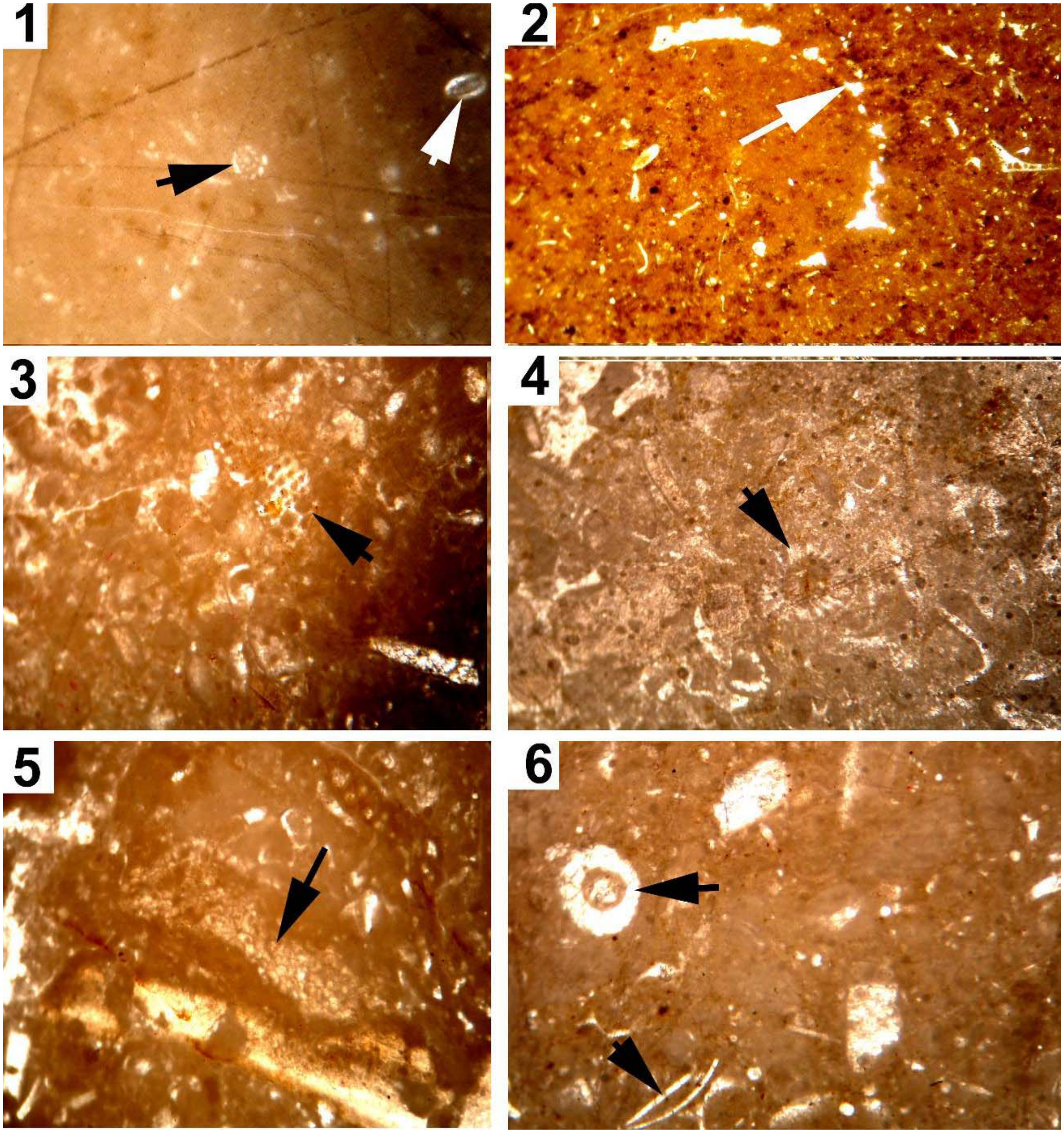

Fig (4-3):
1) Microbioclast Lime Mudstone Submicrofacies, Cyclaminal (black arrow), bioclast (white arrow) Kewa Rash Section. X40, P.L. 2) Bioclast Lime Mudstone Submicrofacies. Green algae, Dacyculadacy (arrow). Halladin Section, X40, P. P.3) Bioclast Lime Wackestone Submicrofacies. Bryozoan (arrow). Halladin Section, X40, P.P.
4) Bioclast Lime Wackestone Submicrofacies. Green algae, Dacyculadacy (arrow). Halladin Section, X40, P.P. L). 5) Bioclast Lime Wackestone Submicrofacies. Bryozoan (arrow). Halladin Section, X40, P.P.L 6: Bioclast Lime Wackestone Submicrofacies. Green algae, Dacyculadacy (arrow).bivalve. Bioclast (arrow) Halladin Section, X40, P.P

the upper part of Sarmord Formation also which is assumed as transition zone in this study. The *Orbitolina* bed is present both in the neritic zone and in the foreslope sediments (Wilson, 1975). The same author mentioned that *Orbitolina* has been described from Iran, Oman, Sudia Arabia, Syria and Lebanon. *Orbitolina* species have been described from many localities of the Middle East and Tethys sea and have been considered as an important fossil in the Early Cretaceous deposits of the region. Al-Sharhan, (1995) has recorded *Orbitolina*-rich lime mudstone and wackstone in the Middle Cretaceous rudist bearing carbonate in the Arabian Gulf. These facies (rocks) are interbedded with thin partings and beds of buff to gray shale.

According to Pittet, *et al*., (2002) discoidal orbitolinids and calcareous algae were deposited during early transgression. Microbolites and microencrusters dominated the late transgression to early highstand facies; and a rudist and milliolid-dominated facies is a typical of the highstand. They added that Orbitolinid beds and carbonates formed by microbiolites and microencrusters seem to be the shallow-water carbonate response to global changes affecting Late Barremian to Aptian paleoclimate .

Fig.(4.4) *Orbit0lina* bearing microfacies which can be observed in the L4 of the Piramagron and Qarasard anticlines.

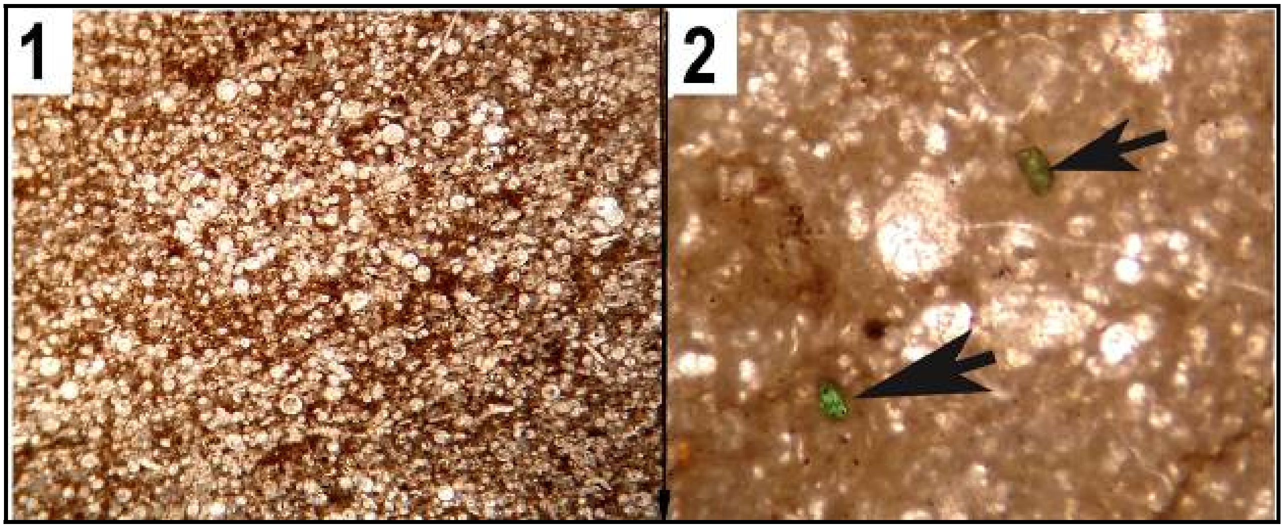

Fig.(4.5):1) Globogerinal ooze facies, Warte section, X20, P.L2) *Globogerinal* ooze facies, include glauconite grains (arrow) Warte section, X40,N.L.

4.2.3. Packstone Microfacies

This microfacies includes two submicrofacies, these are:

4.2.3.1. Peloidal Packstone Submicrofacies

Peloids are structureless oval or spherical grains (0.2—1mm), but may be irregular due to crystallization and dolomitization of micritic composition, which constitute major components of this facies. In this facies some intraclasts, few milliolids and echinoderms occur too (Fig.4.6). The presence of this facies is limited within the lower part of the sections in the Qamchuqa Formation (Figs.2.3, 2.5 and 2.8), and in the transition zone with Sarmord Formation in Halladin section (Fig.4.8). The peloidal grainstone microfacies may be deposited in shallow warm waters with moderate circulation (Wilson, 1975),

4.2.3.2. Bioclast Packstone Submicrofacies

This submicrofacies consists of fragmented skeletal grains up to 60% leaving minor micrite in-between (Dunham, 1962).The types of skeletal grains consist generally of pelecypods and non-skeletal grains which include intraclasts and pelloids (Fig.4.6). This type of facies exists in all parts of the Qamchuqa

Formation, even can be seen in the dolomite succession (Figs.2.3, 2.5, 2.8, and 2-11). It is deposited in high-energy environment in both back reef and forereef.

4.2.4. Grainstone – Packstone Microfacies

This facies is characterized by grains supported texture, which is bound by sparry calcite cement. Micrite, is less than 15% (Dunham, 1962). Depending on grain type, this facies is subdivided into the following two submicrofacies:

4.2.4.1. Peloidal Grainstone–Packstone Submicrofacies

Pelloids are circular to elliptical grains composed of micrite and lacking the internal structure with dark color. They are relatively well rounded and sorted particles, with different sizes. Generally, the term pelloid was applied to all particles of various origins, Which consist of cryptocrystalline carbonate (Mc Kee and Gutschick, 1969 in Flugel, 1982). The pelloids are commonly observed to be associated with transported particles, usually fossils. They represent the main and very abundant non-skeletal grains in the studied sections (Figs.2.3, 2.5 and 2.8), which often show signs of replacement by sparite due to crystallization. Pelloids (including pellets) can be developed and created by progressive micritization of bioclasts and or due to reworking of their particles in agitated water. Pelloids, with some bioclasts, are the major components of this facies (Fig.4.6).The presence of this facies is limited within the lower part of the sections (limestone units L1) in the Qamchuqa Formation(Figs.2. 3, 2.5, 2.8 and 2.11). This facies is found in shallow water with moderate circulation (Wilson, 1975).

4.2.4.2. Oolitic Packstone – Grainstone Submicrofacies

Oolites are the major components of this facies**,** which consist of oval or spherical sand- sized grains. They are coated by concentric micritic laminae that surround a previous allochems, such as bioclast and intraclasts or previously formed ooids. When they are coated with thin laminae, then they are called superfacial ooids (Flugel, 1982). The ooids in this study are characterized by presence of one or few thin laminae surrounded large nuclei tagentially, which belongs to superficial types and contains some composite ooids that consist of

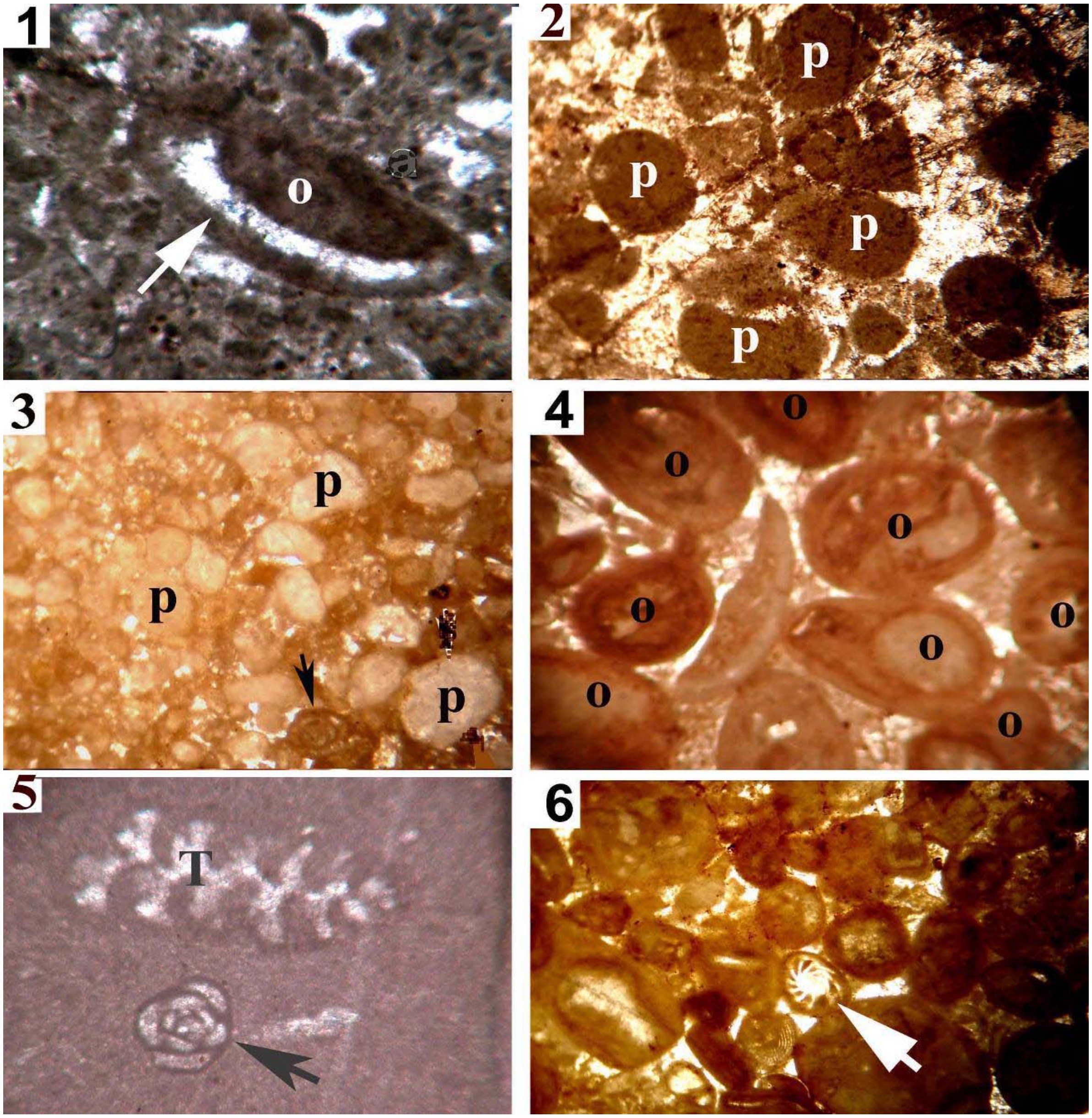

Fig.(4.6):

1) Bioclast Packstone Submicrofacies, longitudinal Ooid (a) formed around the bioclast (arrow). Kewa Rash section, X5, P.p.L.

2) Peloidal Packstone – Grainstone Submicrofacies, Halladin, Section, X20,P.L.

3) Peloidal Lime Packstone Submicrofacies, peloids (P) . Kewa Rash section, X20, P.L.

4) Oolitic Packstone – Grainstone Submicrofacies, Halladin section, X20, P.L.

5) Wackstone Submicrofacies, Milliolid (arrow),Textularia (T)Yakhsamar sectionX40, P. L.

6) Oolitic Packstone – Grainstone Submicrofacies, Ooid grains formed around a fossil (arrow). Halladin section, X40, P. P.

more than one ooids (Fig.4.6), which are encircled by the laminae. This facies is located in the top of L1 in the Halladin section; it has thickness of about 5m and is associated with pale green sandy marl (Fig.4.8). This facies, laterally changes to pale yellow, crystallized and slightly dolomitized limestone. Abed and El-Hiyari (1986) have found in Cenomanian gypsum bearing horizon in Jordan ooids which are nearly similar to those of Qamchuqa Formation.

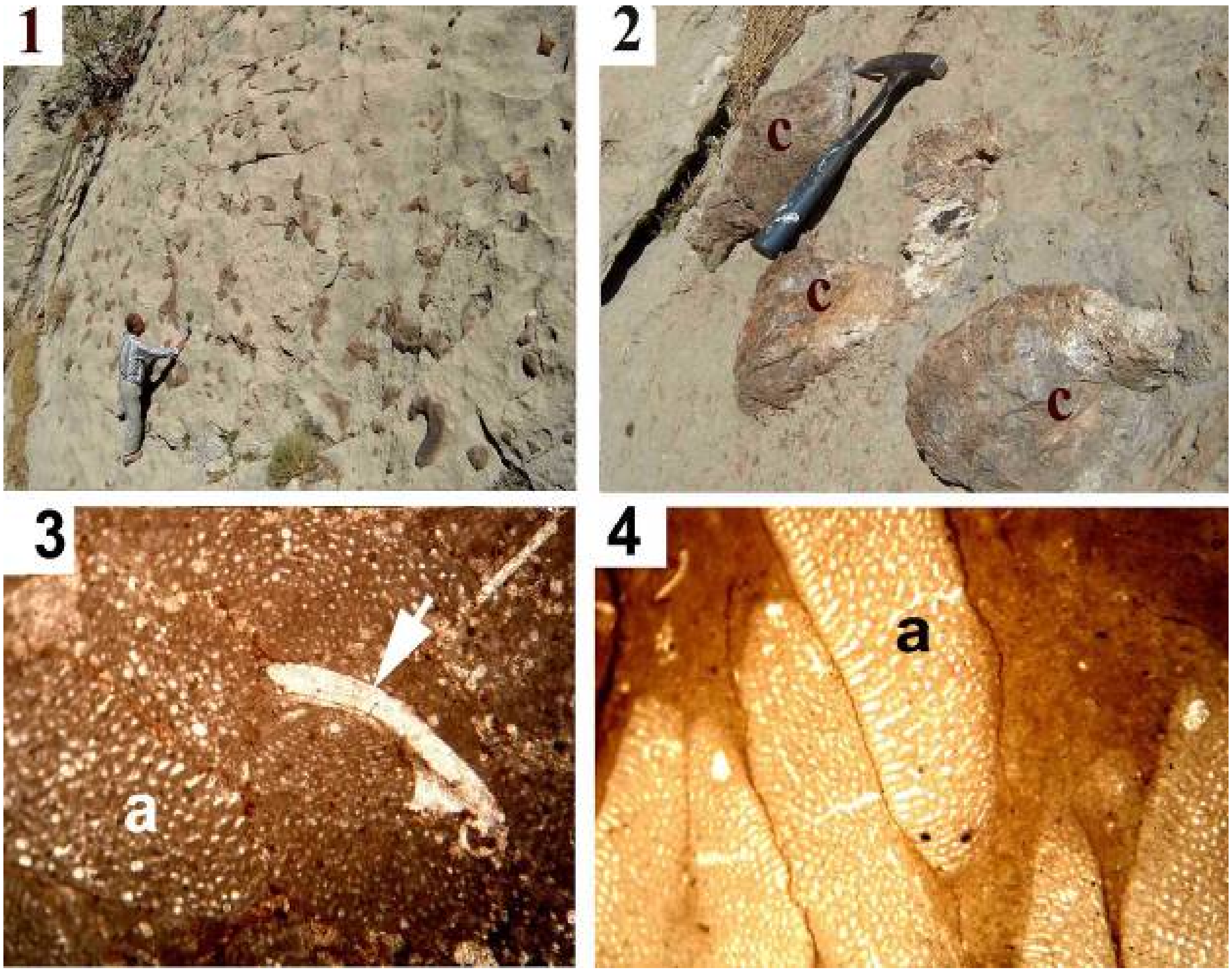

Fig. (4.7): 1) Chert nodules(c) on the top of a limestone bed in the L1 of the Qamchuqa Gorge section. 2) Same chert nodules in close-up view. 3) *Orbitolina* **wackstone submicrofacies,** *Orbitolina* **(a), Piramagroon Mountain, X20, P.L. 4) Orbitolina wackstone submicrofacies,** *Orbitolina* **(a), Qamchuqa Gorge section, X40, N.L.**

The occurrence of superfacial ooids may provide a distinct delineation on paleoenvironmental condition, which is closely associated with low-energy environments.

Oolids are smaller than oncolites 0.5-2mm and the lamina are formed by chemical precipitation of calcium carbonate. However, it is possible to be formed by process of organic accretion as mentioned by Tucker (1991) about the possibility of development of oolids by organic precipitation and he called them micro-oncoids. Blomeier and Reijmer(1999) found ooids similar to those of the present study, they called them tagential–structure ooids.

Fig.(4.8) Halladin section (Babo mountain) showing the interval that contains ooid packstone–grainstone.

4.3. Sedimentary Facies in Qamchuqa Formation

The following lithofacies are recorded in the Qamchuqa Formation

4.3.1. Chert Nodules- bearing Facies

The cherty facies consists of decimeter-scale beds, which contain large chert nodules, distributed on the bedding planes (Fig.4.7). This facies occurs in the lower and middle parts of Qamchuqa Formation in L 2 and L3 (Figs.2. 3, 2.5 and 2.8). Philip *et al.* (1995) have observed, in similar facies, from France, the presence of sponge spicules, echinoids, red algae, annelids, and small benthic foraminifera. In this study, the chert nodules found in limestone units which has characteristics of lagoon and forereef, therefore their development most possibly attributed to the episode of slow sedimentation during sea level rise with a paleo water depth just above or around storm wave base.

4.3.2. Rudist-bearing Facies (Pillar and Sheetstone)

This facies consists wholly or partially of rudist skeletons of medium size and consist mostly of slender Radiolitids and Monopleurids in the Qamchuqa Formation (Fig.4.9 and 4.12). It also contains other faunas such as gastropods and pelecypods. The rudists of the Qamchuqa Formation are small and thin shelled as compared to those of Aqra Formation as shown by Karim, 2006; Karim and Surdashy (2006). In Qamchuqa Formation, the rudists are found in their living position, erected normal to bedding plane and some of them slightly inclined, as those found directly to the northeast of Yakhsamar village on the paved road (Fig.4.10 A).

Castro, *et al. (2001) have* used the term rudist float or rudstone for this facies. Al-Sharhan (1995) recorded rudist conglomeritic floatstone in the Mishrif Formation with lime mudstone and wackstone in the Middle Cretaceous rudist bearing carbonate in Arabian Gulf. These facies (rocks) are interbedded with thin partings and beds of buff to gray shale. Polmar *et al*. (2005) found rudist pillarstone of slender rudist of Hippuritid types.

Wilson (1975) has cited the following facts about rudists (Fig.4.11):

"They are important reef-formers of the Late Cretaceous, but also common in Middle Cretaceous strata. They are known in back-reef biostromes, at tops of shelf mounds and, in the Middle Cretaceous, commonly at shelf margins and on fore-slopes where they were associated with and gradually replaced by corals, spongiomorphic hydrozoans, red algae, and sponges. The shallow water coral forms seem to be replaced at some quieter water shelf edges by the rudists. Cretaceous algae are abundant in the carbonate realm and the major algal groups generally occur with certain of the major rudist groups Radiolited with the red algae in the outer shelf margin position. Rudists are shallow water dwellers and they are common in the Middle East. Rudists or molluscs are common components through the Early Cretaceous of the Tythyan area.

Al-Sadoony (1978) cited the following sentences "*The rudists of the Qamchuqa Formation are assumed to have lived in small isolated patches on hard bottom of shallow, warm water seas. Further more he added that they are associated with hydrozoans, corals, echinoderms and Orbitolina with algae during the transgression induced by tectonic subsidence. Some groups of rudists spanned the interior back-reef protected environments. In general, rudists could thrive better in lime-mud environments than filter feeders such as Coelenterates and sponges. Because of the above facts, rudist buildups in shelf margin position may be expected to have more continuity than those formed chiefly by corals. the high degree of fragmentation of the rudist shells and there abundance in the fore reef area of the shelf in Jambur wells are isolated ridges of rudists on the shelf mixed with some algae, corals. etc. ".*

Rudist association is very similar on a global scale until the Aptian (Skelton, 1982). According to Coogan (1977), Radiolitids (Fig.4.9B) tolerate a wider range of conditions from back-reef to shelf margin to fore-slope. Pomar *et al.* (2004)

mentioned that the rudist buildups consist of a rudist and coral belt at the platform margin, passing landward into a slender hippuritid lithosome, locally overlain by a bioclastic blanket that passes basinward, into bioclastic apron like clinobeds and into fine-grained packstone-wackestone.

Philip and Gari, (2004) mentioned that during the Late Cretaceous hetrozoans rich bioclastic carbonates prevailed in the province platform area. They substituted for rudist rich carbonates, which flourished during the Late Turonian area at the west of Marseilia. They also added that at this locality, the thickness of the bioclastic exceeds 500 m. The hetrozoans carbonates referred mainly to packstones and grainstones. Rudists are also described in deep wells of Kirkuk and Bai Hassan fields (Al Shakry, 1977). The Cretaceous Rudist bearing carbonates of the Arabian Gulf included the main type of the rudist in Shuaiba Formation mainly of caprinids, with a lesser number of caprotinids, monopleurids (Al-Sharhan, 1995, P.531).

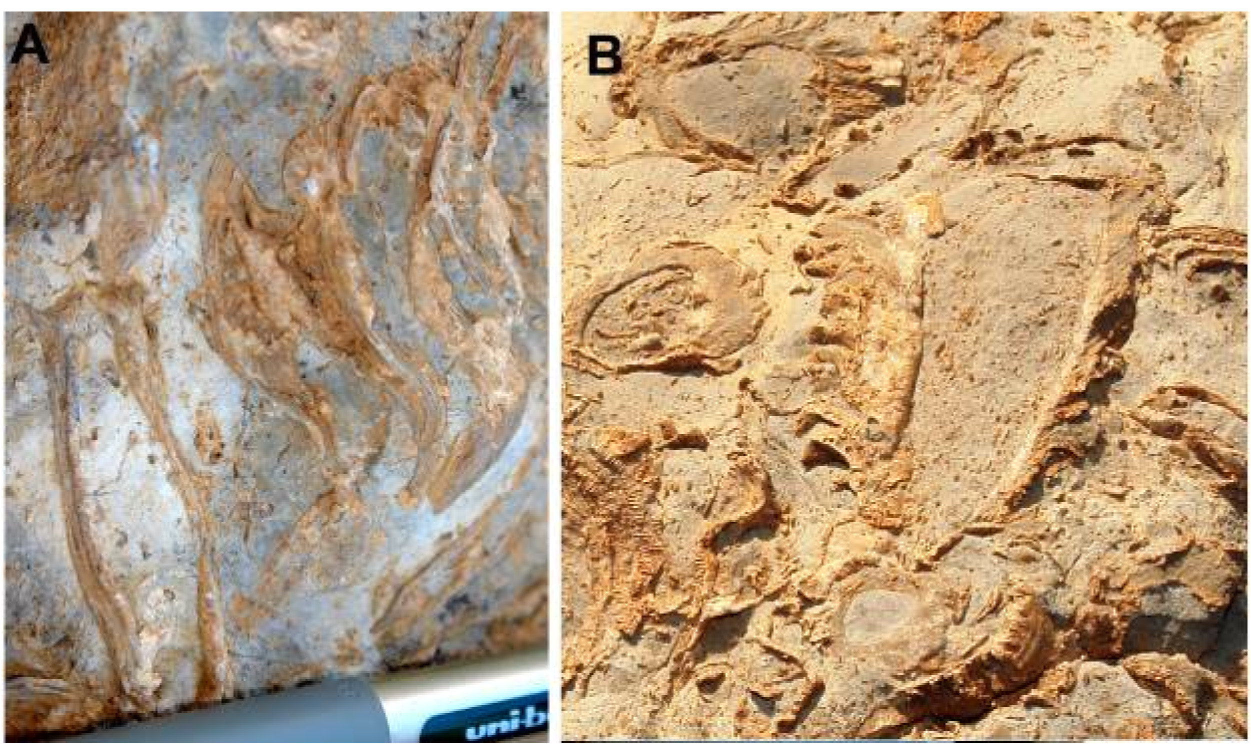

Fig. (4.9). A) Longitudinal sections of Radiotids rudist arranged vertically on bedding plane in their life position (pillarstone) Yakhsamar. B) Longitudinal and cross sections Radiolitids rudist , in Yakhsamar section.

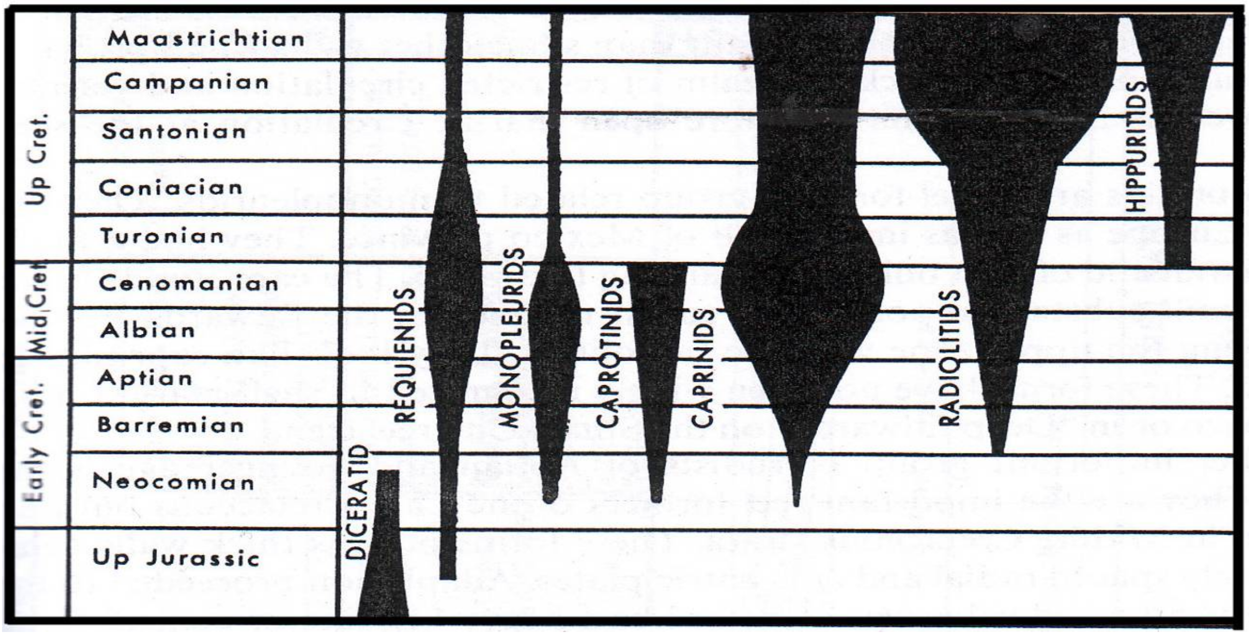

Fig (4.10): Rudist distribution in time (A. J. CooGan, in Wilson, 1975).

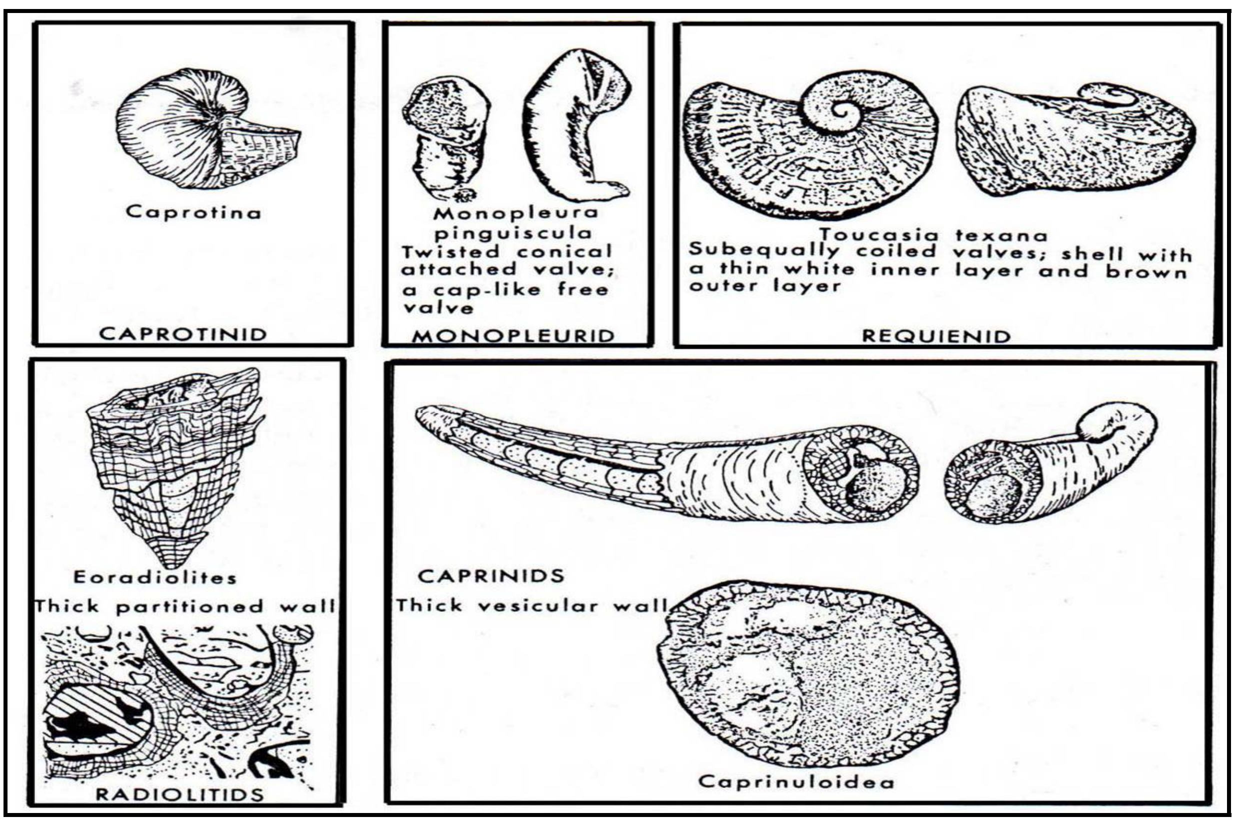

Fig (4.11): Major types (families) of Cretaceous rudist bivalves after drawings by Coogan (cited in Wilson, 1975).

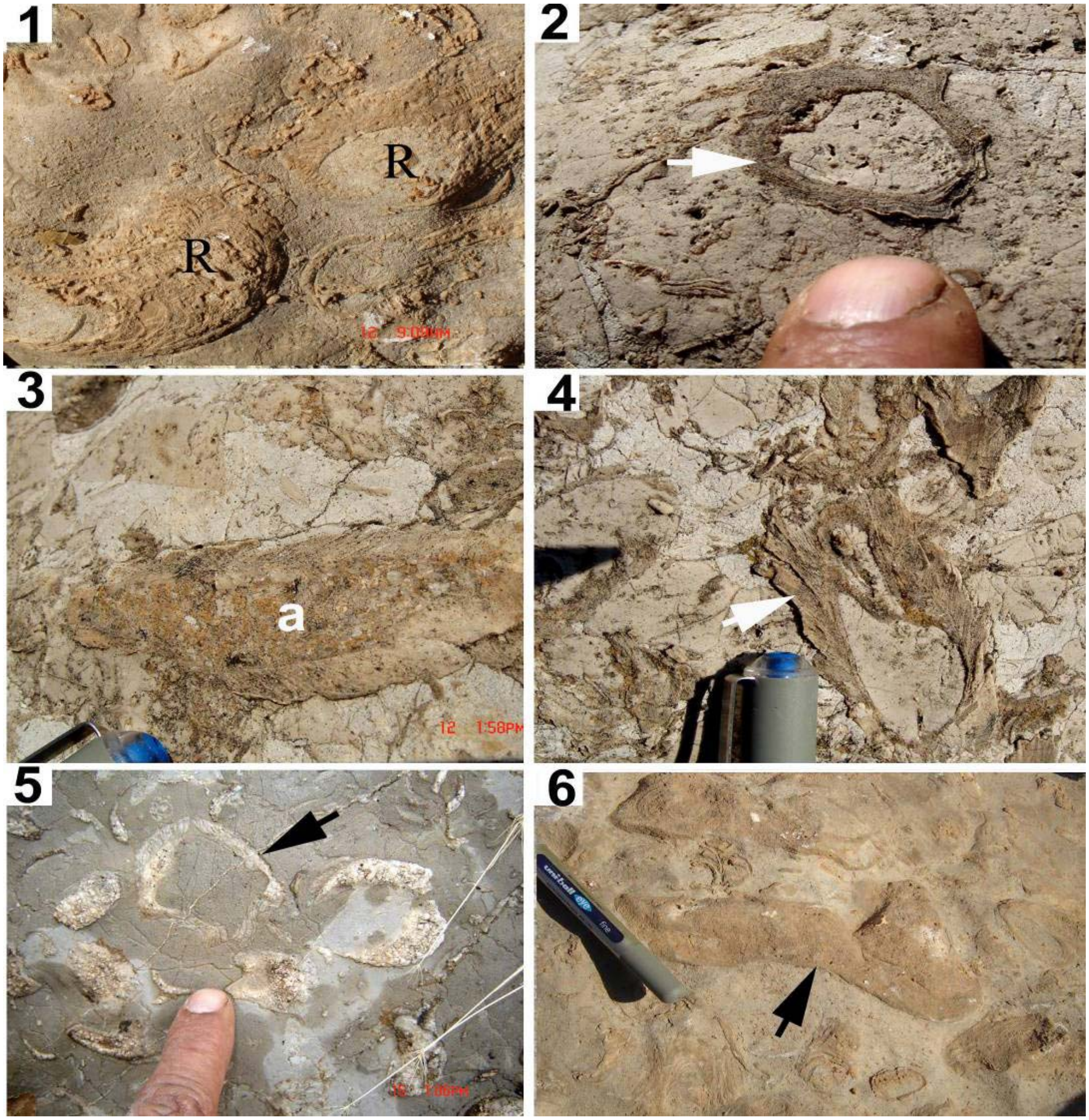

Fig.(4.12):

1) **Rudist facies include Monopleurid (R), Yakhsamar section.**
2) **Right angle section of rudist .Radiolitid type (arrow) circular structures inside the wall, Halladin section**
3) **Longitudinal section of rudist. Radiolitid type (a) ,Halladin section. Challawa area**
4) **Longitudinal section of rudist. Radiolitid type (arrow), Halladin section. Challawa area**
5) **Right angle section of rudist. Monopleurid type (arrow), Halladin section.**
6) **Rudist facies include Monopleurid (arrow), Yakhsamar section.**

4.3.3. Pelecypods Bioclast-bearing Facies (Pelecypod Coquina):

This facies exists in all sections and limestone and some dolostone members but is more common in the northeast of the studied area where Qamchuqa Formation is change to Balambo Formation. The lithofacies exists either as completely skeleton or as worn bioclasts, which give the brown color to the beds related to this lithofacies. The elongate shells appear as parallelly arranged to direction of reworking current. Obed and El-Hiyari (1986) have found this facies in Cenomanian gypsum, bearing horizon and called it Coquina, and assigned the related environment as high energy. The shells have thin shells as compared to their length, which in some cases reach more than 10cm (Fig.4.13) as can be seen in upper part of the formation in the Qarasard Mountain. This facies is commonly highly bioturbated and contains patches of dolomite.

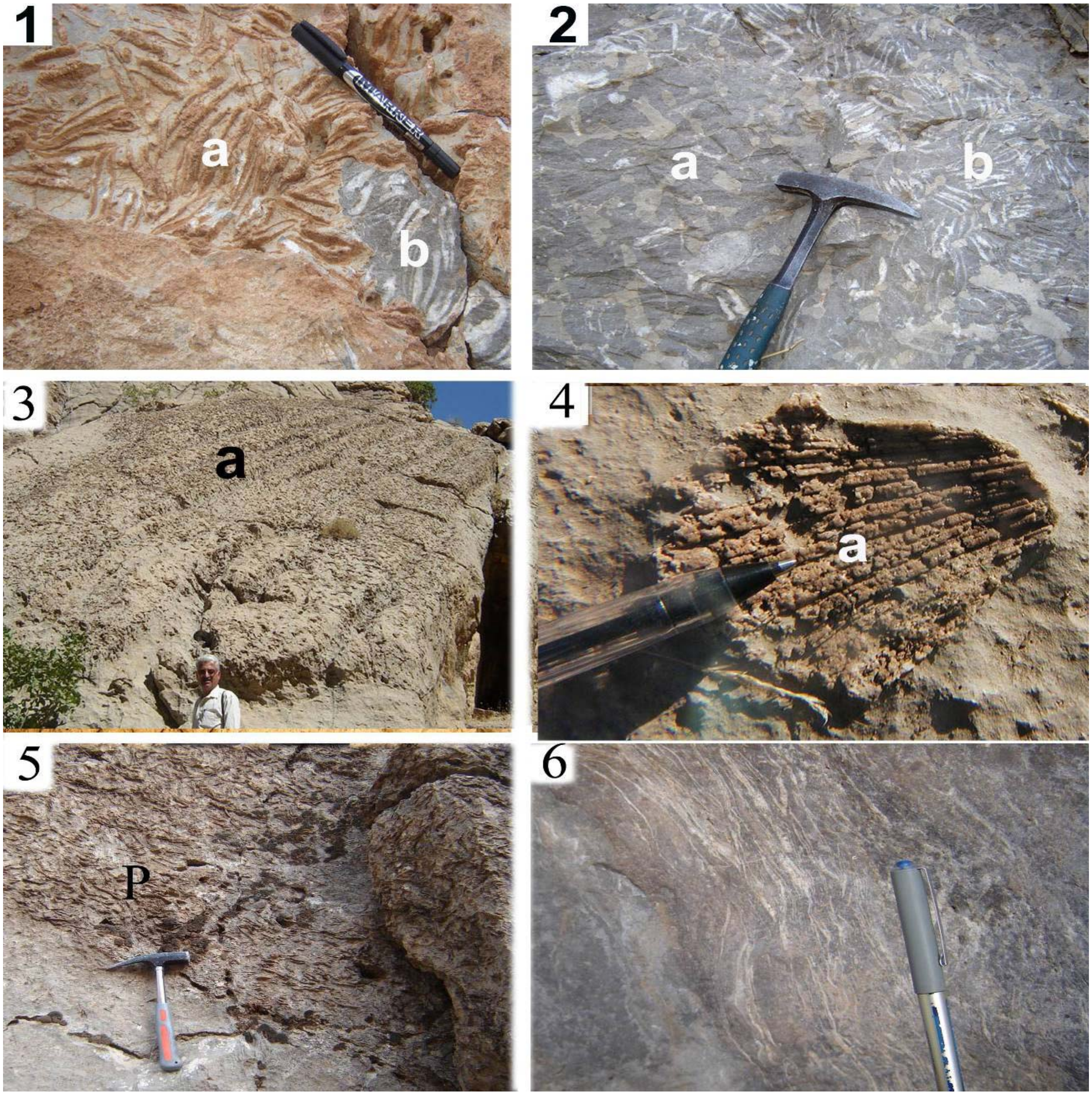

Fig.(4.13):

1) Accumulation of shell of large bivalve replaced by calcite in Yakhsamar section.
a: weathered Surface, b: fresh surface.

2) Burrowing surface (a), high content of large bivalve fossils (b). Yakhsamar section.

3) Accumulation of large pelecypod shells on the bed surface (a). Qamchuqa Gorge section.

4) Large pelecypods above the burrowing surface. Challawa area.

5) Accumulation of large pelecypods shell on the bed surface (P), Tabeen Valley.

6) Calcite filling large pelecypod shells on the bed surface, Tabeen Valley.

4.3.4. Gastropods-bearing Facies

Different sizes of gastropods have been seen in the Qamchuqa Formation in both dolostone and limestone successions (Figs.4.14 and 4.15).

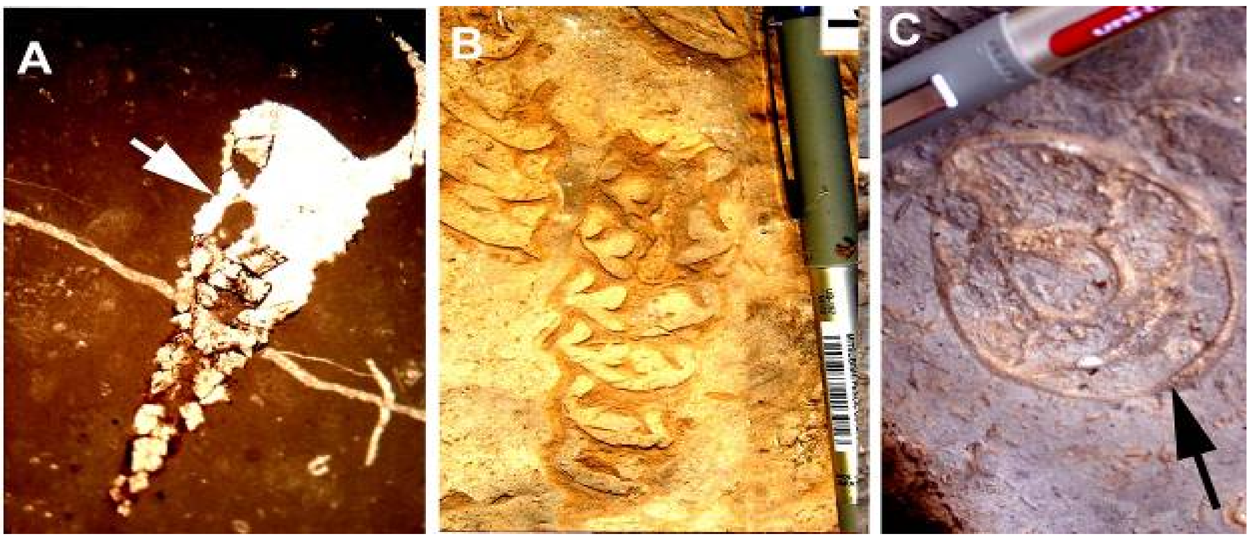

Fig.(4.14). A) Selective dolomitization inside a gastropod shell , X4 normal light . B) Accumulation of large gastropod shell (a), in gastropods facies. Yakhsamar section. C) Gastropod Transverse section.

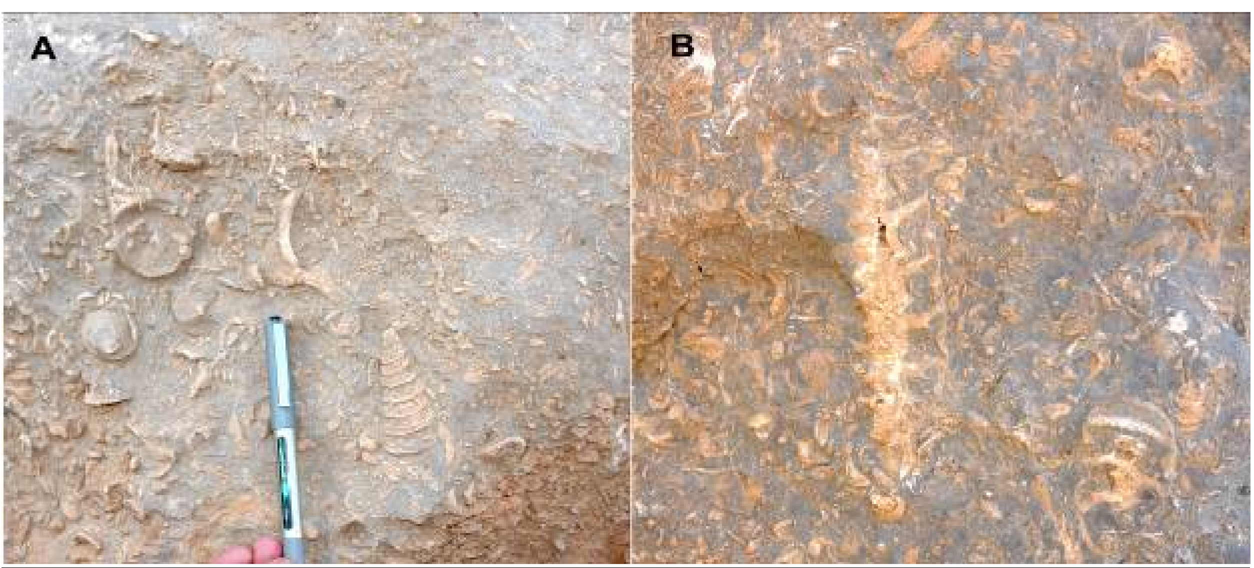

Fig.(4.15). Different species of gastropods with their bioclast in the lower part of Halladin section.

4.3.5. Stromatolite Bindstone Facies

This type of facies contains two types of structures formed by accretion of biofilm and binding processes. These structures, in the Qamchuqa Formation, are stratiform (flat, wavy and vertical) and circular stromatolite (oncoids)(Fig.4.16), and were mentioned previously in details in chapter three, under the title of microbolites.

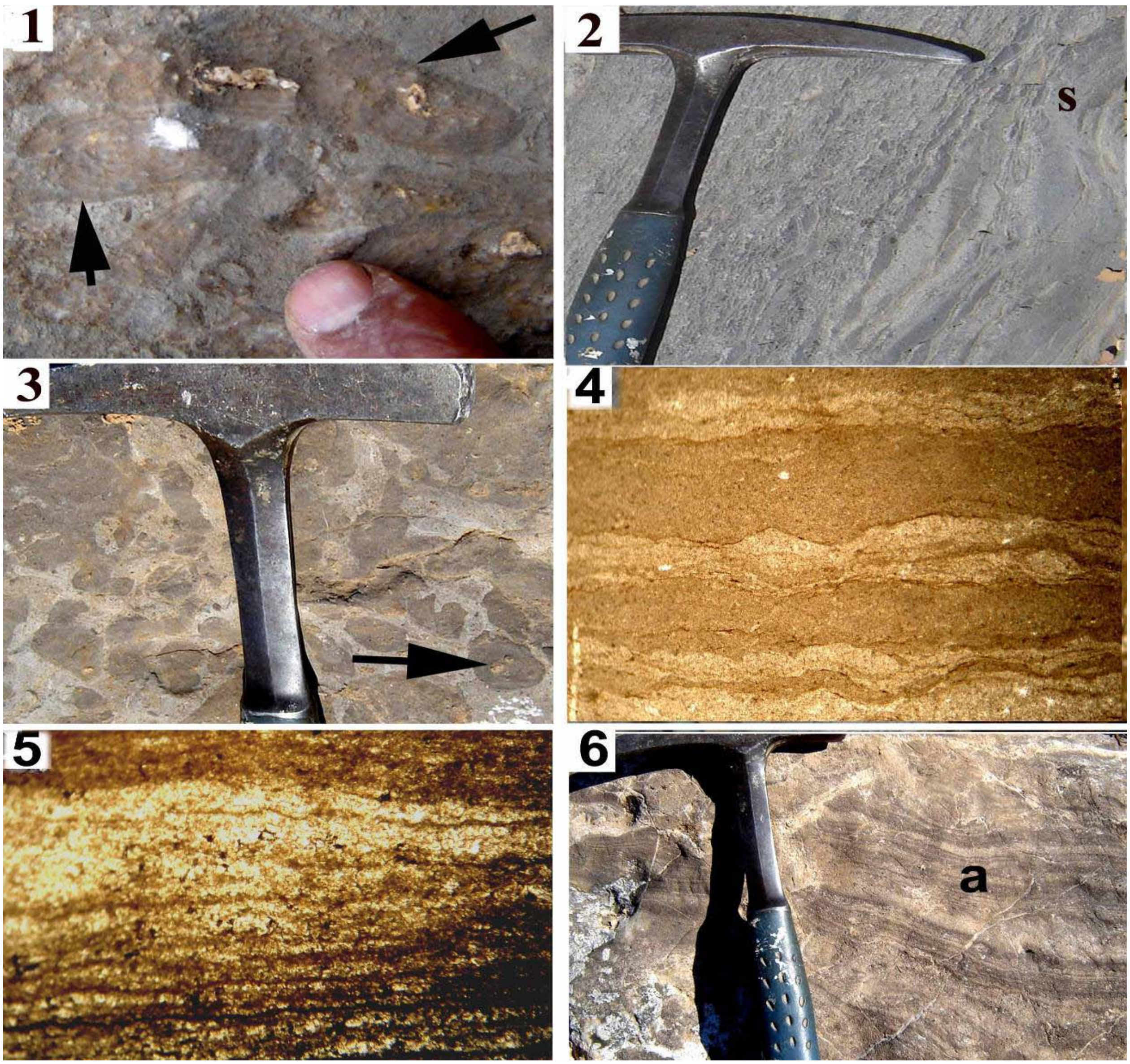

Fig.(4.16): 1) Large oncoids (arrows) inter space between the coral branching highly Brunched, Halladin section. 2) Stratiform stromatolite, Qamchuqa Gorge section. 3) Large oncoid (arrow) in lime wackestone, Halladin section. 4) Stratiform stromatolite, Halladin section, X40, P.P. 5) Slightly deformed stratiform stromatolite Kewa Rash section X40, P.P. 6) Stratiform stromatolite in dolostone of upper part of Qamchuqa Formation, in the southwestern limb of Piramagroon anticline.

4.3.6. Single Colony Coral-bearing Sandy and Marly Limestone Facies

This facies is found in the transition zone between Qamchuqa and Sarmord formations in the Qamchuqa Gorge section and north of Bardashan village (Figs. 2.6 and 4.20). This facies consists of bioturbated sandy marl and marly limestone, which contain in situ (in the life position) single colony coral of scleractinian corals (Genus *Isastrea)*. The sizes of these colonies range from (2–7) cm with well-preserved micro-and macro-structures which shows radial oriented septae and central clumella (Figs. 2.6 and 4.19). In addition to sandy marl bed, the transition boundary contains thick competent bioclastic and bioturbated limestone beds (0.2–3 m thick), with make well-exposed outcrops, while the marl and marly limestone that contain the coral are incompetent and commonly covered (Fig. 2.6). Blomeier and Reijemer(1999) found the bioclasts of this type of coral in slope environment and they mentioned that they derived from platform margin.

From the stratigraphic position and its underlying reefal limestone, it can be assumed that these facies is ascribed to the stage of stabilization of reef community (Figs. 2.6 and 4.19). Most possibly, this facies was part of the fore reef facies, when the environment was not so much stormy or turbid to prevent survival of opportunist corals. The underlying and overlying non-coral bearing bioclastic limestones were deposited during storm episode (event) by reworking. From this facies it can be inferred that the Qamchuqa Formation was prograding northeastwards on the Sarmord Formation, during Valanginain.

4.3.7. Branching Coral Facies (Bafflestone)

This facies contains large and small branching rugose coral colonies, which can be seen in outcrops and under microscopes. The length of some branches is more than one meter, as it is found in the Halladin section (Babo mountain) in the middle of the lower part of the formation (L1) (Figs. 4.17 and 4.19). Unlike the solitary coral, the structure of this type is mainly destroyed by recrystallization;

consequently, the fine texture is replaced by spary calcite. In literature, this facies is called baffle stone (Embry and Klovan, 1971), because it has dendritic form and acts as sediment collector from the nutrient bearing current and waves by filtering ; and trapping sediments. The spaces between the branches are mainly filled by micrite (mudstone or wackstone) with some bioclast and rare oncoids. Walker and James (1992) have put this facies in the colonization stage of the reef structure (Fig. 4.23). The presence of corals indicates normal marine salinity (Riding and Tomas, 2006).

Fig.(4.17). Branching Coral Lithofacies, A) coral in outcrop in the lower part of the Halladin section, B) coral of Kewa Rash section under binocular microscope (normal light).

4.3.8. Rudstone Facies (Reef talus facies)

This facies is introduced into Dunham (1962) classification by Emery and Klovan (1971), it consists of self-supporting large allochems (more than 2mm thick) bounded by mudstone (micrite) (Fig.4.18). This facies can be seen in all sections, more common to the north and northeast of the Halladin and Kewa

Rash sections, which coincide with the lateral transition zone between Qamchuqa and Balambo Formations (fore-reef area) in the extreme northern extent of the formation in the Zhilwan and Karogh anticlines. This facies mostly consists of micritic limestone intraclasts and bioclasts of coral, bryozoans, gastropod and pelecypods. In some cases, this facies grades to conglomeratic grainstone, as milky and spotty appearance and cemented by spary calcite or dolomite. According to Wilson (1975), this facies is deposited in forereef environment where the strong wave and current action are prevalent. According to the above mentioned author, the allochems of this facies must be derived from the reef, but many authors have included the non-reefal allochems in this facies, such as Al-Sadooni and Al-Sharhan, (2003) , have assigned the orbitolina bearing limestone as *Orbitolina* rudstone. Kenter *et al.* (2005) found that boundstone breccia in the forereef area, are formed by influence of gravity.

4.3.9. Floatstone Facies

This facies is rare and consists of grains larger than sand size, which are floated or embedded in fine matrix of lime mudstone. The grains are generally derived from the fragmentation of reef builder skeletons, such as coral or rudist (Fig.4.18). The oncoids may also make up this type of facies, when showing some transportation and floating in fine matrix of bacteria or algal origins.

In all sections there are beds and horizons rich in large bioclasts, of gravels and granules sizes, of rudist, pelecypods embedded in the fine grain grey matrix and form gravely wackstones and packstones. If these rocks included in floatstone facies, then they become common, but the problem is that it is not known whether they are derived from the reef or from fossiliferous beds (biolithosome). Therefore, the very coarse bioclastic limestones are discussed under the name of other facies such as peleypods, gastropod wackstone and packstone facies.

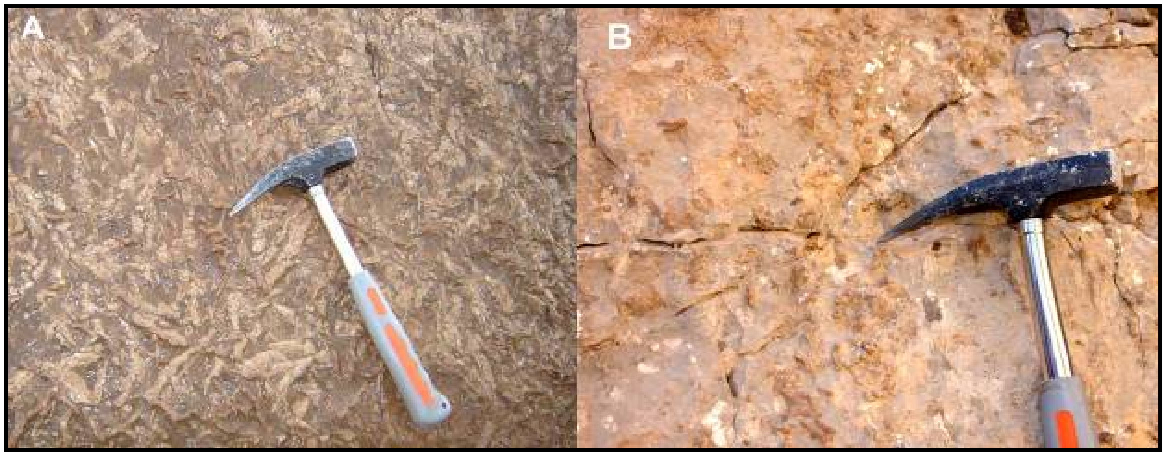

Fig.(4.18). A) Fragments of bryozoa and rudists in fine matrix (rudstone) D3 of Piramagroon anticline. B) Spars fragments of bryozoa embedded in fine matrix (floatstone) L1 of Qamchuqa section.

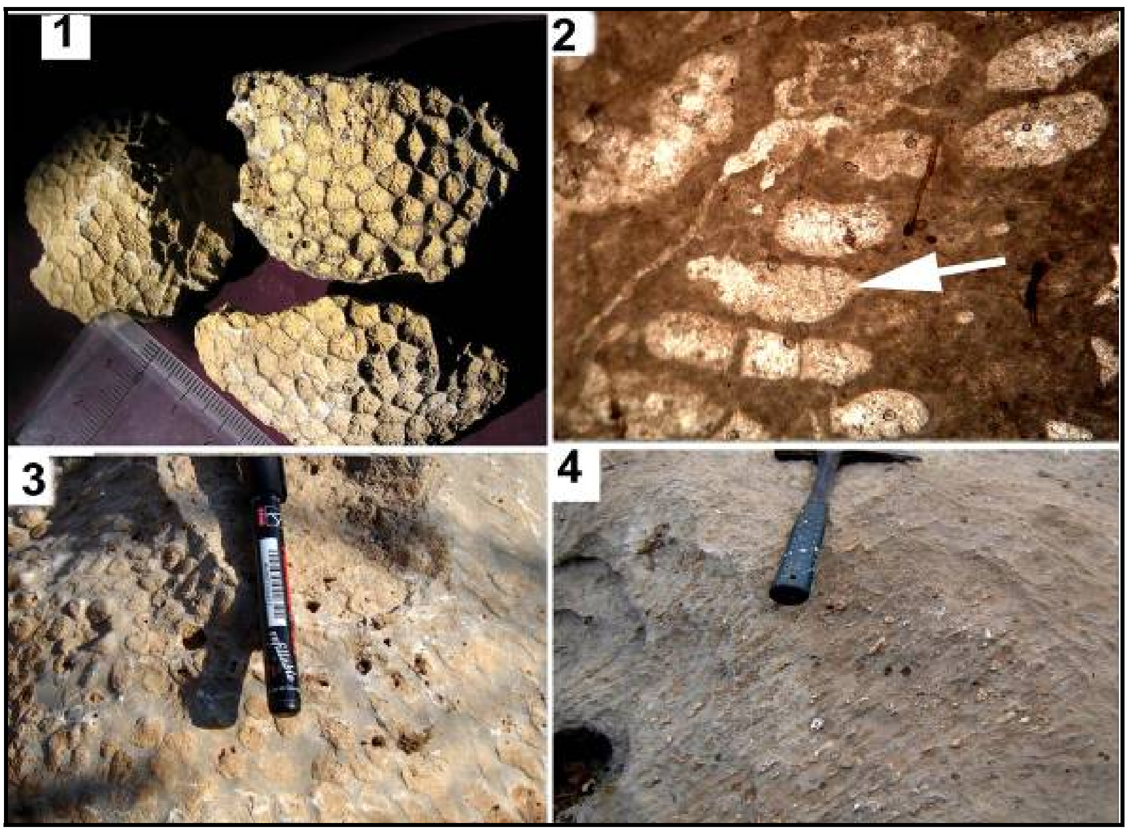

Fig.(4.19). 1) Coral colonies (Isasteria or Hexagonaria), Bardashan village, Raniya area. 2) Cross section of branching corals under stereoscope microscope, X10, N.L. 3) Base of brunched coral colony, Halladin section. 4) Coral highly brunched, Halladin section.

4.3.10. Ichnofacies

Ichnofacies is association of environmentally related trace fossils, which generally reflect activity of soft- bodied organism (Catuneanu, 2006). As a sedimentary facies, it is defined by the types of trace fossils exist within, below or above sediments (Frey, 1975). According to Pembrerton *et al.* (2001), each ichnofacies includes different type of trace fossils (Table 4.2). Although evidences like, lithology and body fossils can be used for environmental deduction, the trace fossils are very helpful in unfossiliferous successions. The traces fossils reflect the effect of organism in homogenizing fine-grained sediments via arranging sediments in different packing mode, reflecting the activity of these organisms within sediments (Flugel, 1982). These activities represent digging or burrowing of sediments during syn- or post-deposition (Greensmith, 1971). When lithified rocks suffer from organism activity, the term bioerosion is utilized instead.

In the Qamchuqa Formation, the ichofacies have low diversity but their occurrences are widespread so that the common features that could be seen in each section are spotty appearance and massiveness of the outcrops. These features are mainly attributed to certain type of ichnofacies that reflects activity of organism in sediment in certain environment. Two types of ichnofacies are observed, they are trypanites and glossifungites.

4.3.10.1. Trypanites Ichnofacies

According to Walker (1984), Trypanites are associated with rocky coasts, reefs, hardgrounds, and other types of discontinuity or unconformity surfaces, and their substrate consists generally of calcium carbonate. He also mentioned that, most of the traces are dwelling structure excavated by suspension feeders and they are intergradational with Glossifungite ichnofacies, indicating important bioerosion agent, in addition to their acceleration of physical erosion. Catuneanu (2006) mentioned that they are association of various boring traces on a lithified

Table (4.2) Classification of ichnofacies based on substrate, environment and related traces (Catuneanu, 2006)

Substrate	Ichnofacies	Environment		Trace fossils
Softground, *nonmarine*	Termitichnus	Subaerial	No flooding: paleosols developed on low watertable alluvial and coastal plains	*Termitichnus*, *Edaphichnium*, *Scaphichnium*, *Celliforma*, *Macanopsis*, *Ichnogyrus*
	Scoyenia	Freshwater	Intermittent flooding: shallow lakes or high watertable alluvial and coastal plains	*Scoyenia*, vertebrate tracks
	Mermia		Fully aquatic: shallow to deep lakes, fjord lakes	*Mermia*, *Gordia*, *Planolites*, *Cochlichnus*, *Helminthopsis*, *Palaeophycus*, *Vagorichnus*
Woodground	Teredolites	Marginal marine	Estuaries, deltas, backbarrier settings, incised valley fills	*Teredolites*, *Thalassinoides*
Softground, *marginal marine*	Psilonichnus		Backshore ± foreshore	*Psilonichnus*, *Macanopsis*
Hardground	Trypanites	Marginal marine to marine	Foreshore - shoreface - shelf	*Caulostrepsis*, *Entobia*, echinoid borings (unnamed), *Trypanites*
Firmground	Glossifungites			*Gastrochaenolites*, *Skolithos*, *Diplocraterion*, *Arenicolites*, *Thalassinoides*, *Rhizocorall.*
Softground, *marine*	Skolithos	Marine	Foreshore - shoreface	*Skolithos*, *Diplocraterion*, *Arenicolites*, *Ophiomorpha*, *Rosselia*, *Conichnus*
	Cruziana		Lower shoreface - inner shelf	*Phycodes*, *Rhizocorralium*, *Thalassinoides*, *Planolites*, *Asteriacites*, *Rosselia*
	Zoophycos		Outer shelf- slope	*Zoophycos*, *Lorenzinia*, *Spirophyton*
	Nereites		Slope - basin floor	*Paleodictyon*, *Helminthoida*, *Taphrhelminthopsis*, *Nereites*, *Cosmorhaphe*, *Spirorhaphe*

substrate (hard ground) that occurs in the marine shallow environment (shelf and shoreface). Bromley (1972) recommended Trypanites to include all pouch-like, single-entrance excavation that is made by bivalves and other organisms. In the Qamchuqa Formation, four evidences are found for Trypanites ichnofacies and associated hardgrounds are recognized. The **first** is omission surfaces with brown color mineralization, which contains dolomite filled small shaft and tunnel about 1–3 cm wide and 4–7 cm long (Fig.4.20). The **second** is that assumed boring has sharp boundary and filled either with light brown dolomite or with yellow marly limestone (Fig. 4.21). The **third** is the occurrence of sharp erosional surface below the omission surface (crude erosional surface) (Fig. 4.21). The **fourth** is the occurrence of pelecypod fossils with the ichnofacies. In this study the trypanites observed in the lower part of Yakhsumar, Halladin and Kewa Rash scctions (Fig.4.21).

4.3.10.2. Glossifungite Ichnofacies

According to Walker (1984), Glossifungite ichnofacies exists on firm but unlithified marine littoral, and sublittoral omission surface, especially on semiconsolidated carbonate firm grounds, where the substrates offer resistance to erosion by currents and waves. The same author recognized these traces as bioturbation and the Trypanite as bioerosion, but because of broad gradational spectrum of substrate, the two may associate in the Glossifungite ichnofacies. Because of their existence in carbonate rocks, they are occasionally associated with pelecypod, which may be responsible for both boring and burrowing that represent postomission ichnofacies. The glossifungies Ichnofacies has foreshore environment (Catuneanu, 2006). In this study the glossifungies observed with thalassinoids in the lower part of Yakhsumar, Halladin and Kewa Rash scctions (Fig.4.20).

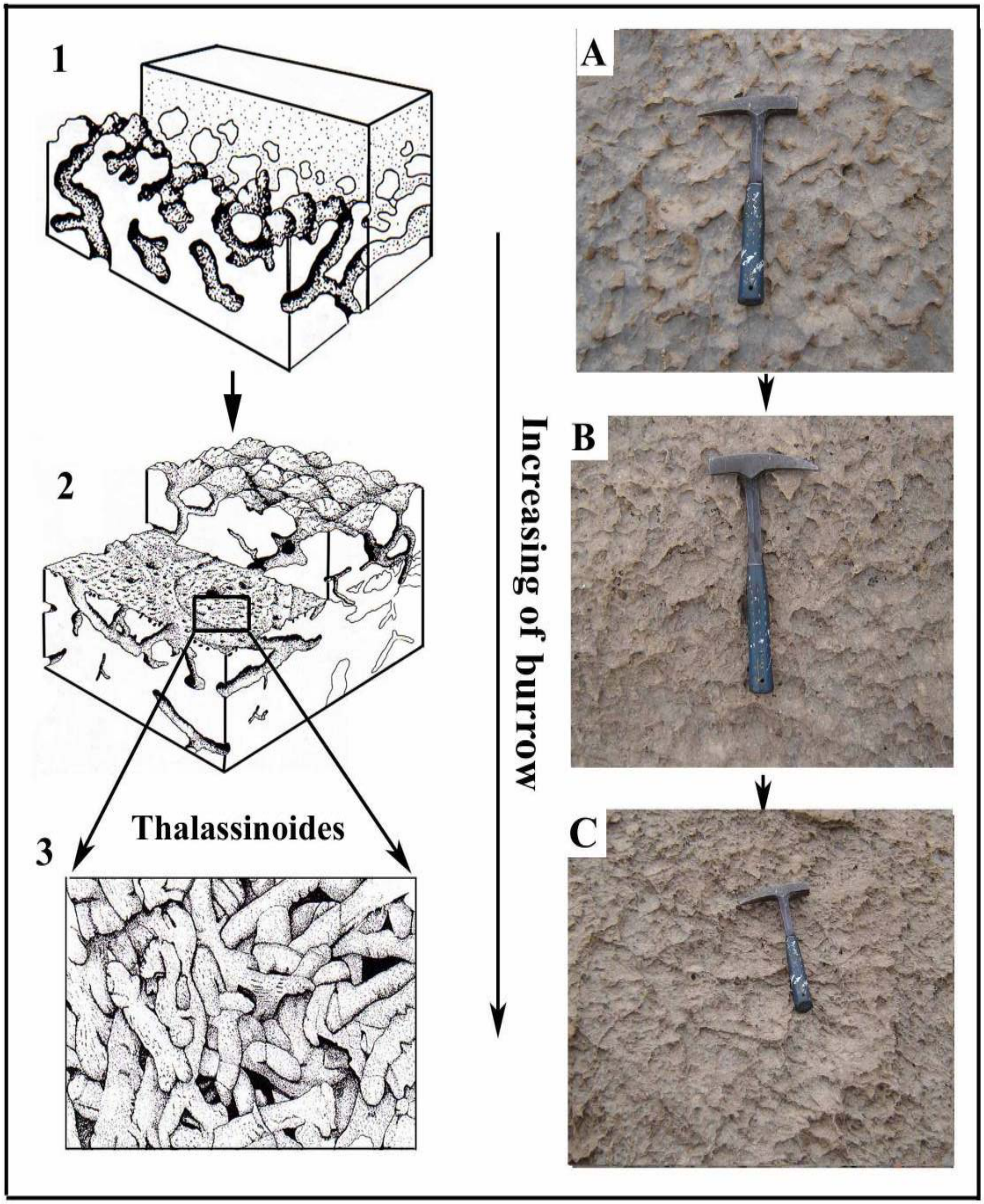

Fig. (4.20): Different stages of burrows (from A to C), also represented the Thalassinoides on the surface (from 1 to 3).

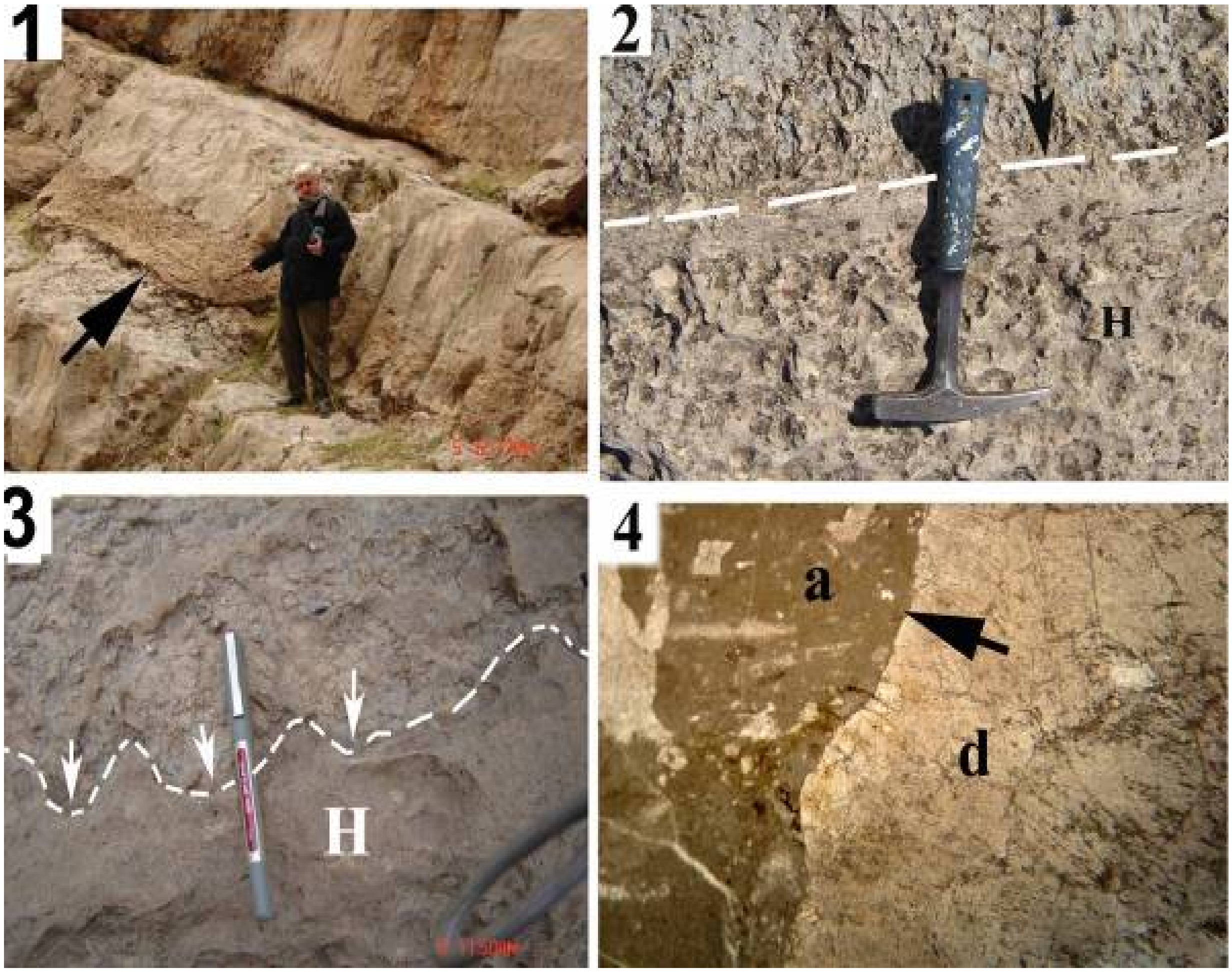

Fig.(4.21)

1) Sharp boundary .omission surface (arrow). Overlying the burrow surface, Kewa Rash section.

2) Sharp boundary .omission surface (wight line). Overlain the burrow surface in hardground (H) Betwata area.

3) Convolute omission surface (arrow) Kewa Rash section, with pelecypods above the hardground surface(H).

4) Sharp contact of the boring in limestone. Kewa Rash section, X10, N.L.

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4.3.11. Dolomitized Facies

This facies consists mainly of dolostone, which contains diffrent grain dolomites. This facies is commonest facies in the studied area which constituent about 55% 0f the total thickness of the formation. This facies is more common in the middle and upper parts (D2, D3 and D4). In most places, they are fractured and even brecciated; the fractures are filled with white coarse crystalline dolomite. Under microscopes, they show high porosity with moldic, vuggy and intra crystals type, which acts as an excellent hydrocarbon bearing beds (reservoirs). The origin and depositional environment of these dolomite successions are most problematic in the study of Qamchuqa Formation. This is because nearly all original components are destroyed by pervasive dolomitization. In this study, tens of outcrop sections are inspected to find if some relict of the original component can be seen.

In some of these sections, the following four original components are found. The **first one** is a large elongated gastropods (3cm wide and 6cm long), which are found north of Zewe village on the Piramagroon mountain, with some bioclastics. The **second** occurrence of regular and continuous millimeteric laminae in some thick succession south of Sargelo and Smaqully gorges in addition to Zhelwan and Piramagroon mountains. In these localities, the lamination consists of alternation of white coarse crystalline dolomite and grey or dark brown dolomite (Fig.4.22). The **third** original component was found is wavy and patchy laminations with ragged boundary that are recorded north of Marga village and on the southeastern sides of Piramagroon and Kewa Rash mountains(Fig.4.16). These laminations are not continuous (extend laterally no more 40cm) and terminated from left and right sides with ragged boundary. These types are similar to those found in the lower limestone succession (L1 or L3), except for their large sizes, as compared to those found in the limestone units. The **fourth** type is dolostone with relict of coarse bioclastic, which recorded in Kewa Rash Section and Zhelwan anticline (5kms northeast of Halladin section).

From the aforementioned **four points**, it could be deduced that the dolomite successions are not primary (depositional) in origin, but most possibly altered by early or late digenetic processes (pervasive dolomitization). It is possible that the dolomitization is assisted by high Mg contents of the basin of the Qamchuqa Formation during deposition due to high temperature environment of upper part (see depositional environment for more detail). In this concern, Millman and Muller (1973) and Sartori (1974 in Reading p.360) mentioned that High-Mg calcite was formed during high-elevated temperature. Consequently, the micrite and most allochems are transformed to medium or fine rhombs of dolomite (Fig, 4.22). The low diversity of fossil and high dolomite content of this facies suggest a sever environment (hot and dry climate) in which opportunist animals survived. This environment was most probably consisted of sand flat behind the reef. After deposition, these sediments are covered by high Mg lagoonal water due to progradation of lagoonal sediments over the reefal limestone. Another reason for extensive dolomitization is probability of flooding of the both reefal and sand flat sediments by high Mg water of the lagoon during or after progradation of the reefal limestone. By this progradation the reefal and lagoonal environments have changed location geographically (specially) or vertically (temporary) with time. Consequently, the porous reefal and sand flat limestones are overlain by lagoonal high Mg water. Then, late dolomitization occurred by percolation of lagoonal water in the rocks.

In this basin the components were in direct contact with Mg ions after deposition for early dolomitization, which aided by reworking of the components by bioturbating organisms. The dolomitization was supported by addition of Mg ions during the burrowing from the seawater to the sediment or strata and causes the dolomitization. It is possible that bioturbations, which are very common, were exposing the sediments several times to seawater during which the introduction of Mg^{+2} ions were occurring for dolomitization. This process is mentioned by

Allen and Allen(1990,p.325), they stated that the burrowing metazoans churn up the sediment to a depth of 5 to 30 cm, allowing the penetration of oxygen and sulphates into the sediment column, thus promoting bacterial degradation. In our opinion, this is also true for adding Mg ions into the sediments. The limestones Units (L1, L2, L3 and L4) also contain localized dolomite as irregular spots, these patches are nothing except the burrows of organism, which attached by selective dolomitization.

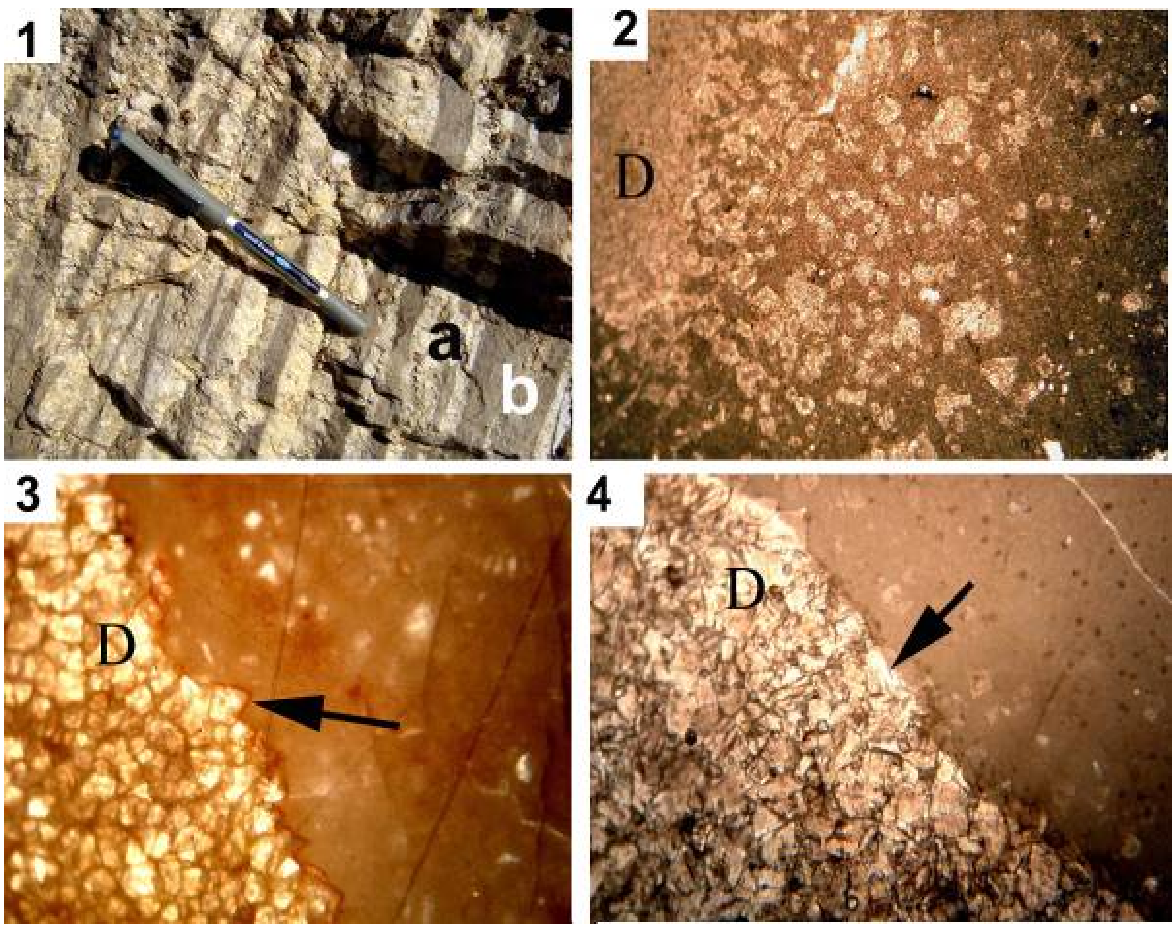

Fig (4.22). 1) Alternation of dolostone(b) and sparry white dolomite (a) lamina in the D2 of the Yakhsamar section. 2) Spreading out of dolomite crystals (selective dolomitization) from the burrows in the Kewa Rash section. 3 and 4) The contact (arrow) between a borrow and host rock at the left showing selective dolomitization with sutured (3) and straight contact (4), Kewa Rash section . 15X, N.L.

4.3.12. Marly Limestone Facies

This facies is dominant in the top of the lower, middle and upper parts of the sections (Figs.2.3, 2.5, 2.8 and 2.11), in addition to transition zone between Qamchuqa and Sarmord formations. This facies dose not represent more than 5% of the total thickness of the sections. This facies is interbedded occasionally with highly fossiliferous limestone beds, which contain rudist whole skeletons, pelecypods bioclasts and Orbitoid Foraminifera. It is possible that they are formed during the sea level rise in the lagoon when high amount of erosion is happened by stormy episode, and the product is deposited in more oxygenated and less saline lagoon in which organisms survived.

4.4. Depositional Environment

It is generally known that the depositional environment of the formation is platform. From lithofacies and fossils contents, it is clear that the platform included several environments such as reef (barrier reef), lagoon, forereef, slope, and slope-basin plain transition, which were represented by Balambo Formation(Fig.4.26). These environments were repeated several times along the whole thickness of the formation and during time span of the deposition of the formation. These changes can be seen in the sections as alternation of successions of limestone and dolomite beds (L and D units). The massive dark gray limestones successions represents mostly reef core, while the well-bedded light grey limestone successions indicate deposition in lagoonal environments at significant distance from reef.

As mentioned above it is known that environment of the formation is platform but three things are important to be clarified. The **first** is that it is not known if the platform was totally attached, or it has suffered from isolation, intermittently. The **second** is whether the platform consisted of ramp, rimmed shelf or barrier.

The **third** is the problem of climate; temperature and salinity that prevailed in the basin during different ages. The field and microscopic study of thin sections had revealed different types of fossils and facies, which change both laterally and vertically. Some fossils give specific environment such as scaleritarian (tabular corals) and branched corals, oncoids, stromatolites, rudists, *orbitolina* and *millolids*. All these fossils indicating shallow depositional water, the first one indicates forereef while branched corals, oncoids, stromatolites and rudists indicate reef and the others indicated lagoonal environment.

Some of the lithofacies, being bearing these fossils and other allochems, are very helpful for environment indication, such as oolitic packstone–grainstone. This facies indicates very shallow winnowing environment for some short interval time in a very limited extend while the prevalence of mudstone and dolostone lithofacies in both lateral extend and thickness shows that the environment of the deposition is generally calm and wet which was neither stormy nor stagnant. Einsele (2000) showed by diagram that association of green algae, coral; and others are survived in wet tropical seas.

These fossils and lithofacies indicate that the environment of the lower part was of mid–latitude circulated normal marine platform environment as typical algal and coral reef is developed. However, toward the upper part thick and massive–bedded succession of dolomite increases, which might be attributed to increase of temperature, salinity and isolation (relative restriction). This may be related to the green house phenomena that prevailed during Early Cretaceous (Barremian–Aptian) as mentioned by Friedrich *et al.* (2003) and Hillgärtner *et al.* (2003). The former author added that the mid-Cretaceous (nearly coincide with deposition of upper part of the Qamchuqa Formation) was the extremely warm while the Late Cretaceous (Campanian–Maastrichtian) interval marks the onset of waning greenhouse conditions. Another possible reason for abundant of dolomite in the upper part is the narrowing of the basins (northeastern basin in which Balambo and Qulqula Radiolarian formations are deposited) by the southwest advance of Iranian plate (see chapter five for more detail).

This warm condition and restricted circulation was favored by high evaporation and early dolomitization of the sediments. In addition to thick dolomite successions, the burrows in the L1, L2 and L3 are also dolomitized. Most of the sediments inside burrows have more than two times more dolomite than the host rocks, especially in the upper part (Fig.4.20). This is ascribed to high Mg content of the sea water, so that the reworked sediments in the burrows and bioturbated horizons suffered from several mixing with seawater. In this connection, (Millman and Muller, 1973, and Sartori, 1974, in Reading, 1991) mentioned that high Mg calcite precipitated during high-elevated temperature. Evidence to the warmness of the climate during Albian–Cenomanian is the deposition of the evaporite concurrently with deposition of upper part of Qamchuqa Formation in the western Iraq as Jawan Formation (Buday, 1980, Dunnington, 1959 and Jassim and Goff, 2006).

The scarcity of large Foraminifera, except *Orbitolina*, can be signal for the restricted and saline environment of deposition, except for some short intervals. When one compare between the rudists of Upper Cretaceous (Aqra Formation) with that of Qamchuqa Formation, he realize restriction of the environment of the latter formation as compared to the former one. The rudist of Aqra Formation gained large sizes more than three times than that of Qamchuqa Formation for same genus. According to Pittet *et al.,* (2002), orbitolinid beds and carbonates formed by microbolites and microencrusters seem to be the shallow-water carbonate response to global changes, affecting Late Barremian to Aptian palaeoclimate and palaeoceanography.

4.4.1. Reef Environment

Coral growth is favored by intense wave action and an absence of terrigenous clay and silt. The majority of reefs occur along shelf margins, an agitated zone where waves and currents of the open sea first imprinted on the sea floor. The coral-rudist-microbolite boundstone is related to episodes of reef development at the platform margin (Reijmer and Immenhauser, 2005, p.370).

Corals are common and remarkable fauna in the shallow carbonate seas, and were major contributors to reefs and banks from the Ordovician to the Recent (Horowitz and Potter, 1971). Small patch reefs are developed in open lagoons behind shelf margin reefs. Many different organisms can be and have been involved in the construction of reefs. now, the main reef builders are coralline algae(Fig.4.23). Special attention can be made of cynobacteria (formerly known as blue green algae) constructing stromatolites, bioherms and biostromes (Wilson, 1975).

In Qamchuqa Formation, the reef is built by three types of Organisms. Those that are providing a skeletal framework consist of corals and rudists, which form the framestone facies (pillarstone). Those that have the habit of encrusting are those that consolidated the frameworks, such as algae, and cynobacterias which makeup the bindstone facies (sheetstone). The reef users are also common such as bivalves and gastropods, which may form floatstone with other allochems. The oncoids may both act as binder and framestone.

The reefal environment is clear in Qamchuqa Formation from outcrop and thin section study. In outcrop, all sections appear as crudely bedded to massive which form high cliffs that are more resistive to weathering and erosion than lagoonal limestone. They consist of light grey coral, algal and stromatolitic limestone with various types of rudist gastropods and pelecypods(Fig.4.25). It is not known exactly the type of reef: if it is fringing, barrier or atoll reefs. The first one is entirely excluded from consideration, as this type is relatively close to the shoreline, which cannot be applied to Qamchuqa Formation, because the whole thickness of the formation contains no clastic interval that can be attributed to effect of shoreline progradation. The facies maps of Buday (1980) and Dunnington (1958) illustrate that the shoreline was more than 250 km far from the studied area to the west. In literature, Emmehauser, (2005) mentioned that Nahr Umer Formation opened into deep and large Bab intrashelf basin of the United Arab Emirates, this deep basin is other evidence for barrier reef.

The most suitable type of reef is the barrier reef, which fits with the geographical (lateral) and stratigraphical (vertical) facies changes of the Qamchuqa Formation. This is explained by the following **two** points. The **first** evidence is that the formation has good development of lagoonal limestone succession, which consists of well-bedded miliolids bearing mudstone and wackstone, in some section this lagoonal deposits are more than 120 m thick (L2), as in case of Yakhsamar and Qamchuqa Gorge sections (Figs.2.3 and 2.8). This lagoonal limestone, in spite of high thickness, contains no clastic beds except one or two thin beds of marly limestone. These marly limestones are possibly deposited during high storm by mean of which some wind blown clay deposited or deposited by submarine erosion above storm wave base. The **second** evidence for the barrier reef is that the formation contains thick succession of dolomite (D2, D3 and D4), especially in the upper part (Figs.2.3, 2.5 and 2.8).The extensive occurrence of dolomite and lagoonal limestones, suggest a platform with wide top which may contain local irregularities.

By this model (barrier reef), the depositional environment or the relation of the dolomite to the reef core can be indicated. Therefore, the thick and massive dolomite successions are located at that part of back reef that form sand flat, which according to the model, it consist of wide area behind the reef(between the reef core and lagoon). The sediments, in this flat area, were porous bioclastic (mostly high Mg) and were in contact with Mg-rich water of the lagoon for early dolomitization when the wind and sea level changes was supportive for invasion of lagoonal water. The dolomitization in limestone units especially in L1 is aided by bioturbation organism, which may have stirred the sediments several times and then enriching with high Mg lagoonal water, during each stirring phase. In the field several examples has observed that the dolomite clearly increases with increase of bioturbation (Fig.4.21). On this flat, the oolitic limestone is deposited (Fig.4.8) in the lower part of the formation and remained without destruction when the chance for dolomitriztion was absence. The associated lagoon was semi–restricted in the lower part as can be seen from the lithofacies and biota, while that of the upper part was restricted and even closed lagoon.

Another probability is that barrier reef may be transformed to atoll reef, intermittently. This is aided by high but sporadically recording of reefal limestone in all Iraqi territory (Al-Sadoony, 1978). This extensive lateral extends of reef, apparent patchy reef, for more than 200km across basin paleobathymetery, is difficult to be attributed to facies migration. Otherwise, it is possible that the reefs have grown on a basin irregularity (long and parallel-submerged high) during Early Cretaceous. On these, topographic highs were generated more or less similar to large atoll reef (Fig. 4.24). Due to this atoll reef, in the incomplete outcrops in the studied area (as removed by valleys development) and in borehole sections, the reef appears patchy. In the studied areas, there is other evidence for irregularites of the platform top (atoll topography), which is manifested by some signs of deepness in Ranyia–Smaqully area and shallowness in the north and south of this area. The formation is showing more massiveness on both Kew Rash and Safeen Mountains, while shows lesser massiveness and thickness in the area between the two mountains.

Although some clean bioclasts (coquina) could be found, in areas that are assumed as the deposits of the forereef area, but the slump, channel deposits and calcareous turbidite (limestone turbidites) are not found, at least in the studied outcrops. This may be ascribed to possible gentle slope of the fore reef area and calm climate during deposition of the Qamchuqa Formation. Another factor is citation of Hillgärtner *et al.* (2003) whom stated that the Early Aptian platform margin had showed a marked change to purely agragational geometries and a well-developed platform barrier that was formed mainly by microbial buildups. The sudden dominance of the microbial activity has led to cementation and stabilization of the margin and slope and therefore a decrease down a slope sediments transported by turbidites. They also mentioned that the Late Aptian large part of the Arabian craton was subaerially exposed and a fringing carbonate platform formed. Lehrmann *et al*.(1998) studied the isolated platform of the Great Bank of Guizhou in China, they attributed its richness by wackstone and mudstone to its largeness of its top (atoll lagoon) and less winnowing.

According to Read (1985) the type of atoll in Qumchuqa Formation is called pericratonic isolate platform. which may be surrounded by deep lagoon. He added that these type is differ from true oceanic atool, which rise frome volcanic foundation on oceanic crust.

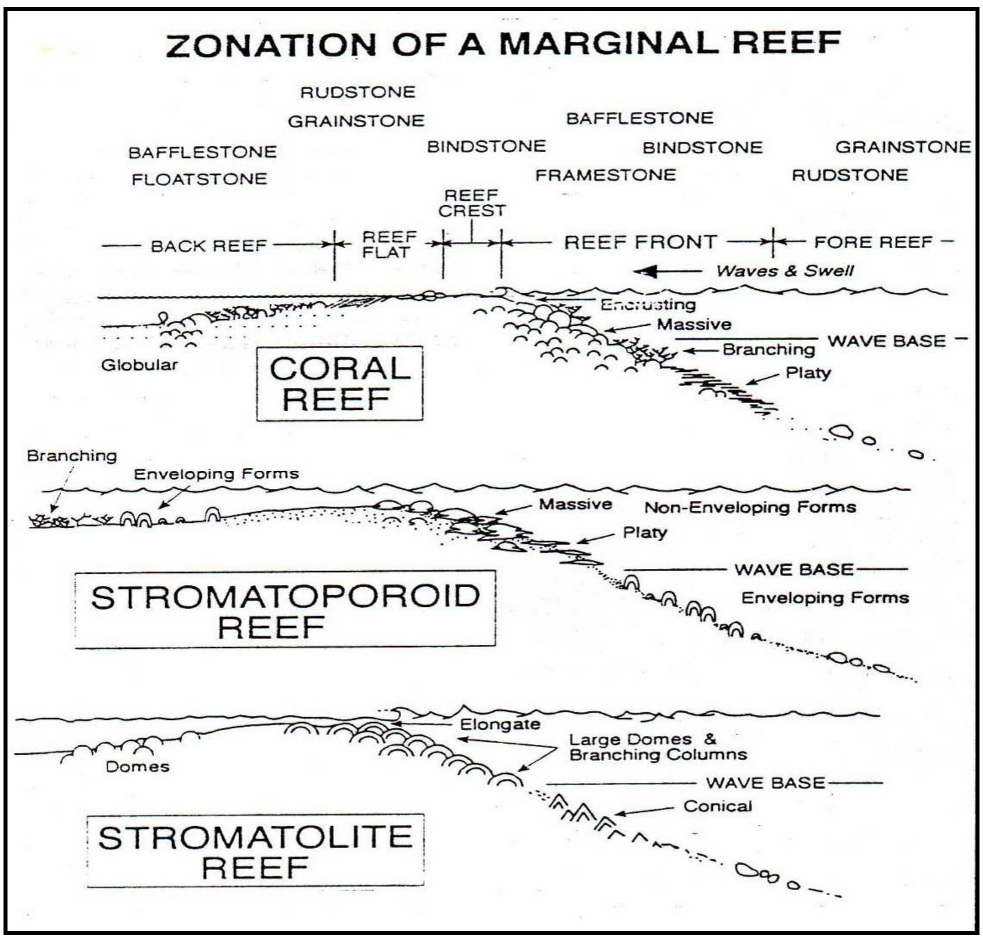

Fig. (4-23): Cross sections through hypothetical zoned marginal coral, stromatoporoid and stromatolite reefs (Walker and James, 1992) from which the reef of Qamchuqa Formation is consisted of the combination of the three types reef.

4.4.2. Possibility of the patchy reefs

Many authors mentioned the possibility of the growing of the reefs in shallow outer-part of a protected lagoon (back reef zone) behind a larger reef barrier (Einsele, 2000, p.140). This author further mentioned that Patchy reefs are frequently associated with skeletal and oolitic sand bars. In deep lagoons, the patchy reefs may developed into isolated conical body, surrounded largely by carbonate. Al-Sadoony (1978, p.120) mentioned that no reefal facies recognized in Qamchuqa Formation.

Many authors mentioned or recorded patchy reef in the Qamchuqa Formation, among them are Al–Shakry (1977) and Al-Sadoony (1978). The attribution of the deposition of the Qamchuqa Formation to patchy reef is not ascertained in the present study, due to two points. The **first** one is the patchy reefs are commonly associated with terrigenous influx which does not exist in Qamchuqa Formation, at least in the studied area. During studying of the outcrops these patchy reefs were not recognized and could not be missed because they are clear for their massiveness and resistance to erosion and appear as mound. However, their occurrence is not excluded in the lagoonal or forereef areas. The fact that the true reef is not recorded by previous authors may be attributed to uncertainty of the role of microbial limestones and their role in the reef building and binding of the constituents.

The **second point** is the well-developed lagoonal limestone succession as represented by (L2, L3 and L4), these succession continuous for tens of kilometers without changing to reefal facies. The thickness of these facies, decipher occurrence of large lagoon, which must be separated by large reefal buildup also. In other sides, these successions are overlain by massive and thick dolostones successions (D2, D3 and D4). The stratigraphic position of these dolostone succession are indicating deposition in the reefal body that one day separated the lagoon from the open sea in which Balambo Formation are deposited.

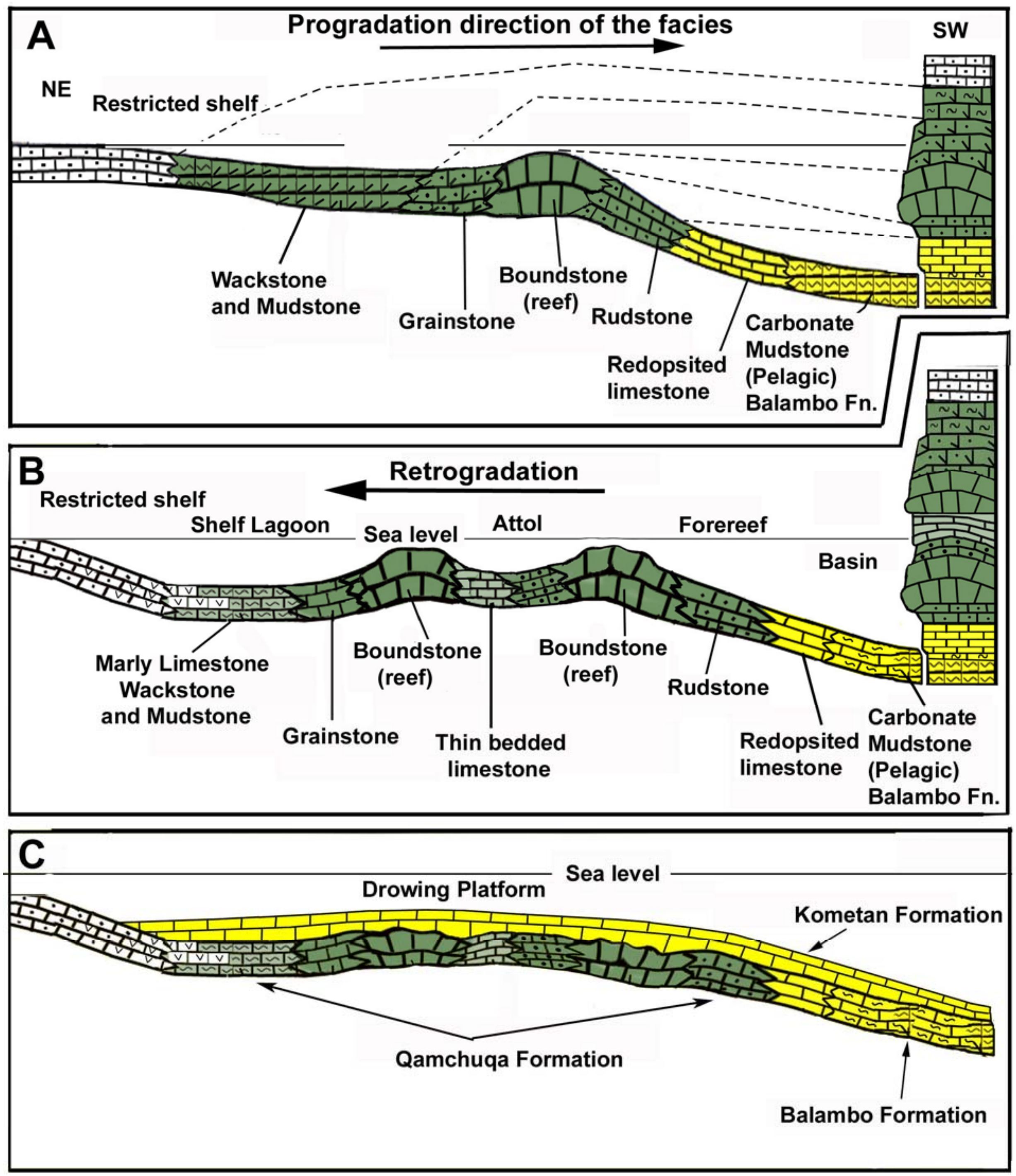

Fig. (4. 24): Two depositional models for Qamchuqa Formation. A) Barrier reef during Aptian. B) Atoll during Albian. C: Drawing platform during Turonian Santonian.

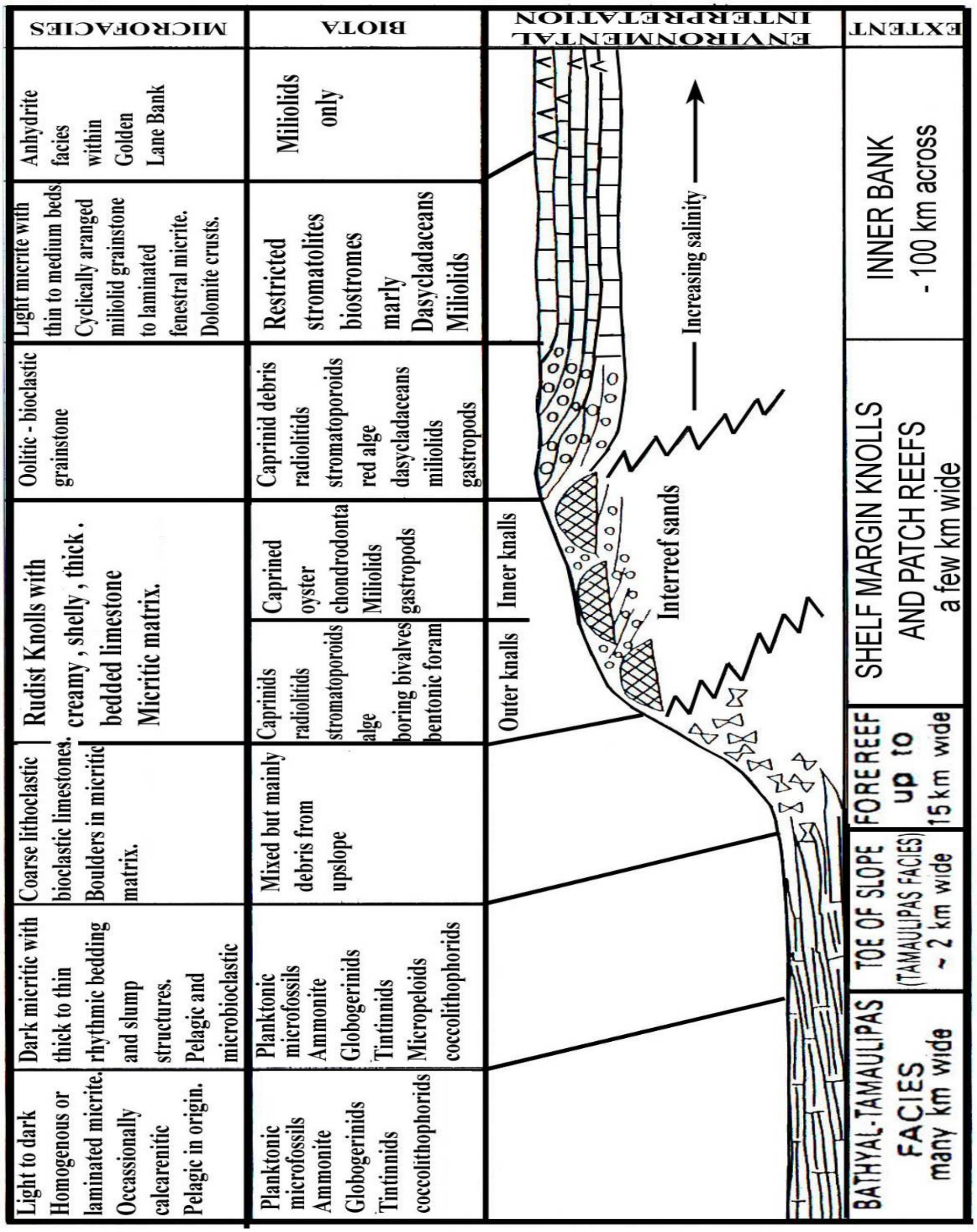

Fig.(4.25):Generalized topography, biofacies and environment cross the margin of the Golden Lane reef, Mexico (Reading, 1979) which highly resembles that of the Qamchuqa Formation in facies and topography .

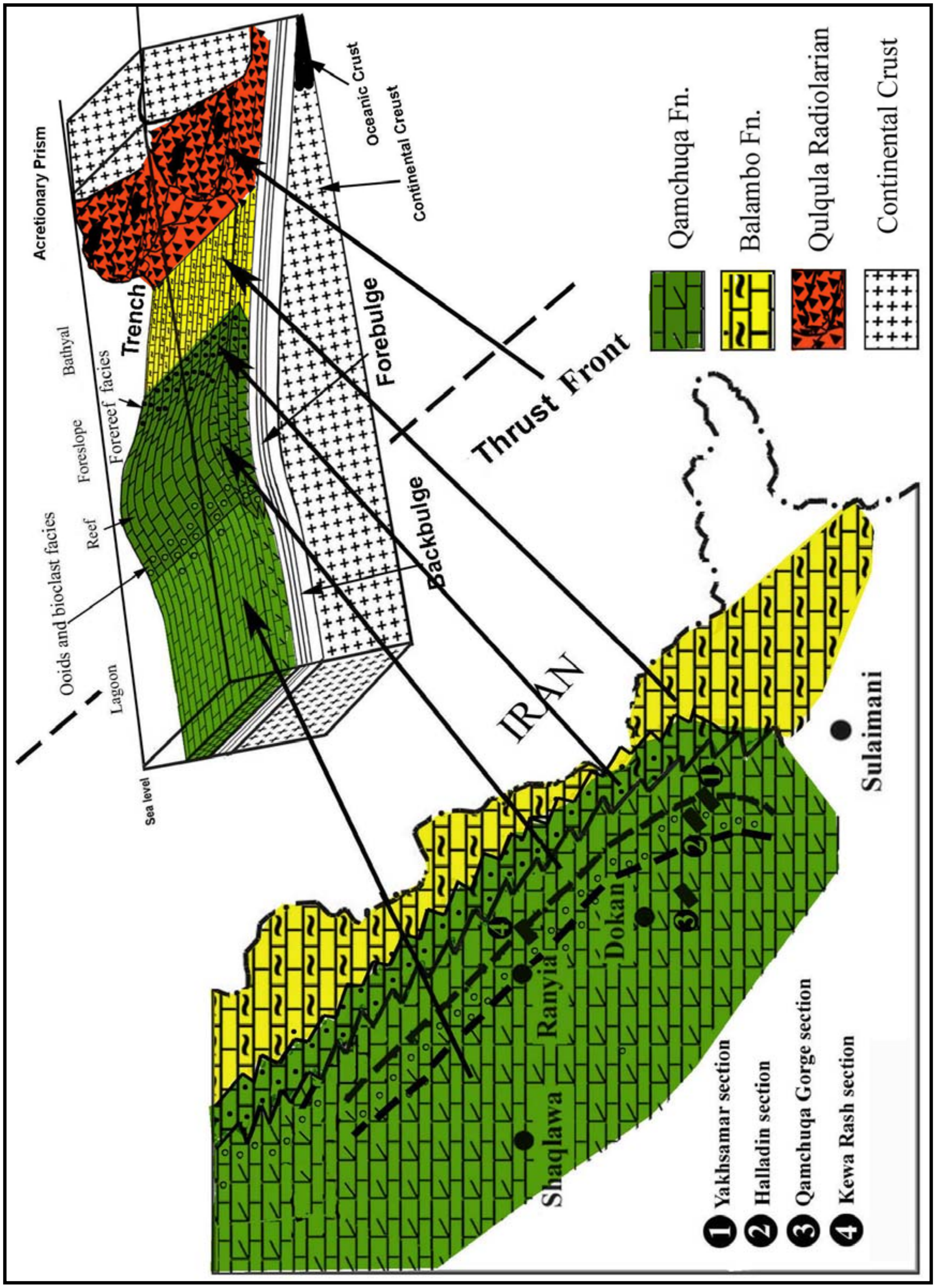

Fig.(4.26): Position of different facies in depositional environments of Qamchuqa Formation, during Aptian.

CHAPTER FIVE

TECTONIC AND DEPOSITIONAL HISTORY

5.1. Preface

For establishing, realistic tectonic model and depositional history that agree with field and lab data of the Qamchuqa Formation, The following points must be mentioned:

1- Buday (1980) has divided the rocks of the Lower Cretaceous in to several cycles and subcycles on the basis of break in sedimentation and tectonic phases, which cause widespread of regression and subaerial erosion as shown by time expanded stratigraphic column by Bellen et al.(1959). These cycles are as follows:

A–Late Berriasian– Albian cycle

a–Late Berriasian–Aptian subcycle in which Lower Qamchuqa, Lower Sarmord Formations, and were deposited in platform and Lower Balambo Formation in miogeosyncline in the studied area.

b–Albian Subcycle during which Upper Sarmord, Nahr Umer, Mauddud (Upper Qamchuqa) Jawan, Rim Siltstone, Qamchuqa, and Balambo Formations are deposited.

B–The Cenomanian–Lower Campanian cycle

a–The Cenomanian–Early Turonian cycle during which Rutba, Ahmadi, Mishrif, Dokan and Upper Balambo Formation.

b–Turonian–Lower Campanian (out the scope of this study)
In the studied area, these cycles and subcycles are not identified by present auther.

2- Buday (1980) Buday and Jassim (1987) and Jassim and Goff (2006) had considered the Albian–Cenomanian (during which upper part of Qulqula Conglomerate is deposited) as the age of unrest and occurrence of strong Mid–Cretaceous phase of orogeny. They mentioned that the Qulqula Conglomerate, as eugeosynclinal wild flysch, had deposited during this age, which has the thickness of 1500m. In contrast of these ideas, Baziany (2006), Karim and Baziany, (2007) and Baziany and Karim (2007) concluded that Qulqula Conglomerate is not exist and suggested to remove it from stratigraphy of Iraq.

3– Numan (1997), in his tectonic scenario of Phanerozoic of Iraq, has not indicated the tectonic position of Qamchuqa Formation. However, he separated Mauddud Formation (equivalence of Upper Qamchuqa Formation) from Balambo Formation by a positive land. According to this tectonic model, the two formations are deposited on the Arabian platform during spreading of the oceanic floor (during separation of the Arabian and Iranian Plate)(Fig.5.1).

4– The most helpful data in the literature for reconstructing the paleogeography during Early Cretaceous is the facies isopach maps given by Dunnington (1958) and Buday (1980) gave many clues to the basins paleogeography of the studied area during deposition of the Qamchuqa Formation (Early Cretaceous). These maps revealed that the studied area consisted of a platform and the deep basin was located to the northeast. These maps showed that slope direction (paleo–depositional dip) was towards northeast, during Early Cretaceous until Middle Turonian in the studied area (Figs.5.2 and 5.5). Karim (2004); Karim and Surdashy (2005b) mentioned that during Coniacian and Santonian the general basin paleoslope direction was reversed 180 degree towards southwest. They mentioned that this reversal is associated with colliding of continental parts of Arabian and Iranian Plates during Late Cretaceous by which the studied area transformed from carbonate platform to foreland basin after subsidence of the studied area.

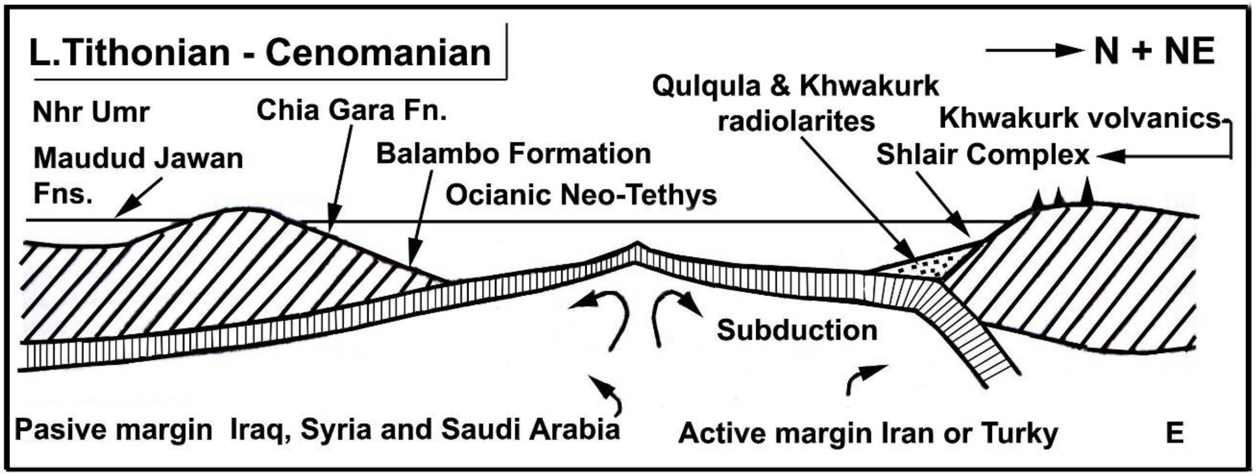

Fig.(5.1) Tectonic model of the Lower Cretaceous by Numan(1997) asummed that Qamchuqa Formation is deposited during divergent (oceanic spreading) of Arabian and Iranian plates.

5– From aforementioned facts, it is clear that the studied area was relatively calm and no important tectonic events were taking place during Early Cretaceous in the studied area. As a part of the Qamchuqa Formation was deposited during Albian–Cenomanian, the above conclusions are very important for understanding the depositional history and tectonic setting of the Qamchuqa Formation. Among the studies that have an important contribution are that of Karim *et al.* (2007, in press), which revealed that the contact between Kometan and Shiranish Formations is conformable; and that of Karim and Surdashy (2005a and 2005b), which changed the tectonic setting of Tanjero Formation from subduction trench to early Zagros Foreland basin during Maastrichtian and Paleocene.

6– In addition to these studies, the gradational boundary between the formation with the underlying and overlying formations permit the geologists to combine all the Early and Late Cretaceous formations in one basin, depending on the Walther Law as cited in Blatt *et al.* (1980). By this combination, the tectonic evolution of the basin in which Qamchuqa Formation was deposited, can be visualized (Fig.4.24). Depending on these literatures and result of the present study a model is drawn for deposition of the Qamchuqa Formation that is compatible with the above facts, which shows more or less continuity in deposition during periods of Early and Late Cretaceous (Fig.5.2 and 5.5).

7–Dunnington (1958) and Jassim and Goff (2006) have separated the Qamchuqa Formation and equivalent units into two sequences of Valanginian–Aptian and Albian – Cenomanian. The two later authors mentioned that the Lower Balambo Formation was deposited in Valanginian–Middle Albian. They added that the Lower Balambo Formation passes into the Lower Qamchuqa (Shuaiba) Formation to the west and southwest. Bellen *et al.* (1959) mentioned that Balambo Formation, as a whole was deposited in a deep-water bathyal environment in outer shelf basin near the margin of the Arabian Plate in NE Iraq.

In the field, the lateral change of Qamchuqa Formation to Balambo Formation could be followed. The transition zone shares the characteristics of both units, which is represented by well beds of planktonic Foraminifera bearing limestone in which some bioclasts and dolomite occur. The massiveness and dolostone increase toward latter Qamchuqa Formation, while decease to the former one. This means that the erosional products (submarine bio and physical erosion) of Qamchuqa Formation were transported towards northeast and deposited in relatively deep water as Balambo Formation. The fine products of erosion (current and wave transported lime mud) are deposited as Balambo Formation. The field evidence for this relation is the occurrence of clean (washed out) bioclastic limestones near the transition zone inside the Qamchuqa Formation (Fig.2.3). These bioclastic limestones (or rudstones) can be seen more frequently in the south of Mawat, North of Ranyia than other areas, which indicate probable forereef area during Early Cretaceous. Therefore, it is clear that the sediment transport and paleocurrent were mainly toward northeast during Early Cretaceous.

Consequently, nearly all the major tectonic events that are mentioned in previous studies, during the Early and Late Cretaceous are canceled. The canceling of these events and simplification of the studied area by (Karim, 2004, Karim and Surdashy (2005a and 2005b) Bazinany (2007) and Karim and Baziany (2007) enabled the present author to put forward new tectonic models and depositional history for Qamchuqa Formation (Fig.5.9).

Therefore, finding the benchmark, among these controversies, for starting the discussion and construction of a tectonic model of the Qamchuqa Formation is not a simple task. This is because, clear clastic rocks are not found in the studied area and the previously claimed conglomerates and erosional surfaces of the upper contacts not ascertained in this study (see section: 2.2.3).

5.2. Depositional History

The most suitable paleogeographical setting, for Qamchuqa Formation, is a wide carbonate platform, which occasionally transformed in to isolated platform due to intermittent surrounding by deep water nearly from all sides. The isopach map of Dunnington (1958) shows position of reefal limestone (possible position of forebulge) during Valanginian–Aptian. On this map, the reefal limestone is surrounded from several sides by deep facies (marl) which may be due to isolated platform setting (Fig.5.2).The lithologic evidence for this setting is that the lower part of Qamchuqa Formation contains lesser dolomite lithofacies than the upper part. Among the units of the lower part, the limestone units are very thick while in the upper part the limestone units are relatively thinner. This wide platform is developed by the uplift of the studied area during Berremian due to colliding of the oceanic part of the Iranian microplate and Arabian plate as shown in the next sections.

5.3. Forebulge tectonic model

According to Einsele (2000) and Allen and Allen (1990), forebulge is a wide and low amplitude uplift, generated on the continental crust of subsided plate by an enormous tectonic load accumulated on it by the overriding plate. Alavi (2004), in fig. (5.4) has shown two cross sections of the Zagros Fold-Thrust belt in Iran during Upper Cretaceous. In these sections, he showed the forebulges that swing back and fro due to properties of the plate and location of the load. It is possible that the alternation of Lagoonal; and reefal limestone successions of the Qamchuqa Formation ascribed to the similar tectonic oscillation during Lower Cretaceous. The lateral and vertical migration of this forebulges is well documented by Allen and Allen (1990), Einsile (2000) and Catuneanu, 2006) (Fig. 5.3).

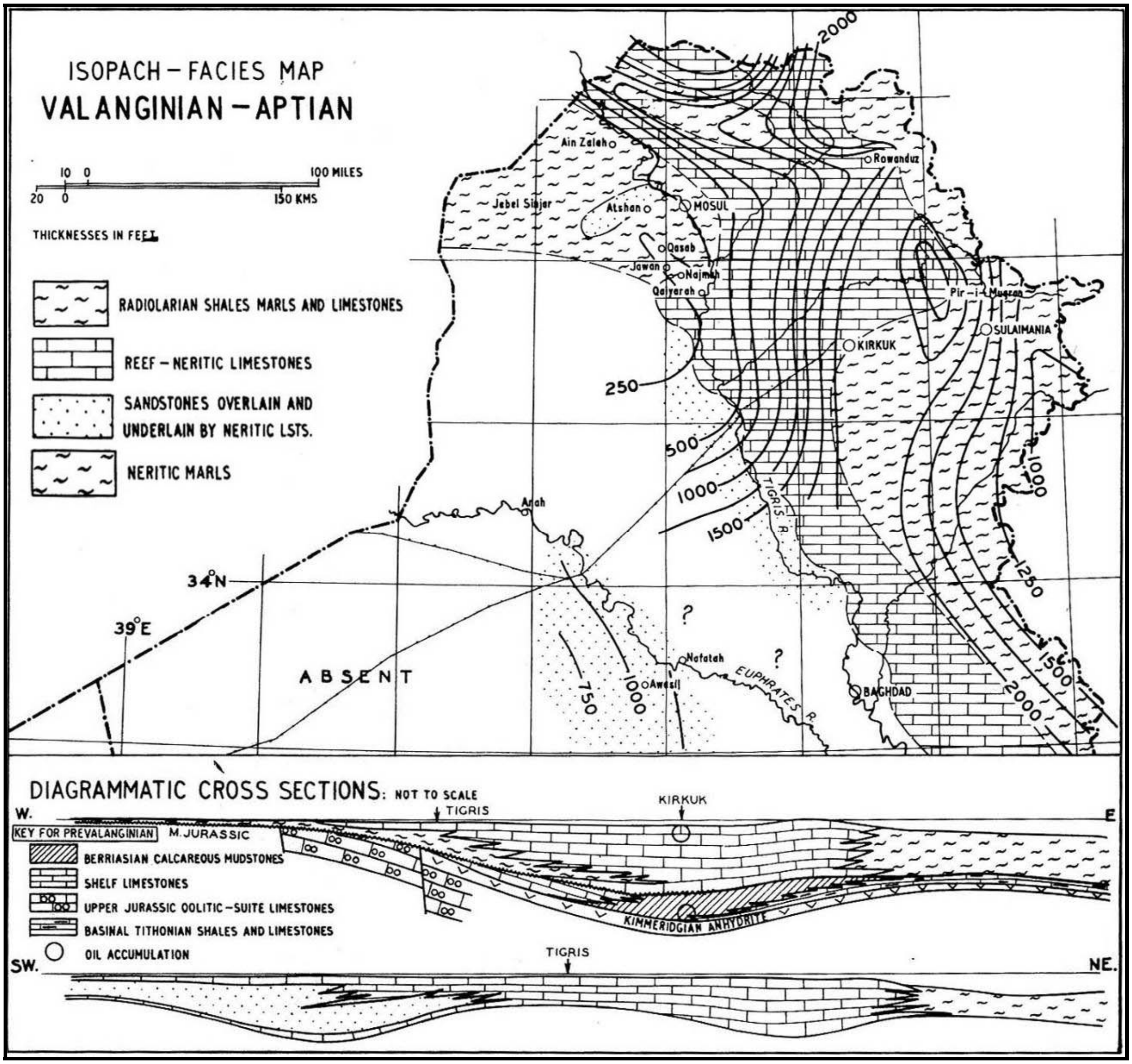

Fig.(5.2) Isopach facies map of Valanginian–Aptian (Dunnington,1958) shows position of reefal limestone (possible position of forebulge). The reefal limestone is surrounded from several sides by deep facies (marl), which may be ascribed to isolated platform setting.

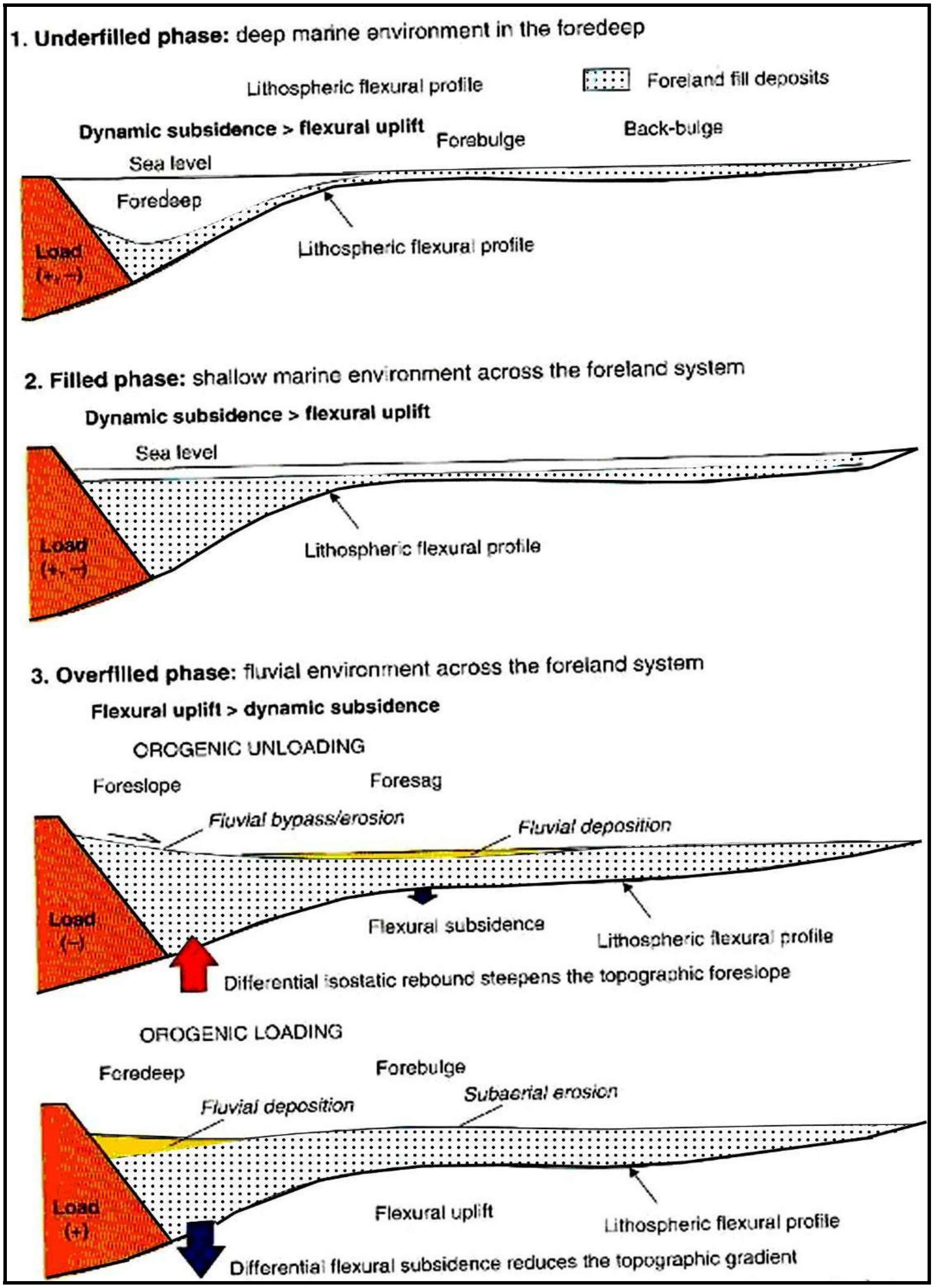

Fig.(5.3) Diagrammatic cross sections of convergent margin showing the generation of the forebulge by flexture uplift (Catuneanu, 2006).

We mentioned that the studied area was tectonically calm (relatively) during deposition Qamchuqa Formation as demonstrated by the studied lithofacies, which contain no conglomerate and terrigineous clastics. However, to the northeast and away from the studied area, major tectonic events were occurring. Inside Iran and near to the present location of Sanandaj-Sirjan belt, the oceanic part of the Iranian and Arabian plates had collided during Berremian.

By this colliding, the Arabian plate had suffered from subduction under the Iranian one and, the previously depositerd radiolarite, had began to accumulation in the trench between the two plates forming accretionary prism (Fig. 5.9). The radiolarite were continuously accumulated with it's concurrent deposition far from the center of accumulation at the area between the Balambo and the trench. In this connection, Jassim and Goff (2006) mentioned that a carbonate ridge probably separated the pelagic Balambo basin from the deep-water continental margin on which the Qulqula radiolarites deposited in Albian time, when silica-rich water of the Southern Neo-Tethys flowed into the Balambo basin.

During this colliding, with radiolarite, the slices of oceanic crust and upper mantle were emplaced into the trench as ophiolite bodies. During Valanginian until Cemomanian, the accumulation was continuous. During early stage and before large accumulation of radiolarite, the Sarmord Formation was depositing in the studied area as pelagite and hemipelagite facies in deep basin and most possibly graded to Qulqula Radiolarian Formation at the northeast. By southwest advance of the overriding plate, huge quantities of radiolarites and ophiolites were accumulated. This accumulation formed an accretionary prism in the trench and had imposed heavy load on the Arabian plate. This load had forced part of Arabian plate to flex or bend elastically forming a **forebulge** (wide uplift). This forebulge generation was happened relatively slowly and calmly on which Qamchuqa Formation was started to deposit instead of Sarmord Formation during Valanginian. This transformation of the studied from the deep basin to reefal one can be seen in the field by deposition of the conformable contact between the two formations. this contact consists of transition zone which contain alternation of bioclastic limestone and pelagite with growth of colony of coral (scleractinia corals) (Fig.4.18 and see section 2.2.1). Because of this calmness and gradual change, Van Buchem, *et al.* (2002) mentioned that during Albian–Early Cenomanian in Oman, role of tectonism was only minor factor in the creation of basin topography.

During Valanginian to Cenomanian, the accumulation and southwest migration of the wedge were continuous. This forced the basin of Qamchuqa Formation to subside and uplift in different times under the effect of loading and relaxation (when principles of basin analysis of Allen and Allen, 1990 and Einsele, 2000 are used). This oscillation can be seen in the field in the form of the alternation of lagoonal and reefal carbonates (L1, D1, L2, D2… and so on).

The rubbing and scraping of radiolarite (Qulqula Radiolarite Formation) and ophiolite from the ocean floor was main mean of the accumulation by horizontal stress of Iranian plate front along the present elongation of Zagros mountain belt. By the end of Albian, the velocity and the load of the accretionary prism (submarine tectonic wedge) are increased and become more close to the basin of the Qamchuqa Formation. This closeness and heavy load had caused rapid subsidence of the basin of Qamchuqa Formation, ceasing (stopping) the growth of reefal and lagoonal limestone due to drowning of the platform on which Qamchuqa Formation was deposited. Consequently, Instead of platform carbonate, deep marine carbonate was deposited as represented by Kometan Formation. This phase of subsidence in the studied area was gradual and occurred relatively calmly as represented, in the field; by conformable contact between Qamchuqa and Kometan formations.

5.3.1. Qamchuqa Formation: A submerged platform

The subsidence of the studied area (previous platform) is resulted from farther southwest advance of the Iranian Plate with considerable increase of accretionary prism thickness. This process is attributed to possible migration of the forebulge towards southwest, which most probably, coincide with the location of those mentioned by Alavi (2004) for Late Cretaceous in Iran. The subsidence had changed the previous normal platform to relatively deeper water environment, which can be called drowning platform during early Turonian or Late Cenomanian by relatively rapid flooding (subsidence) (Fig.4.24).

On this drowning platform, the deep-water facies of Kometan Formation is deposited on shallow water facies of Qamchuqa Formation. According to Tucker (1990), most pelagic limestones are deposited by these processes while Vincent *et al.* (1998) mentioned that drowning carbonate platform is a common feature of continental margin succession. During deepening, the reefal limestone could not keep pace with the rate of subsidence and finally condition for reefal growth is prohibited due to changing of the environment from photic to aphotic. In the field, this deepening is demonstrated by gradational boundary between Qamchuqa and Kometan Formations through which the thick and massive dolomitic limestone of the former formation change to white well; bedded planktonic bearing planktonic bearing Foraminifera.

After deposition of Kometan Formation, the two continental parts of the Iranian and Arabian Plates were collided. Slightly before colliding, the trench was filled with scarped and deposited sediments (Radiolarite) and ophiolites. These materials are uplifted and thrown onto the subsided continental part of the Arabian Plate. The uplifted and over–thrown materials have formed positive land in the suture zone of the two plates. According to Karim (2004) Karim and Surdashy (2005b and 2006), due to this colliding, the studied area was transformed from passive margin to active Early Zagros Foreland basin. According to these authors, the Shiranish, Tanjero and Kolosh Formations are deposited in this foreland basin. They added that the collision changed the accretionary prism to source areas (orogenic Belt) for Late Cretaceous sediments such as Shiranish and Tanjero Formations.

5.3.2. Strength and weakness of the forebulge tectonic model

The problem that arises against this model is the fact that, in contrast to southeastern part (Sulaimani Governorate) of the studied area, its northwestern part (Northeast of Arbil and whole Dohuk Governorates) was remained shallow water as a platform and not submerged during Turonian. To minimize the effect of this problem the author clarifies **two** points.

The **first** is that according to Karim and Surdashy (2005a) the depositional axis, during Late Cretaceous, was deviated (divert) away, as compared to trend of present anticlines, from Iraq along their elongation from Arabian Gulf to Turkish border. The depositional axis depends on the tectonic front (or deformational front) of Iranian Plate, during its advance toward southwest (Karim and Surdashy, 2005b). Therefore, the northwestern part was at more distance than the southeastern part and other southern area. When the Iranian Plate front gradually had become closer (relatively) to the former areas, they submerged gradually, by step back of carbonate platform towards northwest from Early to Late Cretaceous.

The **second** point is that according to many authors, the tectonic front (Iranian Plate front) is not a straight line, but it acts as more or less sinuous line in local scale (such as northeastern Iraq). The front may be more ahead in a certain place than others (Turrini, *et al*. (2001), Schreuer, *et al.* (2001) and Marshak, (2004). Therefore, it is possible that the tectonic front during Turonian and later ages was closer to the southern area than to northern one.

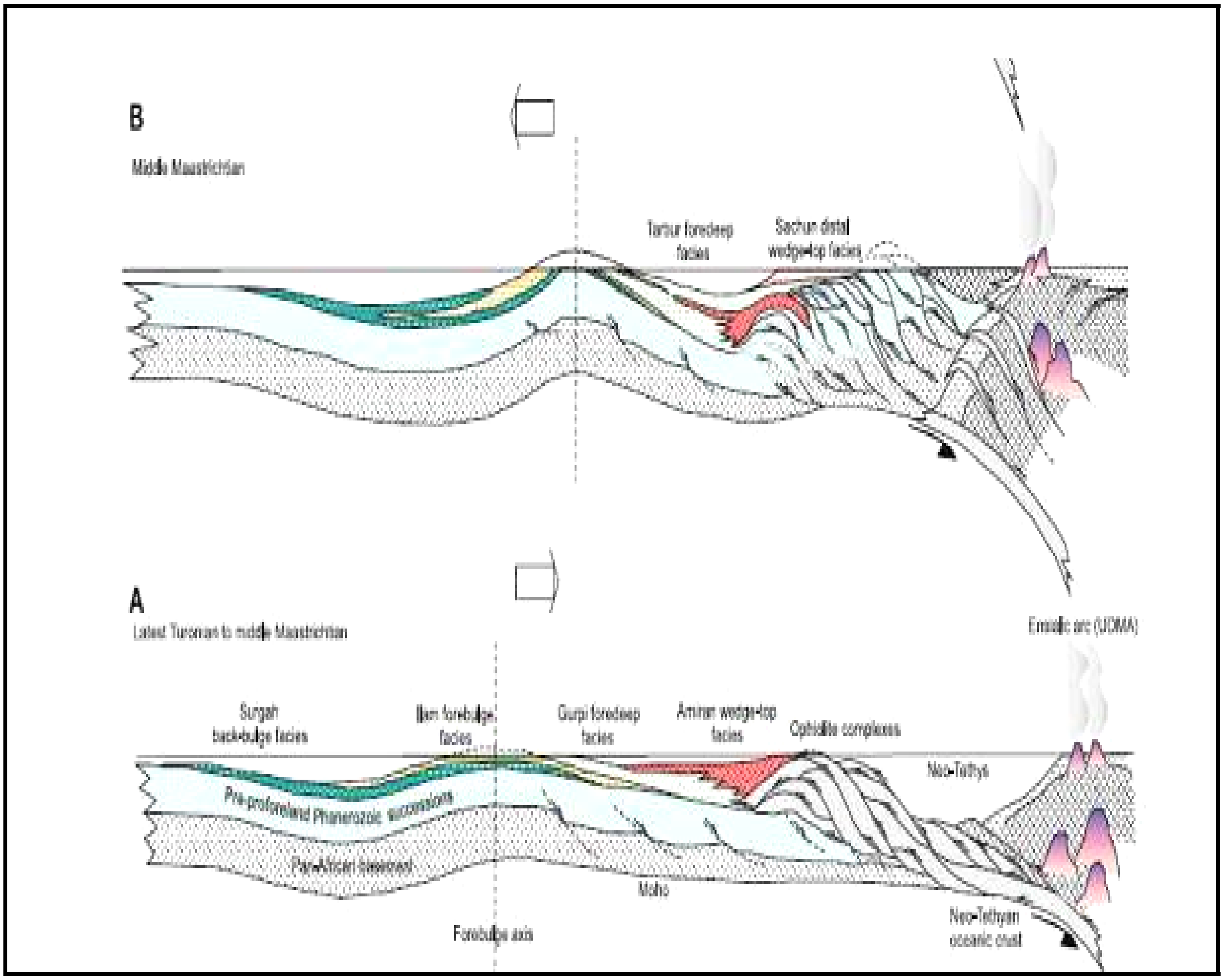

Fig. (5.4). Forebulge and its swing back and fro -in front of Zagros accretionary prism during Turonian and Middle Maastrichrian (After Alavi, 2004).

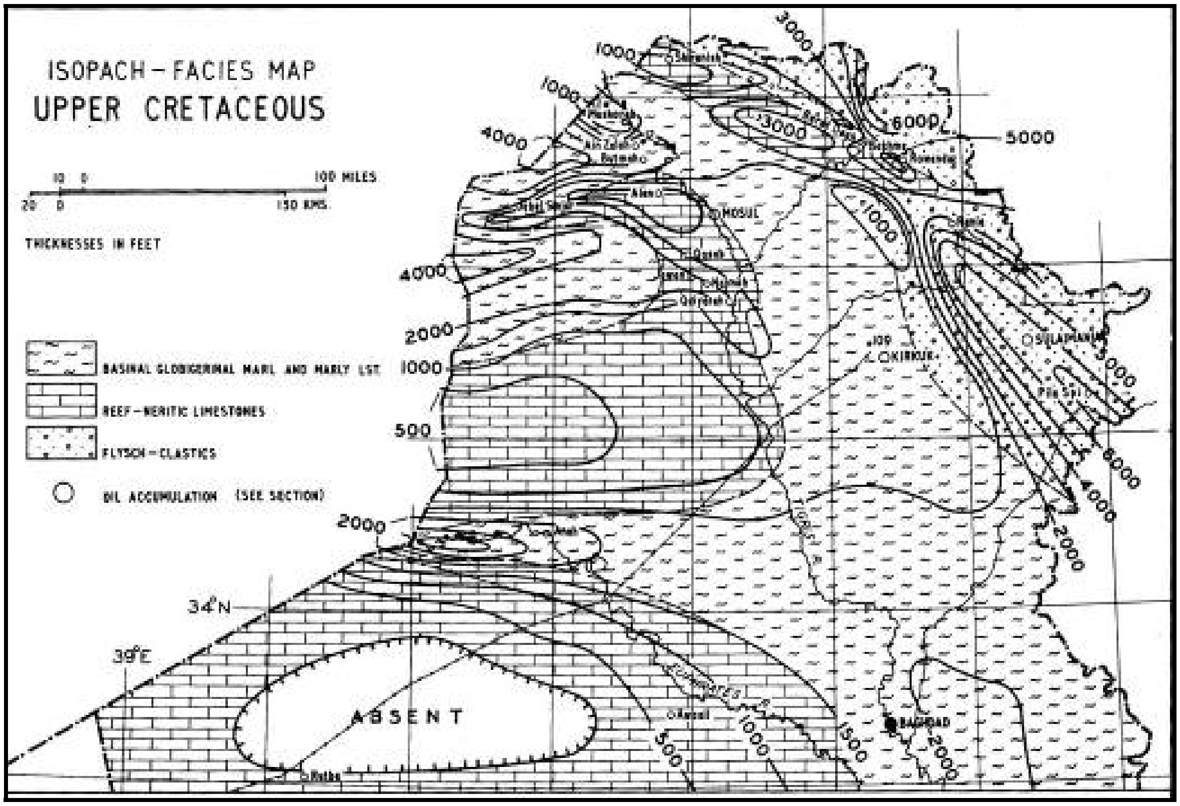

Fig.(5.5). Isopach facies map of Late Cretaceous (Dunnington, 1958) shows migration of reefal limestone to western Iraq from northeastern Iraq from Early to Late Cretaceous. This migration possibly is related to forebulge retreat.

5.4. Genetic classification of the Qamchuqa Platform

In the section (5–2), it was mentioned that the Qamchuqa Formation was deposited on wide platform of which performed as both attached and isolated platform. According to Razin, *et al.* (2002) carbonate platform margins are sensitive records of changes in sea level and climate and reveal the relative importance of global and regional controls on platform evolution. In the Late Aptian, large parts of the Arabian craton were subaerially exposed and a fringing carbonate platform formed. The reconstruction of the margin geometries suggests that tectonic activity played an important role in the Early Aptian.

In this concept, we see if this platform has any position within the new genetic classification of platforms, especially those that are connected with the plate tectonic (Bosence, 2004). A genetic classification of carbonate platforms based on their basinal and tectonic settings in the Cenozoic (Bosence, 2004)(Fig.5.7 and 5.8) have value in describing platform margin morphology and stratigraphy from a range of different tectono-stratigraphyic setting indicators. In this classification, the basinal and tectonic settings of a platform can be used to erect a first–order, genetic classification of carbonate platforms. The basinal and tectonic settings of carbonate platforms are shown to control their occurrence, the overall 3-D platform morphology, the large-scale stratigraphic features and depositional sequences.

From reviewing of well exposed outcrops and seismically imaged Cenozoic platforms, Bosence, (2004) recognized eight types of carbonate platforms based on their basinal and tectonic settings: Fault-Block, Salt Diapir, Subsiding Margin, Offshore Bank, Volcanic Pedestal, Thrust-Top, Delta-Top and Foreland Margin carbonate platforms. Wilson and Lockier, (2002) has given less detailed classification of platforms than that of former author. In the latter classification, the varieties of tectonic settings in which Cenozoioc carbonate platforms are known to occur were provided for platforms in Southeast Asia (Fig. 5.7). These different types of carbonate platforms developed in different tectonic and basinal settings using examples from the Cenozoic; both ancient and modern are shown in Table (5.1) .These diagrams differ in the detail and length reflecting the current knowledge of these different platform types (Bosence .2004). In article (Figs.5.7 and 5.8), the present author referred to shapes, sizes, stratigraphic features and examples of different Cenozoic carbonate platform types.

In these classifications or models, the most applicable one that can be applied to Qamchuqa Formation is that shown in Figs. (5.7 and 5.8) which is called Foreland Margin Platform (Bosence, 2004). Nevertheless, this one cannot be applied to the Qamchuqa Formation without modification because foreland basin is the basin generated after colliding of continental parts of the plates. In Iraq, it is known that the foreland basin is developed during Eocene (Buday, 1980 and Numan, 1997) or during Late Cretaceous (Karim, 2004, Karim and Surdashy, 2005, and 2006). Therefore, the studied area, during Early Cretaceous was still not transformed to foreland basin, because only the oceanic part of the plates were collided during this time with accumulation of the radiolarite and ophiolite in the trench of the suture between the two plates.

Table (5.1) Different Cenozoic carbonate platforms showing size, shape, stratigraphic features and examples (Bosence, 2004) in which Arabian Gulf is listed in the category of foreland margin.

Table 1
Shapes, sizes, stratigraphic features and examples of different Cenozoic carbonate platform types discussed in text

Platform types	Platform morphology		Platform size			Cenozoic examples (for details see text)
	Plan	Cross-section	Length	Width	Thickness	
Fault-Block	Rectilinear Trapezoidal Polygonal	Wedge-shaped	8 km 100 km 14 km	3 km 50 km 3 km	<130 m[a] <1000 m[b] 800 m[c]	Red Sea, Gulf of Suez, Gulf of Aden, Malta, SE Spain, North Cyprus, Southeast Spain, South China Sea, Java Basin, NE Australia
Salt Diapir	Circular, arcuate, amoeboid, elongate with subcircular embayments and reentrants	Inverted bowl/saucer (convexo-convex) with large thickness variations	Irregular shapes from 1 to 140 km across (southern Red Sea)		450 m[d] (Farasan)	Salif (Yemen), Farasan (Saudi Arabia), Daghlak (Eritrea), NW Red Sea (Egypt), Garden Flower Banks, Gulf of Mexico
Subsiding Margin (or attached)	Elongate and tracking coastline	Sigmoidal with progradational geometries	thousands of kilometres	hundreds of kilometres	<kms	NW Australian shelf, Brasilian shelf, SE USA shelf, Mediterranean margins, Murray Basin
Offshore Bank (or unattached)	Equant, amoeboid, rectangular, polygonal	Flat to bell-shaped (plano-convex) with progradational geometries	tens to hundreds of kilometres across, up to 6600 m thick[e]			Bahama Banks, Rockall Bank
Volcanic Pedestal	Circular; isolated or amalgamated	Inverted bowl/saucer (convexo-convex)	19 km 2200 km 2 km	12.5 300 km 1.5 km	<1400 m[f] 13–1400 m[g] <50 m[h]	Anewetak, Comoro, Bermuda, Muaruroa, Mauritius. Reunion, Hawaii–Emporer chain, Maldives, Saya de Malha, Las Negras, El Hoyazo
Thrust-Top	Elongate, lenticular and sheet-like	Lenticular, inverted saucer-shaped (convexo-convex), sigmoidal and progradation	tens of kilometres (Not well constrained, see text)	kms	<80 m	Southern Cyprus, Central Sicily, SE Spain (Betic Cordillera)
Delta-Top	Lenticular, arcuate	Sigmoidal and lenticular	8 km 50 km	3 km 5 km	40 m[i] 5 m[j]	NW Red Sea, Gulf of Aqaba, Gulf of Suez, Central Sicily, Fortuna Basin, Pyrenean Basin (Spain), Borneo.
Foreland Margin	Ribbons following foreland margin palaeogeography	Lenticular to sigmoidal with aggradational and backstepping geometries	hundreds of kilometres	<100 m	<1200 m[k]	Alps, S. Pyrenees, Arabian Gulf, Apennines, Himalayan Foredeep, Timor Trough, Papuan Basin

For establishment of the most suitable mode, two models of Bosence (2004) are combined for constructing a tectonic model and depositional setting of Qamchuqa Formation. The first model is the subsiding platform or passive margin carbonate platform that is shown in Fig. (5.8) and the second is the foreland margin platform, which can be seen in the Fig. (5.7). this is conducted to construct the model that fits with the tectonic setting of the formation and to match the model of forebulge. Forebulge is defined by Einsele (2000) and Allen and Allen (1990) as wide and low amplitude uplift, generated on the continental crust of subsided plate, when an enormous tectonic load accumulated on it by the overriding plate. The first model (subsiding platform or passive margin carbonate platform) coincides with the low subsiding basin and reef growth of compensation of the Qamchuqa Formation, while the second model (foreland margin platform) coincide with the huge accumulation of the load on the northeastern end of the Qamchuqa platform. The slow subsidence and submarine accumulation of tectonic load coincides with our assumed model, where the tectonic setting, can be called **transition to foreland basin (or pre-foreland platform margin)** (Fig. 5.9).

This means that the deposition of Qamchuqa Formation occurred slightly before Zagros Foreland basin generation (when this generation was occurred in the Campanian as mentioned by Karim and Surdashy, 2005 and 2006). This is well illustrated by the present author in fig.(5.9), which shows the enormous load of submarine accretionary prism (before become orogenic wedge) to the northeast of the depositional location of the formation. The same figure also shows the trench, and possible lagoon, from the northeast toward southwest. It could be seen that during foreland generation and later on, nearly same lithology of Qamchuqa Formation was deposited, as Late Cretaceous Mushrif Formation. This may be attributed to migration of the forebulge by continuous southwest advance of accretionary Prism (which was become orogenic wedge during Late Cretaceous).

5.5. Source area

In literature, Emmehauser, (2005) mentioned that alluvial to coastal deposits, rimmed the Arabian–Nobian Shield in the southwest, grading northeastward into a shallow marine carbonate shelf. He added that, in Oman, this carbonate was superposed by a depression, here referred to as the Nahr Umer basin. According to(Razin, *et al.* 2002), the carbonate, platform margins are sensitive records of changes in sea level and climate; and reveal the relative importance of global and regional controls on platform evolution. In the Late Aptian, large parts of the Arabian craton were subaerially exposed and a fringing carbonate platform formed. The reconstruction of the margin geometries suggests that tectonic activity played an important role in the Early Aptian. The Maps published by Buday (1980) and Jassim and Goff (2006) showed that the Iraqi Western Desert (Rutba–Jezira Zone) was area of non-deposition or erosion during Jurassic and Lower Cretaceous. The following sentences by Jassim and Goff (2006) (Fig. 5.6) gives some evidence on the source area for clastic influx during Early Cretaceous. *The Albian sequence was separated from the underlying Aptian sequence by major sequence boundary with a break in the Stable Shelf but not within the Unstable Shelf area. The Mesopotamian and Salman zones were characterized by a clastic inner shelf (Nuhr Umr), which was later covered by a carbonate shelf (Mauddud Formation). Originally, the Nahr Umr, Maudud, Jawan, Rim Siltstone, Qamchuqa and Balambo Formations assigned to the Albian sequence. The Mauddud and Jawan considered as individual tongues of the Qamchuqa. The Rim Siltstone considered equivalent to the Nahr Umr. Maudud Formation here replaces the Upper Qamchuqa Formation"*. According to above facts the source area was from west.

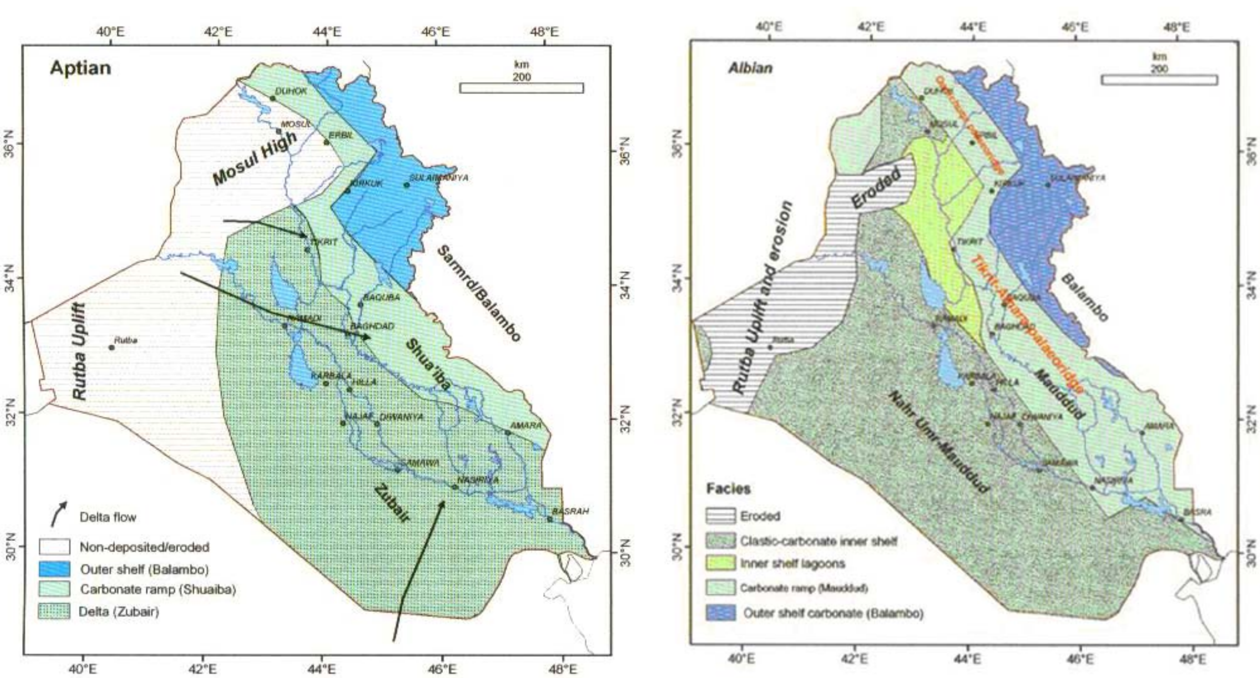

Fig. (5.6) Aptian and Albian paleogeography (after Jassim and Goff, 2006)

In section 5.3, it is clarified that the Qamchuqa Formation is deposited on mainly on attached platform. The lithology of the formation contains only rare fine-grained detritus of quartz in one horizon only. According to this fact, it is clear that toward southwest, the content of the fine clastics is increasing. These suggest a probable attachment of the platform with southwestern source area of Western Desert of Iraq. In this connection (Murris, 1980) mentioned that the source area for the Middle Cenomanian influx of clay must have been the exposed Arabian shield. This is confirmed by regional subsurface correlations showing the gradual increase and earlier arrival of clays in southwest Oman. The widespread distribution of clays at that time is probably due to a combination of an increase in the clay flux and the slow creation of accommodation space, allowing the clay fraction transported over the carbonate platform, while inhabiting carbonate production (Frans *et al*., 2002).

According to aforementioned information, it is possible that the main regional source area for the Balambo basin was located at the western Iraq.

From the source area, the clastics sediment are transported toward east and southeast and deposited in basin coastal area of the lagoonal basin of the Qamchuqa Formation. This sediment is deposited as Nahur Umer Formation but the effect of this clastic influx cannot be seen clearly in the studied area. It is possible, that the main source for the clay (included in the thin beds of the marl and marly limestone) in the Qamchuqa Formation is frequently emerged reefal body. These clays are derived from the reefal limestone by chemical and physical weathering separated from insoluble residue of the limestone. After weathering, the lithoclasts are deposited near by the reef body, while clay is deposited far from the clasts and mixed with lime mud to form marl. All sections that are located in the Imbricated Zone (northeastern sections) contains less marl than the High Folded Zone (southwestern sections) in which marl is recorded in the upper and middle parts of the formation, in the type section and both limbs of Qarasard anticline. To the south of the studied area, Sissakian and Youkhana (1984, p. 5) have described a succession of marly limestone with interbed of shale at the upper part of the formation.

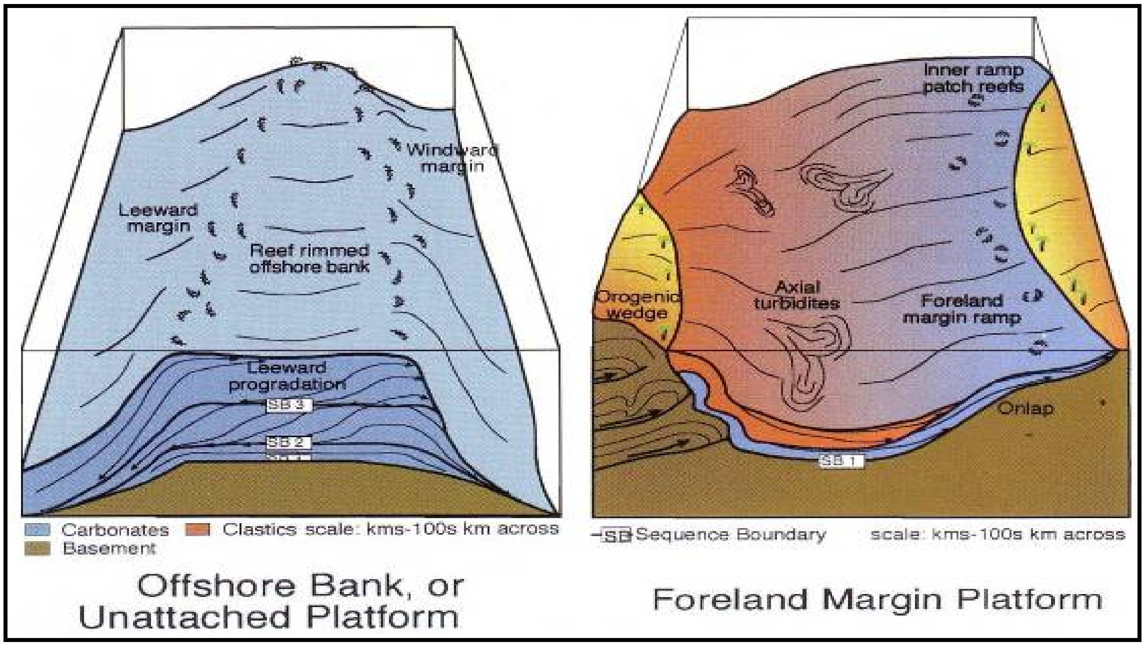

Fig.(5.7) Two tectono-stratigraphic models of the carbonate platform (Bosence, 2004) which has close relation to platform of Qamchuqa Formation.

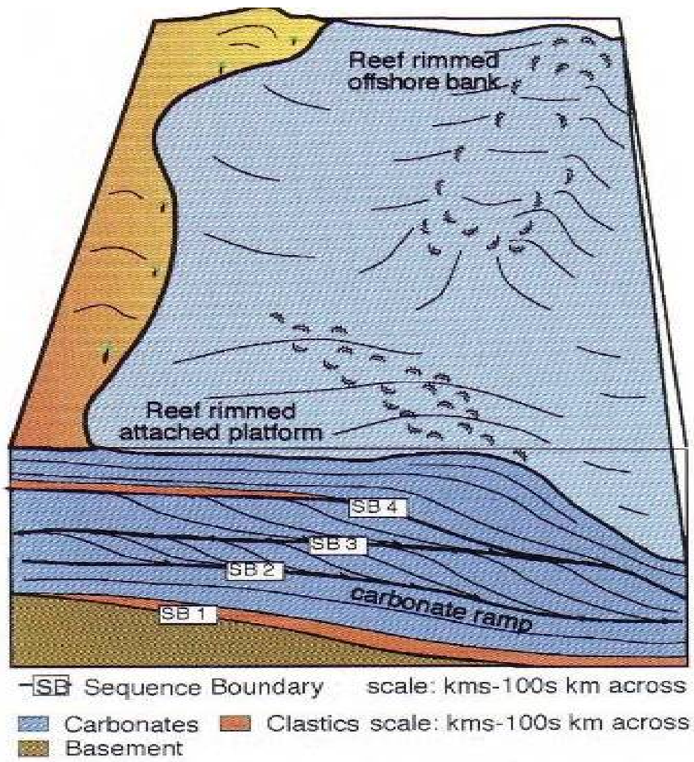

Fig.(5.8) Subsiding platform or passive margin carbonate platform of Bosence (2004)

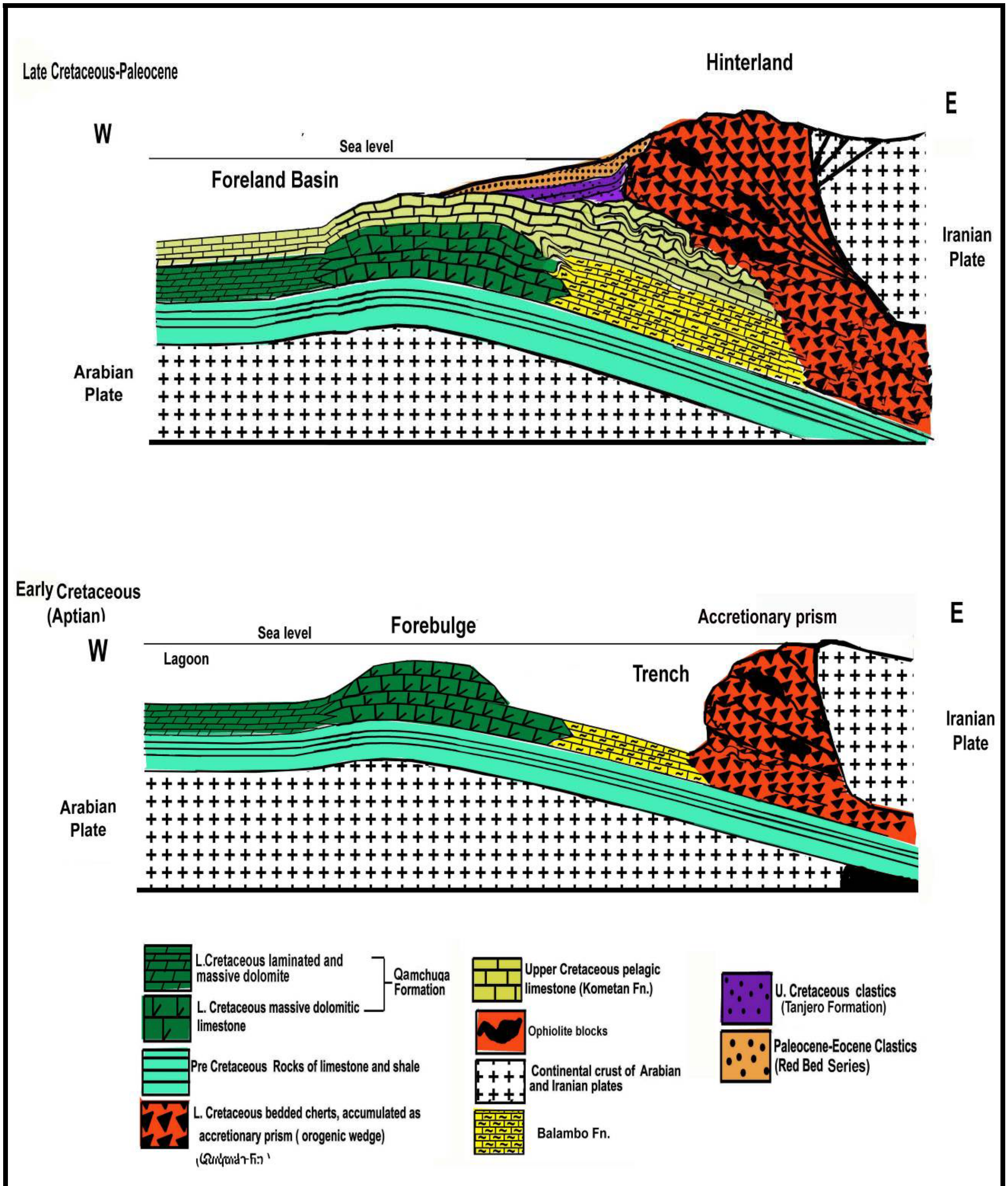

Fig.(5.9). Tectonic development of Qamchuqa basin as considered in this study

5.7. CONCLUSIONS

This thesis has the following conclusions:

1-The previous unconformable contact between Qamchuqa and Kometan Formations is re-studied in four sections, in all these sections no unconformable contact or erosional gap are recorded. According to the detailed field observations, it is inferred that both lower and upper contacts are conformable with Sarmord and Kometan and / or Dokan Formations, respectively. In the contact, neither conglomerates nor erosional surface are found. Therefore, the above contacts are amended to gradational, with a transition zones.

2- the Qamchuqa Formation is divided into eight units, based on the lithology and fossils content,

3- For the first time, microbialites are described in Iraq, which are represented by several types of limestone that are deposited by microorganism (microbes) such as algae (cynobacteria and baccinella), in addition to fungi. These rocks show structures such as stromatolites, thrombolites.

4- The most prevailing facies are lime mudstones, wackstones and dolostone whereas packstones grainstone is rare. Many new facies that are found in the formation such as Ooid grainstones, stromatolites bearing lithofacies (sheetstone), Rudist bearing lthofacies (pillarstone), oncoidal wackstone–packstone (ballstone) and branching coral bearing lithofacies (bafflestone).

5- In this study, it is estimated that the dolomitization is resulted from the selective dolomitization caused by burrowed lime mudstone and bioclastic packstone. Several stages of dolomitizations could be seen depending on burrows, as shown by the different stages. The pervasive dolomitization is

6- The facies analysis showed that the Qamchuqa Formation was mainly deposited in reef, backreef , forereef and lagoon environments. These environments are characterized by relatively low energy, which was of normal marine water during Aptian, while toward Cenomanian, the salinity and temperature were increased. The reef was barrier reef with the possibility of existence atoll-reef type.

7– The reef body consist of reef builders such as coral, rudist, algae and stromatolite.

8- The tectonic setting of the Qamchuqa Formation was a wide forebulge formed by flexture of Arabian Plate by the load of the accretionary prism that accumulated by southwest advancing of Iranian Plate, before colliding of continental parts.

observed in the dolomite units (D1, D2, D3 and D4).

5.8. RECOMMENDATIONS

The author suggests the studying of the following aspects in the Qamchuqa Formation:

1. Detailed biostratigraphic study.

2. Combination of the Lower and Upper Qamchuqa Formations into Qamchuqa Formation in the studied area. Because Qamchuqa Formation, in the surface outcrops can not be separated lithologicaly into lower and upper parts, also it is very rare, to see any features for differentiation of the contact between the two formations.

3- The sequence stratigraphy of Qamchuqa Formation, in detail.

4. Comparison between the Qamchuqa Formation in both surface and subsurface sections (wells in Kirkuk and Mosul area) to correlate them and achieve the final idea about the depositional environment in the whole Iraq.

5. studying of the upper contact in order to reveal the probable occurrence of Cenomanian and Turonian, which are represented by Dokan and Gulnery Formations, respectively. Because the previous studies determined erosional surface in the upper contact between Qamchuqa and Kometan Formations.

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