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STRATIGRAPHY OF THE LOW FOLDED ZONE

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ABSTRACT

The stratigraphy of the Low Folded Zone, in Iraq is reviewed. The oldest exposed rocks are Late Cretaceous in age, which belong to the Shiranish Formation, whereas the youngest are of Pliocene – Pleistocene age, which belong to the Bai Hassan Formation. The exposed stratigraphical column is represented by 24 formations. Moreover, ten main types of Quaternary sediments, which have wide geographic extent, are reviewed too.

The Cretaceous and Paleogene rocks are mainly of marine carbonates with rare clastics, the Cretaceous rocks represent synrift sediments. The Early Neogene (Oligocene) rocks form a complex of reef – back reef – fore reef and are restricted almost in the eastern, central and western parts of the involved area, especially in Qara Chouq anticline, with other restricted exposures in different parts. The Early and Middle Miocene rocks are mainly of marine origin, lagoonal carbonates and evaporate, respectively. The Late Miocene rocks, which represent the beginning of the continental environment, together with the rocks of Pliocene – Pleistocene consist of molasse sediments, deposited in sinking foredeep. The Quaternary sediments are well developed, especially Pleistocene river terraces of different stages, and polygenetic sediments that fill the synclinal troughs, with other different types.

For each exposed formation, the type locality, exposure areas, subsurface extension, main lithology (as described inform of members and/ or informal units), thickness, fossils, age, depositional environment, and the lower contact are described. The described lithologies of the formations by different authors from different localities are reviewed, with occasional remarks of the present authors. The main tectonic events and the paleogeography are reviewed briefly. Each formation is discussed, for majority of them the present authors' opinion are given, with many recommendations for future studies. Some new ideas dealing with many aspects for many formations including proposals for establishing new formations are given, too.

طباقية نطاق الطيات الواطئة

فاروجان خاجيك سيساكيان و بثينة سلمان الجبوري

المستخلص

تمت مراجعة طباقية نطاق الطيات الواطئة في العراق، من أقدم الصخور المتكشفة والتي تعود الى عصر الطباشيري المتأخر المتمثلة بتكوين شيرانش والى عصر البلايوسين – البلايستوسين المتمثلة بتكوين باي حسن. إن العمود الطباقي المتكشف في نطاق الطيات الواطئة يتمثل بأربعة وعشرين تكوين متكشف، إضافة الى عشرة أنواع رئيسية من ترسبات العصر الرباعي ذات الامتداد الجغرافي الواسع والسمك الكبير.

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إن غالبية صخور العصر الطباشيري والتي تمثل ترسبات مزامنة للهبوط (rift) والپاليوجين هي صخور بحرية كلسية مع القليل من الصخور الفتاتية، بينما صخور النيوجين الأسفل (الأوليگوسين) تمثل صخور معقد الحيد وتتموضع خاصة في طية قرة چو المحدبة وفي مناطق صغيرة منتشرة في النطاق. أما صخور المايوسين المبكر والأوسط هي في الأغلب صخور بحرية كلسية – لاغونية وتبخيرية.

إن صخور المايوسين المتأخر تمثل بداية البيئة القارية وإنها إضافة لصخور البلايوسين – البلايستوسين تتمثل بترسبات المولاس الفتاتية المترسبة في الحوض العميق (foredeep basin) للأرض الأمامي (foreland). إن عدم ترسيب صخور الأوليگوسين بشكل واسع في منطقة نطاق الإلتواءات الواطئة تمثل من أهم ظواهر عدم الترسيب (غير التوافقي)، حيث إنها تتركز في المناطق الوسطى والغربية والشرقية ولا توجد في المناطق الشمالية، وسبب ذلك هو نهوض منطقة نطاق الطيات العالية وحركات الصفيحة العربية. كما أن ترسيب صخور المولاس ابتداء من المايوسين المتأخر تمثل ظاهرة مهمة أخرى، حيث تشير الى تغير البيئة الترسيبية من البحرية إلى القارية، بينما لا توجد ترسبات قارية قبل هذا العصر في المنطقة، وسبب تغير البيئة هو تصادم النيوتيثس (الصفيحة العربية) مع نطاق سنندج – سرجان. أما العصر الرباعي فيتمثل بشكل رئيسي بالترسبات الفيضية المختلفة وإن بعضها متأثرة بالحركات البنيوية الحديثة وهناك أدلة عديدة لوجود واستمرار هذه الحركات.

تم وصف كل تكوين متكشف بشكل نظامي، وشمل الوصف كل من: الموقع المثالي، التوزيع الجغرافي السطحي وتحت السطحي، الصخارية (وكما جاء في وصف كل عضو أو وحدة في التكوين)، السمك، المتحجرات، العمر، البيئة الترسيبية والحد الأسفل. ونظرا لكون غالبية التكوينات تتكشف في مناطق مختلفة جغرافيا، فقد تم دراسة هذه التكوينات من قبل العديد من المؤلفين، لذا تم وصف المكونات المذكورة في أعلاه لكل تكوين وكما جاء في وصف المؤلفين في المناطق المختلفة، مع ذكر بعض الملاحظات للمؤلفين الحاليين. وذكرت أهم الأحداث البنيوية والجغرافية القديمة باختصار لكل الفترات الزمنية. كما تمت مناقشة كل التكوينات مع إبداء الرأي لغالبيتها وإعطاء المقترحات للدراسات المستقبلية وكذلك أضيفت أفكار جديدة لبعض التكوينات ومقترحات لتسمية تكوينات جديدة في عدة مناطق.

INTRODUCTION

Since the early seventies of the last century and onwards, huge amount of data were acquired concerning the stratigraphy of the Low Folded Zone, in Iraq. These were mainly achieved through the regional geological survey, which was conducted by the Iraqi Geological Survey (GEOSURV), started in 1971 and was terminated in 1982. The second stage, of data collection, achieved through the detailed geological survey. During this stage, which started in 1984, detailed stratigraphical studies were conducted, too. Through both aforementioned stages, many formations were amended and their ages, lithological constituents and relation with other formations were elucidated more clearly than before. Based on the regional geological survey data, GEOSURV compiled the Geological Map of Iraq, at scale of 1: 1000000, in 1986 (Jassim *et al*., 1986). The second edition was issued in 1990 (Jassim *et al*., 1990), based on some additional detailed geological data. The third edition was issued in 2000 (Sissakian, 2000), based on all executed regional and detailed geological surveys, utilizing the compiled and published series of geological maps at scale of 1: 250000 (39 sheets). The last (fourth) issue is already updated and printed (Sissakian and Fouad, 2012) depending on the most recent available data, which is checked continuously in the field, some of the recently acquired data is already utilized in this paper.

This paper is an attempt to review and explain the stratigraphy of the Iraqi Low Folded Zone, depending mainly on the regional and detailed geological surveys carried out by GEOSURV geologists. It aims to elucidate the Geology of the Low Folded Zone, which is published in the enclosed Special Issue No.5, with other four chapters, which deal with the main geological aspects: Geomorphology, Tectonics and structure, Hydrogeology and Mineral Occurrences. The best available data is used to acquire this paper, which represents GEOSURV's opinion. A location map is added to each special issue; to illustrate the coverage area of each special issue. The location map is added to the chapter of the Introduction.

LOCATION

The Low Folded Zone covers considerable part of the Iraqi territory. Its coverage area is about 56930 Km². Its contact with the Mesopotamia Plain runs parallel to Himreen and Makhoul Ranges, in the southeast and central parts, then extends northwest wards to Sinjar Mountain, and extends inside Syria. The northeastern, northern and northwestern contact with the High Folded Zone runs almost parallel to the first ridge of the Pila Spi Formation. It forms a continuous ridge in the Iraqi territory; from Bammu Mountain; in the east and extends northwestwards to Qara Dagh, Darbandi Bazian, Haibat Sultan, Permam, Peris, Alqosh, Dahqan and Be-Khair Mountains and continues northwest wards to the Iraqi – Syrian borders (Fig.1).

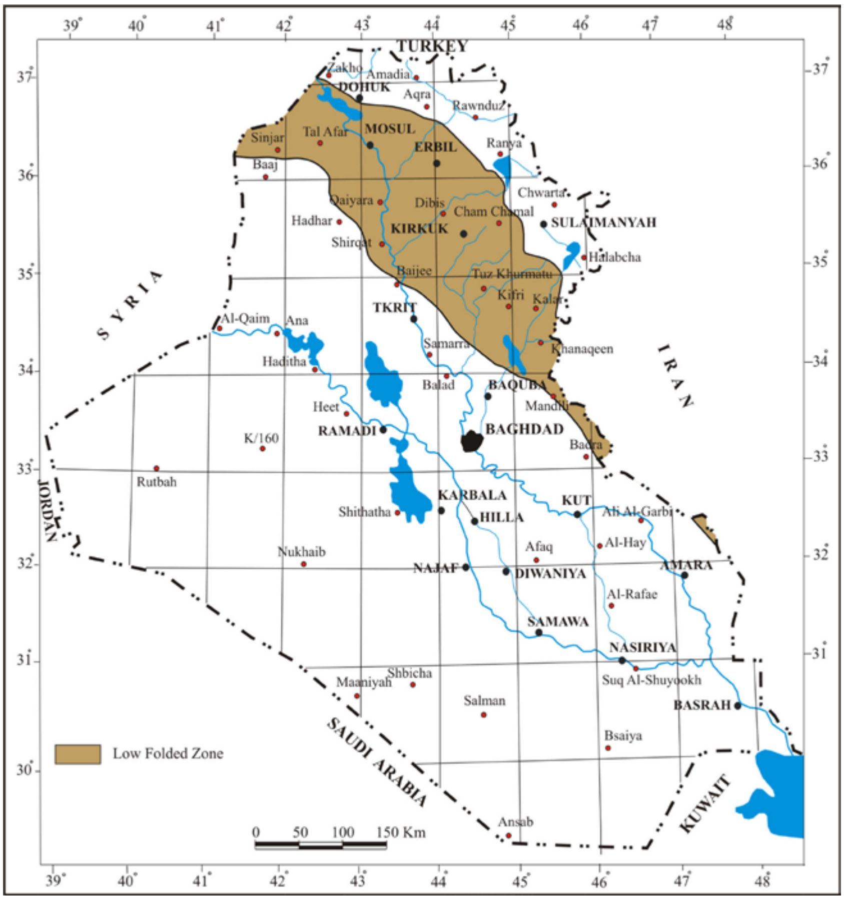

Fig.1: Location map of the Low Folded Zone

GENERAL TOPOGRAPHY

The Low Folded Zone is characterized by different topographic natures, which reflects the type of the exposed rocks, their thicknesses and the structural effect. Generally, two main different topographical forms could be recognized, this is mainly due to presence of longitudinal and narrow anticlines, and wide synclines, with the Tigris, Greater Zab, Lesser Zab, A'dhaim and Diyala Rivers that dissect the involved area. Mosul, A'dhaim and Himreen Lakes are within the area too. The two parts are:

– **The elevated (mountainous) parts,** which consist of rocky surface dissected by shallow valleys running either parallel to the main strike in NW – SE and SE – NW directions, or perpendicular to the main strike in NE – SW direction.

– **The flat and undulatory parts,** these form the trough of the synclinal areas, which are filled by thick Quaternary sediments. Usually form wide plains that are dissected by axial valleys and/ or streams, which run almost in the axes of the synclines in NW – SE and SE – NW directions, with their tributaries, which are perpendicular to them; either in NE – SW or SW – NE directions. These areas are usually used as agricultural lands.

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The Low Folded Zone belongs, tectonically to the Unstable Shelf of the Arabian Platform (Al-Kadhimi *et al*., 1996 and Jassim and Buday in Jassim and Goff, 2006), whereas Fouad (2012) considered it within the Outer Platform. Therefore, the tectonic and structural effects have controlled the type of the exposed rocks, thicknesses, and surface and subsurface extensions of the formations. The compression associated with the ophiolites obduction, during Late Campanian, had caused the exposure of Cretaceous rocks in very restricted areas within the Low Folded Zone, those areas represent inverted grabens. The Mosul High, which was formed due to movements during Early Turonian, also have affected the type of the exposed rocks and their thicknesses on both sides, causing lateral facial changes, due to changes in the depositional basin (Buday, 1980). Moreover, Sinjar, Qara Chouq, Ba'shiqa, Ain Al-Safra, Maqloub, Aj Dagh and Qara Wais anticlines had played big role in restriction of the exposed formations and limitation of their basins. Certain formations are restricted to the mentioned anticlines, they could be found neither on surface nor in subsurface.

In order to facilitate the description of the exposed geological formations in the Low Folded Zone, they are divided, age wise into Mesozoic and Cenozoic Eras, the eras are divided into epochs. Moreover, each formation is described in a systematic style, starting with the type locality, exposure areas, subsurface extensions, lithology; as divided into members and/ or informal units, fossils, age, depositional environment and the lower contact. Generally, different authors divided each formation into many members and/ or informal units. Usually, the same formation is divided into different members and/ or informal units, by different authors in different localities, within the Low Folded Zone. Consequently, different names were given to the units, within the same formation. The name of the members and units are mentioned in bold letters, as different authors from different geographic locations mentioned them; even if they contradict the rules of the International Code for the Stratigraphic Nomenclature. The name of some formations, however are amended from the original name; to be in accordance with the rules of the International Code for the Stratigraphic Nomenclature. For example, the Avanah Limestone Formation is mentioned as Avanah Formation. Other formations are renamed, because their type localities are outside of the Iraqi territory and abandoned in their original countries, as the Lower Fars Formation is renamed by Jassim *et al*. (1984) and Al-Rawi *et al*. (1992) as Fatha Formation. The adopted age by GEOSURV is mentioned between parentheses, beside the name of each formation.

Wherever the authors have found it is necessary to give explanations, hints, comments concerning the descriptions and/ or ideas of previous authors, or when contradictions have met, for any reason, then these are cited as **"Remark".** The Remarks indicate the opinions of GEOSURV that are presented in published geological maps and documented reports in GEOSURV's library or published articles.

The exposed geological formations, from the oldest to the youngest are described hereinafter. A geological map, at scale of 1: 1000 000 (Figs.2, 3, 4 and 5), elucidates the geographical distribution of the formations. The location of the type localities and/ or sections is presented in Fig. (6), their reference numbers are mentioned in Table (1).

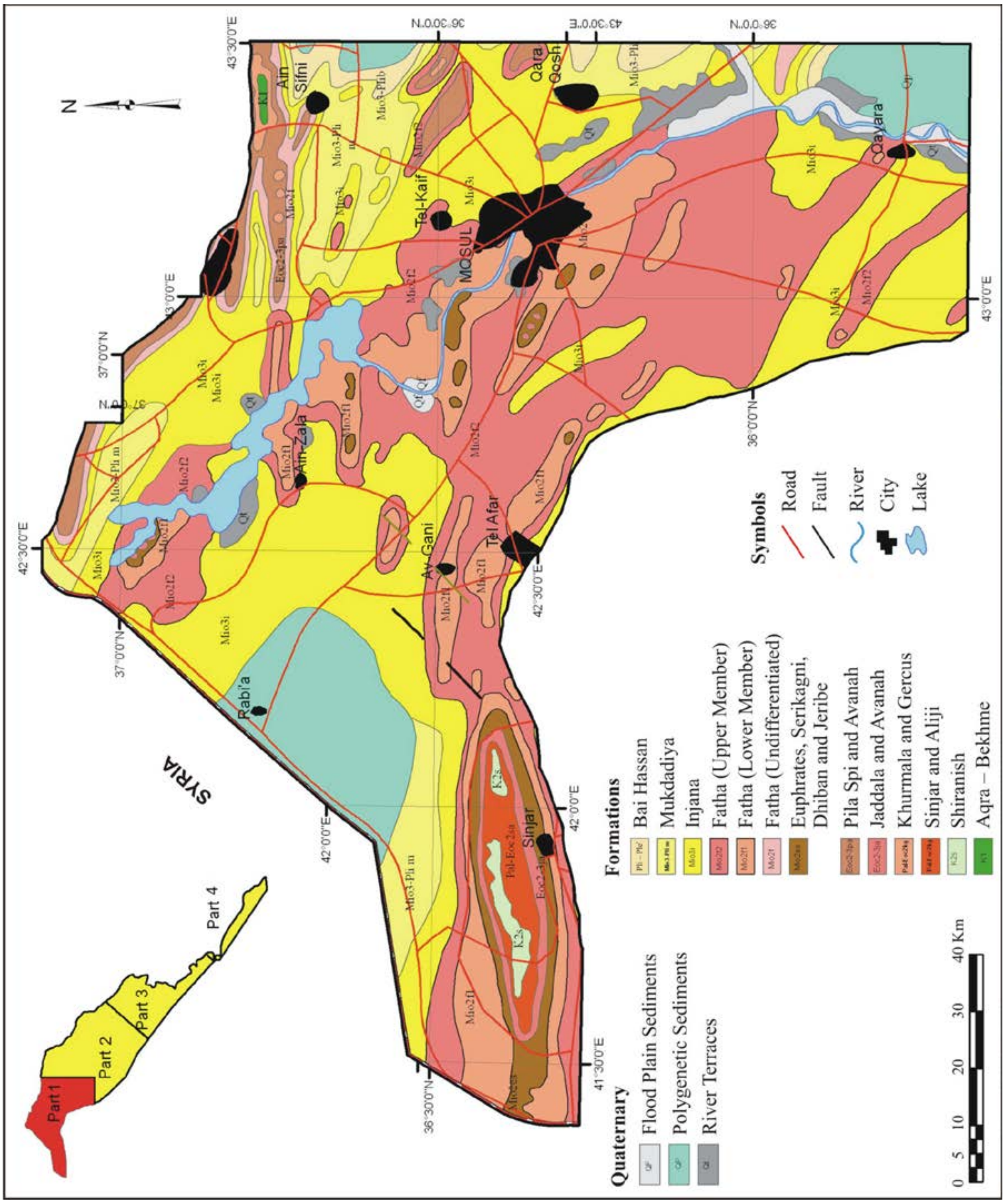

Fig.2: Geological map of the Low Folded Zone (Part 1) scale 1: 1 000 000 (after Sissakian and Fouad, 2012)

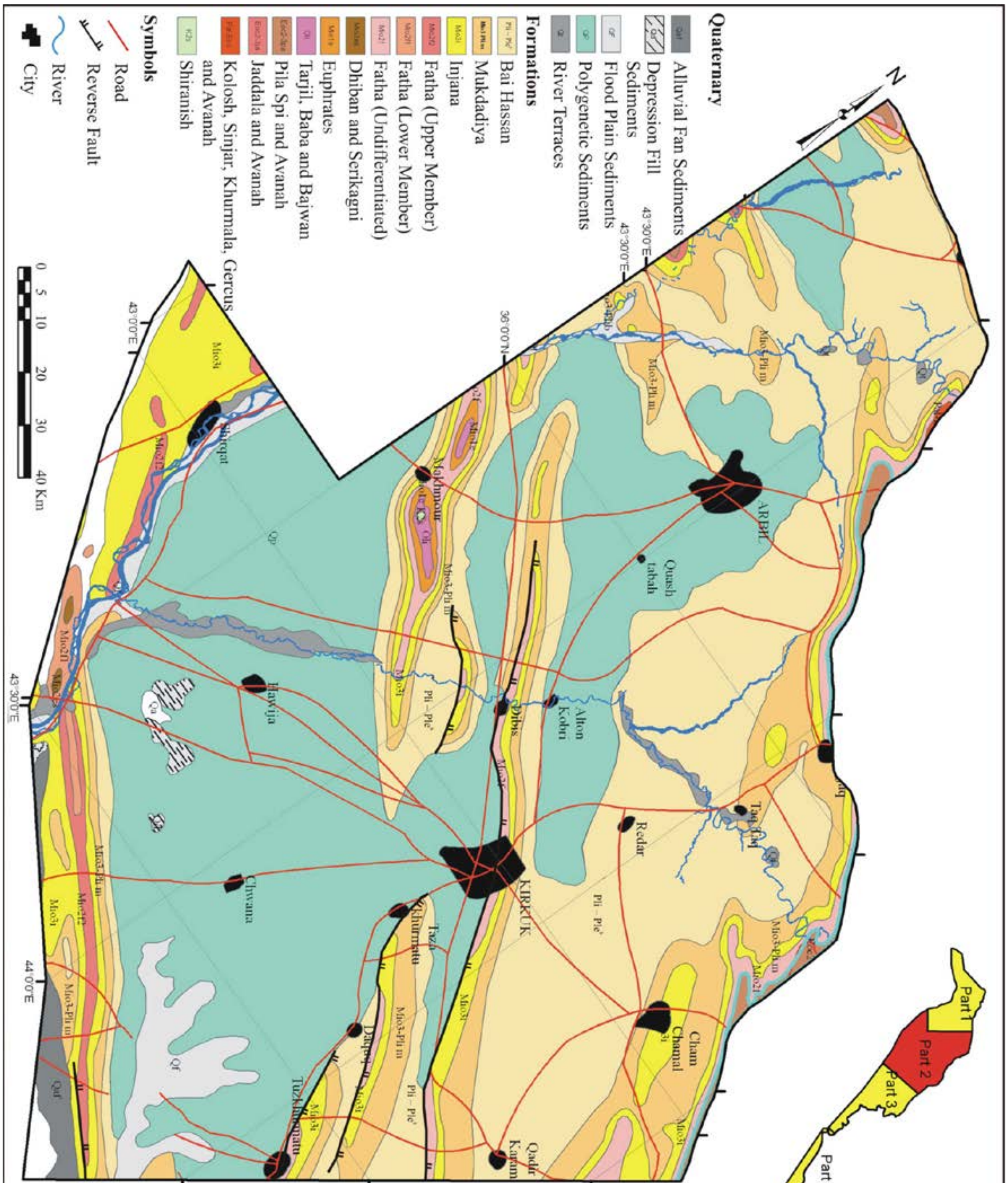

Fig.3: Geological map of the Low Folded Zone (Part 2) scale 1: 1 000 000 (after Sissakian and Fouad, 2012)

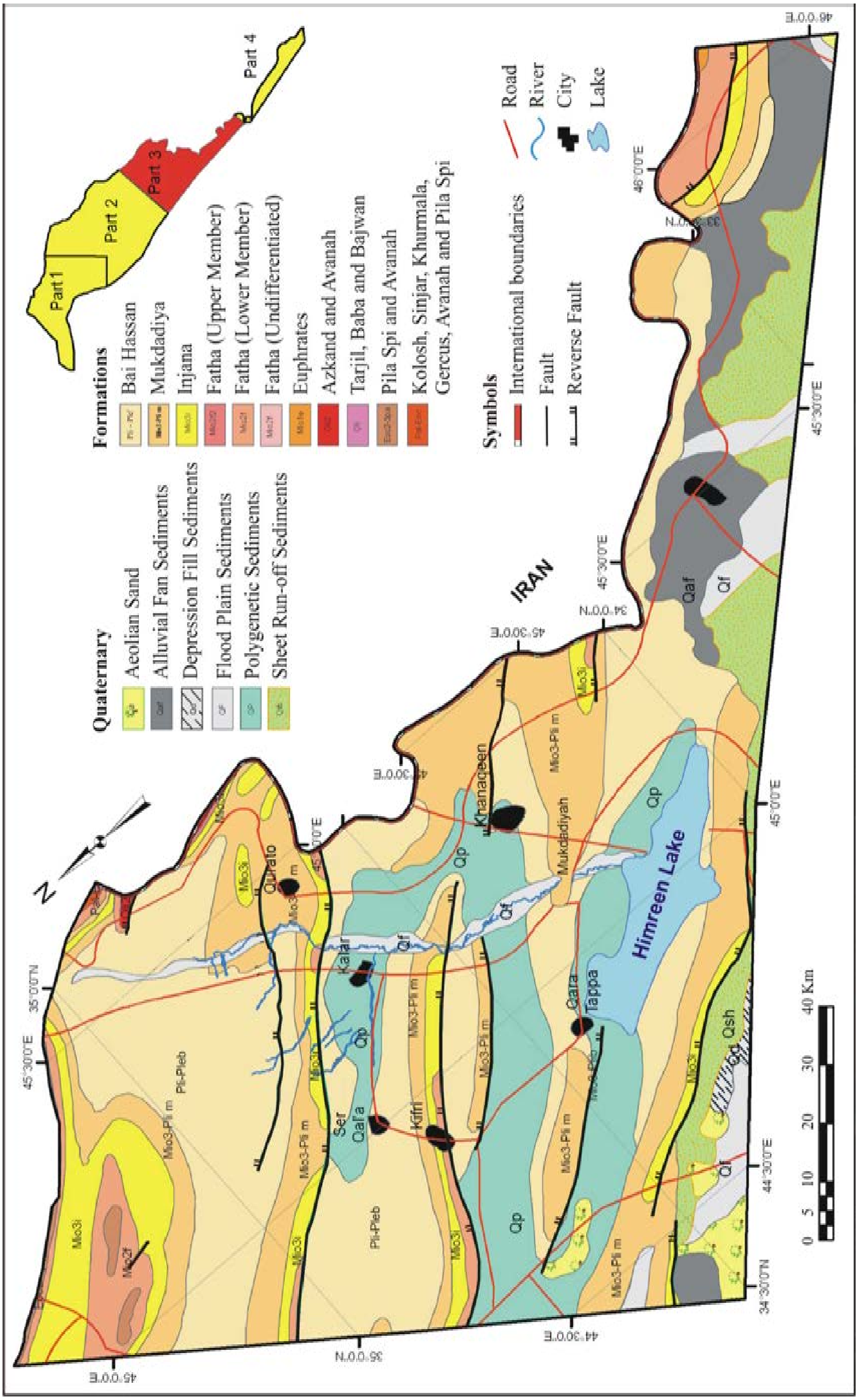

Fig.4: Geological map of the Low Folded Zone (Part 3) scale 1: 1 000 000 (after Sissakian and Fouad, 2012)

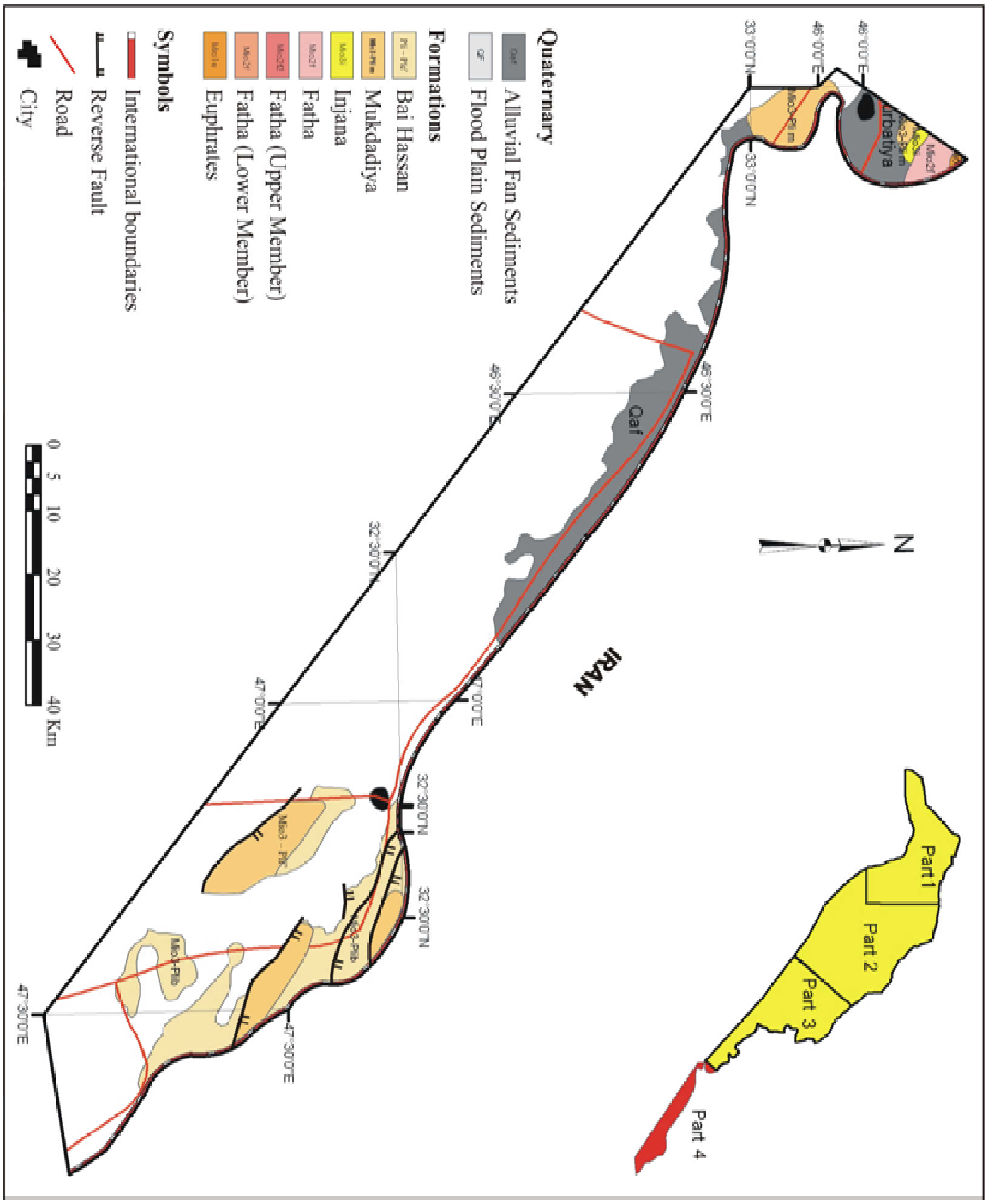

Fig.5: Geological map of the Low Folded Zone (Part 4) scale 1: 1 000 000 (after Sissakian and Fouad, 2012)

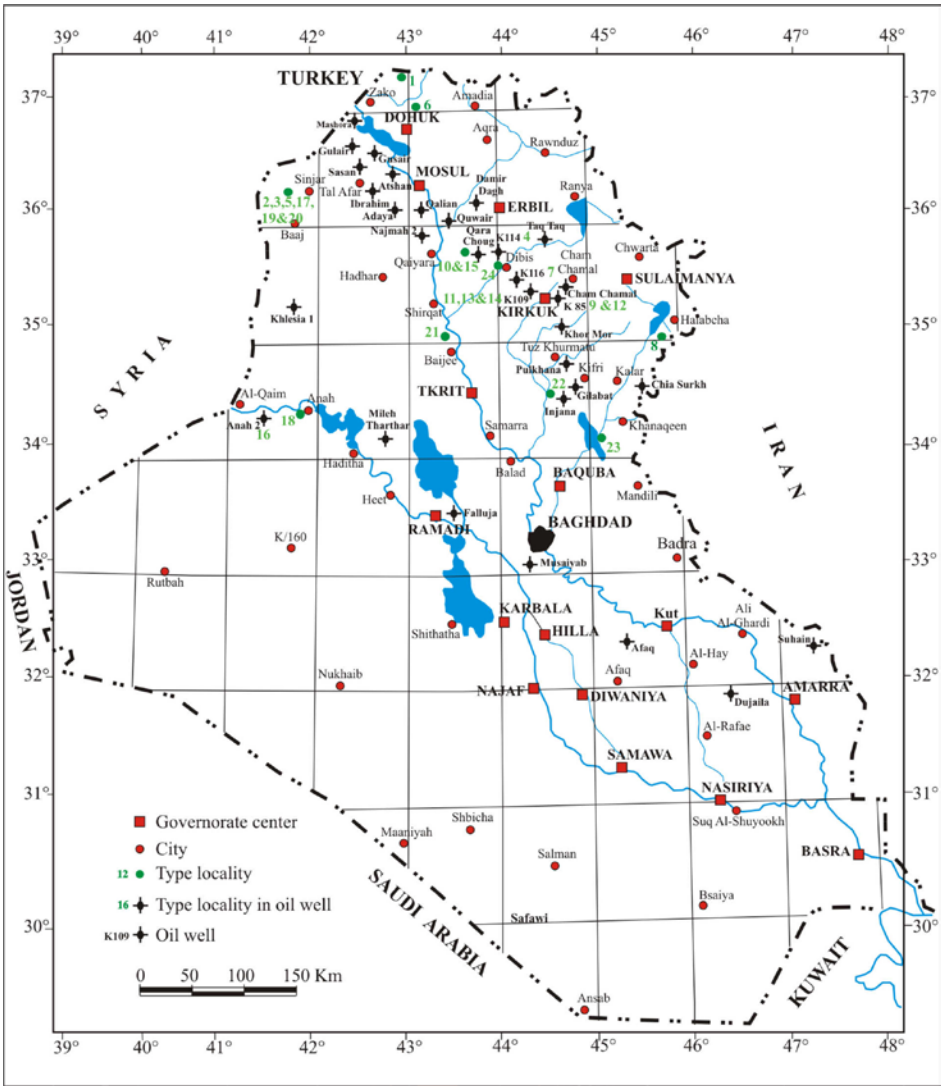

Fig.6: Location of the type localities of the exposed geological formations in the Low Folded Zone
(Numbers in green represent the reference numbers of the exposed formations, refer to Table 1 to indicate the name of the formation)

Table 1: Reference number of the type locality or type section of each exposed formation, as indicated in Figure (6)

Serial No.	Formation	Serial No.	Formation	Serial No.	Formation
1	Shiranish	9	Palani	17	Serikagni
2	Aaliji	10	Sheikh Alas	18	Euphrates
3	Sinjar	11	Shurau	19	Dhiban
4	Khurmala	12	Tarjil	20	Jeribe
5	Jaddala	13	Baba	21	Fatha
6	Gercus	14	Bajwan	22	Injana
7	Avanah	15	Azkand	23	Mukdadiya
8	Pila Spi	16	Anah	24	Bai Hassan

The adopted descriptions of the formations with their geographical distribution and other mentioned data is based on the regional and detailed geological survey reports, which attain 18 reports. These are utilized in compilation of the geological maps at scale of 1: 100 000, based on the original geological base maps (at scale of 1: 25 000 and 1: 20 000), which were used in compilation of the published geological maps at scale of 1: 250 000.

Within each epoch and/ or period, the paleogeography is reviewed briefly, including the shape of the depositional basin and the effect of the tectonics. This is mainly adopted from Buday and Jassim (1987) and Jassim and Buday in Jassim and Goff (2006).

1. MESOZOIC

Within the Mesozoic Era only Late Cretaceous rocks are exposed within the Low Folded Zone, Shiranish Formation represents them, only.

1.1. Cretaceous

The climax of the obduction and closure of the Neo-Tethys occurred during the Late Campanian and Maastrichtian (Jassim and Goff, 2006). This contributed to a major sea transgression across the whole of Iraqi territory. The same stress regime in the northeast of the Arabian Plate led to the formation of intraplate extensional and trans-extensional basins of NW – SE and E – W trend, respectively (Jassim and Buday in Jassim and Goff, 2006). These basins were in form of grabens and were receiving synrift sediments of Late Cretaceous age. Within the Low Folded Zone, the Qara Chouq basin represents the NW – SE basin. The E – W basins are represented by Sinjar basin. In both cases many other basins exist that did not expose the Cretaceous rocks, such as Mushurah, Gulair, Butmah, Injana, in all basins Shiranish Formation is deposited as synrift sediments and is the only exposed Cretaceous rocks in the Low Folded Zone.

1.1.1. Shiranish Formation (Late Campanian – Late Maastrichtian)

The Shiranish Formation is one of the most wide spread formations in Iraq, however, in the Low Folded Zone it has very restricted exposures.

Type Locality: The type locality of the Shiranish Formation is defined from the High Folded Zone, near Shiranish Islam village by Henson in 1949 (Bellen *et al*., 1959) (Fig.6), it is defined by the following coordinates:

Longitude	42°	50'	30"	E
Latitude	37°	11'	32"	N

Exposure Areas: The Shiranish Formation is exposed along the core of Sinjar anticline, in the extreme western part of the Low Folded Zone and in the core of Qara Chouq anticline, as very small exposure in the bottom of Azkand (cirque) valley, along the southwestern limb of Qara Chouq anticline (Figs.2 and 3). However, the subsurface extensions of the formation is uniform over all the Low Folded Zone, it was struck in many drilled oil wells, like Mushurah, Gullar, Gusair, Ain Zala, Butmah, Alan, Sasan, Ibrahim, Adaiyah, Atshan, Qalian, Najmah, Hibbarah, Makhoul, Demir Dagh, K 85, 109, 116, 130, Cham Chamal, Qara Chouq, Bai Hassan, Taq Taq, Pulkhana, Injana, Himreen, Jambur (Fig.6).

Lithology: In the type locality, the Shiranish Formation is composed of "blue marls in its upper parts and thinly bedded marly limestones in the lower division. The sediments are pelagic marls, sometimes dolomitic and of occasional marly limestone beds, with rich microfauna" (Owen and Nasir in Bellen *et al*., 1959). In Sinjar anticline, Ma'ala (1977) divided the formation into three units. **Lower Unit**: Consists of thinly to thickly bedded, blue to grey marl and marly limestone, with ammonites, the thickness is about 80 m. **Middle Unit**: Consists of numerous intercalations of very hard intraformational fragments with marly limestone. The fragmented beds are brownish grey in color, fine grained, thinly bedded (20 – 70 cm), and very hard, showing cross and graded bedding. The marly limestone and limestone beds are light grey in color, well thinly bedded. Several beds (about 14) of intraformational breccia, with fragments of marly limestone and sandy matrix occur too. Basal fragments were developed in the lower part of this unit, consist of marly limestone with subordinate chert and quartz grains, the thickness of this unit is about 405 m. **Upper Unit**: Consists of light yellowish grey, fairly soft marl and marly limestone, occasionally includes limestone beds of sandy texture, the thickness of this unit is 80 m. In Qara Chouq anticline, the formation consists of yellow to yellowish grey thinly and thickly bedded marl, in the uppermost part many lenses of 1 m thick, dark grey claystone is present (Al-Sammarai and Al-Mubarak, 1978).

Thickness: Different authors recorded the following thicknesses of the Shiranish Formation. In the type section it is 225 m, in Sinjar anticline it is 565 m (Ma'ala, 1977), whereas the exposed thickness in Qara Chouq anticline is about 60 m (Al-Sammarai and Al-Mubarak, 1978).

Fossils: The following fossils were recoded in the Shiranish Formation by Amer (1977) and Jawi and Said (1978) in Sinjar area, and Abdul Munim and Jawi (1978) in Makhmour area: *Globotruncana aegyptiaca* NAKKADY, *Glt. arca* (CUSHMAN), *Glt. fornicata* PLUMMER, *Glt. gansseri* BOLLI, *Glt. stuartiformis* DALBIEZ, *Heterohelix punctulata* (CUSHMAN), *Pseudotextularia elegans* (RZEHAK), and *Rugoglobigerina rugosa* (PLUMMER).

Age: The following ages are claimed by different authors for the Shiranish Formation: Maastrichtian (Bellen *et al*., 1959; Amer, 1977 and Jawi and Said, 1978) in Sinjar area, and Abdul Munium and Jawi (1978) in Makhmour area suggested Upper most Lower Maastrichtian – Middle Maastrichtian and Amer (1993) suggested Upper Campanian – Upper Maastrichtian age.

Lower Contact: The lower contact of the Shiranish Formation in the type locality is conformable with the underlying Bekhme Formation; it is based on the base of recrystallized thinly bedded globigerinal limestone (Bellen *et al*., 1959). In both Sinjar and Qara Chouq anticlines, the lower contact is not exposed. However, the subsurface data indicate that the underlying formation differs in different localities. The following formations underlie the Shiranish Formation in the following oil wells (Fig.6): Qamchuqa Formation in Qalian, Butmah, Adaiyah, Alan, Ibrahim, Sasan and Atshan wells. Bekhme Formation, in Demir Dagh well. Mushurah Formation, in Mushurah, Gullar, Gusair, Ain Zala, K116, and Qara Chouq 1 wells. Kometan Formation, in K109, Cham Chamal 2, Makhoul 2, Najmah, Injana 5 and Himreen 1 wells, and Balambo Formation, in Taq Taq and Pulkhana wells (I.P.C., 1963). These data indicate that the depth of the basin of Shiranish Formation was not uniform during the deposition.

2. CENOZOIC

The Middle Paleocene – Eocene Megasequence was deposited during a period of renewed subduction and volcanic activity associated with final closure of the Neo-Tethys. This led to uplift along the northeastern margin of the Arabian Plate with formation of ridges and basins, generally of NW – SE trend in north and central parts of Iraq (Jassim and Buday in Jassim and Goff, 2006).

The Cenozoic formations are widely exposed in the Iraqi Low Folded Zone. The exposed formations are divided, age wise and described hereinafter:

2.1. Paleocene – Early Eocene

Towards southwest of the longitudinal developed basin, during Mid-Paleocene, a foredeep (within the foreland) was developed, which was progressively migrating towards southwest, it occupied the entire nowadays Low Folded Zone, almost extending from Mushurah, Mosul, Kirkuk and Chia Surkh (Fig.6). Open marine marls of Aaliji Formation (Jassim and Buday in Jassim and Goff, 2006) filled this basin. The encountered formations of this sequence are three; they are described hereinafter.

2.1.1. Aaliji Formation (Early Paleocene – Early Eocene)

Type Locality: The type locality of the Aaliji Formation is in Syria, a supplementary type section in Iraq was chosen by Bellen in 1950 (Bellen *et al*., 1959), it lies in Kirkuk structure; oil well K 109 (Fig.6), it is defined by the following coordinates:

Longitude 44° 18' 55" E
Latitude 35° 33' 08" N

Exposure Areas: The Aaliji Formation is exposed only in the eastern part (nose) of Sinjar anticline (Fig.2). However, the subsurface extension of the formation is wider, and most probably it is almost present in subsurface of the entire area of the Low Folded Zone, since it was struck in many oil wells, like Mushurah 1, Gullar 1, Gusair 1, Ain Zala, Butmah, Alan, Sasan, Najmah, K 109, Cham Chamal, Qara Chouq, Taq Taq, Pulkhana and Injana (Fig.6).

Lithology: The Aaliji Formation, in the supplementary type locality consists of grey and light brown argillaceous marls, marly limestone and shale with microscopic occasional fragments of chert with rare scattered glauconite (Bellen *et al*., 1959). In Sinjar vicinity, the formation consists of greenish grey shales. However, large parts of the formation exhibit interfingering with Sinjar Formation, in such areas, the Aaliji Formation consists of limestone, which grades into sandy marl; dark grey, thinly bedded, with scattered chert nodules and glauconite grains. This succession is overlain by poorly sorted conglomeratic limestone. Greenish brown calcareous sandstone horizons also occur (Ma'ala, 1977).

Thickness: The thickness of the Aaliji Formation, in the supplementary type section is 150 m, in Sinjar vicinity it ranges between (20 – 46) m (Ma'ala, 1977).

Fossils: The following fossils were recorded by Amer (1977) within the Aaliji Formation in Sinjar area: *Globorotalia whitei* WEISS, *Glb. primitiva* FINALY, *Glb. elongata* GLAESSNER, *Glb. tribulosa* LOEBLICH and TAPPAN, *Glb. wilcoxensis* CUSHMAN and PONTON, *Glb. imitata* SUBBOTINA, and *Globigerina aquiensis* LOEBLICH and TAPPAN.

Age: The following ages were claimed by different authors for the Aaliji Formation: Late Paleocene (Kassab, 1972 and 1975); Early Paleocene (Amer, 1977); Early Paleocene – Early Eocene (Al-Hashimi and Amer, 1985) and Paleocene – Early Eocene (Jassim and Buday, 2006 in Jassim and Goff, 2006).

Depositional Environment: The Aaliji Formation represents typical basinal (pelagic) facies of warm marine water and normal salinity (Al-Hashimi and Amer, 1985), whereas Jassim and

Buday (2006) in Jassim and Goff (2006) considered off shore, open marine environment for the formation; lying between two belts of platform margin carbonate shoals.

Lower Contact: The Aaliji Formation, in the supplementary type section is underlain unconformably by Shiranish Formation (Bellen *et al*., 1959). In Sinjar vicinity, the formation is underlain unconformably by Shiranish Formation too, the contact is based on the base of a conglomeratic limestone, or a marl horizon; bearing chert nodules (Ma'ala, 1977).

2.1.2. Sinjar Formation (Middle Paleocene – Early Eocene)
Type Locality: The Sinjar Formation was introduced by Keller in 1941; the type locality is near Mamisa village in Sinjar anticline (Fig.6) (Bellen *et al*., 1959), it is defined by the following coordinates:

Longitude	41°	41'	23"	E
Latitude	36°	22'	33"	N

Exposure Areas: The Sinjar Formation crops out only in Sinjar anticline, within the Low Folded Zone (Fig.2). However, the subsurface extension of the formation is spread wider than the surface exposures. It was struck in many drilled oil wells, like Mushurah, Ain Zala 16, Sasan 1, Qalian, Demir Dagh, K 116, Cham Chamal, Taq Taq (Fig.6).

Lithology: In the type locality, the Sinjar Formation consists of limestone showing elements of algal reef facies, lagoonal miliolid facies, and shoal nummulitic facies, the limestones are usually recrystallized. In Sinjar anticline, the formation was divided into three units. **Lower Unit**: Consists of light grey, massive, fine crystalline limestone alternated with thinly bedded reworked clastic limestone. Locally, few lenses of sandstone were observed. In the lowermost 5 m, greyish light brown ferruginous, coarse grained calcareous sandstone was observed. The thickness of this unit is 80 m. **Middle Unit**: Consists of whitish grey, massive, aphanitic fossiliferous limestone, with bryozoan's fragments. The thickness of this unit is 107 m. **Upper Unit**: Consists of whitish grey aphanitic, well bedded limestone. The thickness of this unit ranges between (14 – 50) m (Ma'ala, 1977).

Remark: According to Ma'ala (1977), Sinjar Formation includes in some localities (near Zerwan village) tongues of Aaliji Formation, which consists of limestone alternated with sandy shale. Moreover, in many localities, the uppermost part (43.5 m, near Haligh village) is considered as Avanah Formation, which is separated from the Sinjar Formation by a conglomerate horizon.

Thickness: The thickness of the Sinjar Formation in the type locality is 176 m (Bellen *et al*., 1959). In Sinjar vicinity, it ranges between (176 – 201) m (Ma'ala, 1977).

Fossils: The following fossils were recorded in the Sinjar Formation by Al-Mutter (1977) and Amer (1977): *Alveolina globula* LEYMERIE, *Ranikothalia sahnii* DAVIES, *Saudia labyrinthica* GRAMSDALE, *Idalina sinjarica* GRAMSDALE, *Sphaerogypsina* sp., *Nummulites* sp., *Discocyclina* sp., miliolids, few planktonic fauna and algae.

Age: The following ages were claimed by different authors for the Sinjar Formation: Paleocene –? Early Eocene (Bellen *et al*., 1959), Late Paleocene – Early Eocene (Amer, 1977 and Buday, 1980), and Middle Paleocene – Early Eocene (Al-Hashimi and Amir, 1985).

Depositional Environment: The Sinjar Formation represents the platform part of the Paleocene – Lower Eocene Sea. Bellen *et al*. (1959) recognized three facies within the formation; these are in ascending order: algal reef facies, lagoonal miliolid faciesand shoal nummulitic facies. Al-Hashimi and Amer (1985) suggested that the lower part of the formation (Middle Paleocene) with abundant miliolids and algae was deposited under organic reefal facies or restricted condition on marine platform; whereas the upper part(Upper Paleocene – Lower Eocene), which contains rich larger foraminifera was deposited in for slope area (shoal) in an open marine platform.

Lower Contact: The Lower contact of the Sinjar Formation, with the underlying Shiranish Formation is unconformable (Bellen *et al*., 1959 and Ma'ala, 1977), the contact is based on the base of a sandstone layer; grey to light brown, medium to coarse grained, with subordinate quartz and fossiliferous limestone fragments.

2.1.3. Khurmala Formation (Late Paleocene – Early Eocene)

Type Locality: The Khurmala Formation was introduced by Bellen in 1953 from Kirkuk structure, the type locality is in oil well K 114 (Fig.6) (Bellen *et al*., 1959), it is defined by the following coordinates:

Longitude	43°	45'	21"	E
Latitude	35°	56'	15"	N

Exposure Area: Only one small outcrop of the Khurmala Formation is recorded from the Low Folded Zone, it is in the core of Maqloub anticline (Barwary, 1983) (Figs.2 and 3). The authors prefer to mention it within the Paleocene – Early Eocene sequence, because it is the lagoonal equivalent of the Sinjar Formation and might be present in some outcrops as interfingering with it, although not mapped. The subsurface extension of the Khurmala Formation is also very limited to the central and northwestern parts of the Low Folded Zone, it was struck in few oil wells, like Atshan, Sasan, Cham Chamal, Taq Taq, Quwair, K 42, 81, 116, 122, 144, 151, 162 and K176 (Fig.6).

Lithology: In the type locality, the Khurmala Formation consists of "dolomite, suboolitic in part and finely recrystallized limestone. Probably chemical limestones, interfingering strongly with material from the Kolosh Formation, containing detrital chert, flint, radiolarite, and green rocks of silt and sand size. Anhydrite, which is probably secondary, occurs occasionally" (Bellen *et al*., 1959). In Maqloub anticline, the formation consists of yellowish grey, well bedded to massive, fossiliferous, slightly chalky, fine crystalline, hard slightly cavernous and porous dolostone (Barwary, 1983).

Thickness: The thickness of the Khurmala Formation in the type locality is 185 m (Bellen *et al*., 1959). The exposed thickness in Maqloub anticline is 85 m (Barwary, 1983).

Fossils: The fossils within Khurmala Formation are mostly dwarfed and obliterated by recrystallization; most common are miliolids, small valvulinids, alveolinids, small gastropods and algae (Bellen *at al*., 1959 and Buday, 980).Al-Hashimi and Amer (1985) recorded corals, algae, *Orbitolites complanatus* LAMARK, *Rotalia trochidiformis* LAMARK, *Lokhartia diversa* SMOUT, *Idalina* sp., *Gaudryina* sp., *Tritaxia* sp., and miliolids within the formation.

Age: The following ages were claimed by different authors for the Khurmala Formation: Bellen *et al*. (1959) suggested Paleocene – Lower Eocene age considering the Khurmala Formation as the lagoonal equivalent of the Paleocene and "Lower" Eocene Sinjar Formation. Buday (1980) claimed Late Paleocene – Early Eocene age, Barwary (1983) claimed Paleocene – Lower Eocene age, and Al-Hashimi and Amer (1985) suggested Lower Eocene age.

Depositional Environment: The Khurmala Formation was deposited in organic reef facies in part, and of restricted circulation on marine platform (back reef) facies dominated by miliolids in other parts (Al-Hashimi and Amer, 1985). However, Barwary (1983) and Jassim and Buday in Jassim and Goff (2006) claimed restricted lagoonal environment for the formation.

Lower Contact: The Lower contact of the Khurmala Formation in the type locality, with the underlying Kolosh Formation is conformable, the latter grades into the former through interdigitation (Bellen *et al*., 1959). In Maqloub anticline, the base of the formation is not exposed.

2.2. Middle – Late Eocene

The Neo-Tethys was narrowed and closed during the final phase of subduction. A foredeep basin (within the foreland) was developed southwest of the Balambo – Tanjero Zone ridge (northeast of the involved area); this foredeep was separated from the basin to the southwest by a belt of nummulitic limestone shoals of Avanah Formation. The foredeep basin was located, partly, in the present day Low Folded Zone (Jassim and Buday in Jassim and Goff, 2006).

The Middle – Late Eocene sequence includes four formations, they are described hereinafter.

2.2.1. Jaddala Formation (Early – Late Eocene)

Type Locality: The Jaddala Formation was introduced by Henson in 1940 (Bellen *et al*., 1959), its type locality is near Jaddala village in Sinjar anticline (Fig.6), and is defined by the following coordinates:

Longitude 41° 41' 28" E
Latitude 36° 18' 20" N

Exposure Areas: The Jaddala Formation is exposed only in two localities within the Low Folded Zone; in Sinjar anticline as a belt surrounding the whole Sinjar Mountain and in the base of Azkand valley, which dissects the southern dome of Qara Chouq anticline (Fig.2). However, the subsurface extension of the formation is wider, since it was struck in many oil wells like Gullar 1, Gusair 1, Ain Zala, Butmah, Ibrahim, Adaiyah, Qalian, Najmah, K 109, Qara Chouq, Makhoul, Pulkhana, Himreen, and Injana (Fig.6).

Lithology: The Jaddala Formation, in the type locality, consists of "marly and chalky limestone and marl, with occasional intercalations of shoal limestone (tongues of Avanah Formation)" (Bellen *et al*., 1959). In Sinjar vicinity, Ma'ala (1977) divided the formation into two units. **Lower Unit**: Consists of greenish grey, well bedded, fairly hard shales intercalated with thinly bedded marly limestone, with chert nodules. In the lowermost part, very thin (0.1 m) horizons of sandy limestone occur, overlying dark grey glauconitic marly limestone, slightly dolomitized locally bears iron oxides aggregates associated with chert nodules. **Upper Unit**: Consists of light grey, well bedded marly limestone, with horizons of chert, alternating with grey, laminated marl (Ma'ala, 1977). In Qara Chouq vicinity, the formation consists of two parts: Lowe part (27 m thick) consists of light grey, fairly hard, thinly bedded clayey to marly limestone. Upper part (18 m thick) consists of white, hard, thickly bedded, chalky limestone, with fragments of chert, interbedded with thin horizons of clayey limestone (Al-Sammarai and Al-Mubarak, 1978).

Thickness: The thickness of the Jaddala Formation in the type locality is 350 m (Bellen *et al*., 1959), in Sinjar vicinity it is 517 m (Ma'ala, 1977), whereas the exposed thickness in Azkand valley is 45 m (Al-Sammarai and Al-Mubarak, 1978).

Fossils: The following fossils were recorded within the Jaddala Formation by different authors, from different localities: Henson (1950) in Bellen *et al*. (1959) recorded the following fossils in the type locality "*Globigerina frontosa* SUBBOTINA, *G. venzuelana* HEDBERG, *Globorotalia centralis* CUSHMAN and BERMUDEZ, *Glb. opima rana* BOLLI, *Catapsydrax dissimilis* BOLLI, *Hantkenina alabamensis* CUSHMAN, *Hetrolepa costata* FRANZENA, *Robulus* sp., and *Bulimina schencki* BECK. Amer (1977) recorded the following fossils in Sinjar vicinity: *Globorotalia lehneri* CUSHMAN and JARVIS, *Glb. aragonensis* NUTTAL, *Glb. spinulosa* CUSHMAN, *Hantkenina aragonensis* NUTTAL, *Hastigerina micra* (COLE), *Chilogumblina* sp. Abdul Munium and Jawi (1978) recorded the same fossils of the type locality at Azkand valley in Makhmour area.

Age: The following ages were claimed for of the Jaddala Formation: Amer (1977) suggested early Middle Eocene – Upper Eocene, Buday (1980) suggested Lower – Upper Eocene, and Al-Hashimi and Amer (1985) suggested Middle – Upper Eocene age, whereas Jassim and Buday in Jassim and Goff (2006) claimed late Early Eocene – Late Eocene age.

Depositional Environment: The Jaddala Formation represents a typical basinal facies through out a shelf margin facies (Amer, 1977 and Al-Hashimi and Amer, 1985), whereas, according to Jassim and Buday in Jassim and Goff (2006), the formation represents off shore facies of the late Early Eocene – Late Eocene Sequence.

Lower Contact: The lower contact of the Jaddala Formation, in the type locality with the underlying Sinjar Formation is unconformable, as indicated by the presence of glauconite (Bellen *et al*., 1959). In Sinjar vicinity, the formation is underlain unconformably by Aaliji and Sinjar formations, the contact was based on the bottom of a thin horizon of dark grey chert overlain by marl with glauconite grains, locally bears hematite grains, or thin horizon of yellow fossiliferous sandstone (Ma'ala, 1977). In Qara Chouq anticline, Shiranish Formation underlies the Jaddala Formation unconformably; the contact is based at the first appearance of light grey marly to clayey limestone (Al-Sammarai and Al-Mubarak, 1978).

2.2.2. Gercus Formation (Early – Middle Eocene)
Type Locality: The Gercus Formation was introduced by Maxson in 1936 for Petrol Grubu (Turkey), its type locality is in Gercus, 20 Km north of Midyat in southwest Turkey. A supplementary type section in Iraq has been chosen by Wetzel at Dohuk (Fig.6), and is defined between the following coordinates (Bellen *et al*., 1959):

Longitude	43°	00'	50"	43°	00'	36"	E
Latitude	36°	52'	52"	36°	52'	27"	N

Exposure Areas: The Gercus Formation is exposed only in one locality within the Low Folded Zone, in Maqloub anticline (Fig.3). The subsurface extension of the formation is restricted in a very narrow belt along the marginal part with the contact of the High Folded Zone, therefore it was struck in very limited oil wells, like Taq Taq, Demir Dagh, Cham Chamal (Fig.6), which are nearby to the contact between Low Folded and High Folded Zones.

Lithology: The Gercus Formation, in the supplementary type section, consists of "Red and purple shales, mudstones, sandy and gritty marls with or without pebbles. Some soft pebbly sandstones and conglomerates. Lenticels' of gypsum, especially towards the top. Rare lignite in a sandstone near the base. Rock salt occurs sporadically. The lower 259 m consists of variegated marls, siltstones, sandstones and conglomerates, still predominantly red in color but with green materials also occurring" (Bellen *et al*., 1959). In Maqloub anticline, the formation consists of alternation of varicolored marl, mudstone, siltstone, occasionally limestone and conglomerate occur too (Barwary, 1983).

Thickness: The thickness of the Gercus Formation in the supplementary type section is 838 m (Bellen *et al*., 1959), the exposed thickness in Maqloub anticline, is 56 m (Barwary, 1983).

Fossils: The following fossils were recorded within the Gercus Formation by different authors from different localities, within the Low Folded Zone: Ostracods, radiolarian and planktonic foraminifera, most of these fossils are reworked(Bellen *et al*., 1959; Buday, 1980 and Al-Hashimi and Amer, 1985).

Age: The following ages were claimed for the Gercus Formation: Probably Middle Eocene (Bellen *et al*., 1059), Middle Eocene (Buday, 1980), and Earl Eocene – Middle Eocene (Jassim and Goff, 2006).

Depositional Environment: The Gercus Formation was deposited in a relatively broad sinking molasse trough (foredeep), after the local Van Phase of the Intra Eocene Orogeny (Buday, 1980).

Lower Contact: The lower contact of the Gercus Formation, in the supplementary type section is with the Kolosh Formation. "The contact appears to be gradational but the two formations are separated by a well marked conglomerate. A color change from predominantly green (Kolosh Formation) to predominantly red (Gercus Formation) may also mark the contact. But, the Gercus includes green beds and the Kolosh includes red beds" (Bellen *et al*., 1959). In Maqloub anticline, Khurmala Formation underlies the formation, although the contact is covered by Quaternary sediments, but due to difference in the lithology and color, it is clear and based on the bottom of the first varicolored clastics above the dolostone of Khurmala Formation (Barwary, 1983).

2.2.3. Avanah Formation (Early – Middle Eocene)

Type Locality: The Avanah Formation was introduced by McGinty in 1953 in Bellen *et al*. (1959) from the oil well K 116 in Kirkuk structure (Fig.5) as the type locality, which is defined by the following coordinates:

Longitude 43° 59' 06" E
Latitude 35° 47' 28" N

Exposure Areas: The Avanah Formation has restricted exposures within the Low Folded Zone. It is exposed in the core of Mushurah anticline, in Sinjar anticline as tongues within Jaddala Formation, in two localities within Qara Chouq anticline at Garsur valley; 5 Km northwest of Palani village, and in the core of the Northern Dome of Qara Chouq anticline, and in Atshan anticline; 15 Km southwest of Mosul city (Figs.2 and 3). However, the subsurface extension of the formation is wider, especially in the northwestern part of the Low Folded Zone, since it was struck in oil wells, like Mushurah, Ain Zala, Butmah, Alan, Atshan, K 84, 109, 116, Quwair (Fig.6).

Lithology: The Avanah Formation, in the type locality, consists of limestones, generally dolomitized and recrystallized, representing the shoal facies, with occasional intercalations of lagoonal limestones, which are treated as Pila Spi limestone tongues (Bellen *et al*., 1959). In Mushurah anticline, the formation consists of white to grey, hard, fossiliferous, medium crystalline dolostone, overlain by light brownish grey, fossiliferous dolomitic limestone, rich in nummulites (Taufiq and Domas, 1977). West of Mosul city, the formation consists of light pinkish grey, massive, hard, nummulitic limestone, with chert nodules, overlain by intraformational breccia; pink, compacted, and fractured (Mohi Ad-Din *et al*., 1977). In Sinjar vicinity, the formation consists of alternation of nummulitic limestone and marly limestone. The nummulitic limestone is brownish grey, very hard, splintery, crystallized and fossiliferous, whereas the marly limestone is grey to yellowish grey, fairly hard and thinly bedded to massive (Ma'ala, 1977). In the Northern Dome of Qara Chouq anticline, the formation consists of alternation of light brown marly and dolomitized limestones with recrystallized, thickly bedded, and highly fossiliferous limestone (Hagopian and Veljupek, 1977). In Qara Chouq anticline, the formation consists of globigerinal limestone, it occurs as tongues within the Jaddala Formation (Al-Sammarai and Al-Mubarak, 1978).

Thickness: The thickness of the Avanah Formation, in the type locality, is 212 m (Bellen *et al*., 1959), in Mushurah anticline the exposed thickness is 19 m (Taufiq and Domas, 1977), in Atshan anticline the exposed thickness is about 50 m (Mohi Ad-Din *et al*., 1977), in Sinjar vicinity it ranges between (10 – 82) m and (10 – 32) m, in the southern and northern limbs of Sinjar anticline, respectively (Ma'ala, 1977), in the Northern Dome of Qara Chouq anticline the exposed thickness is 10 m (Hagopian and Veljupek, 1977). In the Central and Southern Domes of Qara Chouq anticline the thickness is not recorded.

Fossils: The following fossils were recorded, by different authors in Avanah Formation: *Alveolina elliptica* var. *flosculina*, *Baculogypsinoides* sp., *Dictyoconus aegyptiensis* (CHAPMAN), *Discocyclina* sp. and nummulites (Bellen *et al*., 1959) *Nummulites atacicus* LEYMERIE, *N. bayharensis* (CHECCHIA –RISPOLI), *N. discorbinus* (SCHLOTHIEM), *N. perforatus var bayharensis* (CHECCHIA RISPOLI), *Alveolina elliptica* (SOWERBY), *Sphaerogypsina* sp., *Orbitolites complanatus* (DEFRANCE) and *Discocyclina sella* (D'ARCHIAC), *Operculina* sp., *Coskinolina* sp. and miliolids (Amer, 1977; Al-Biaty, 1978; Buday, 1980 and Al-Hashimi and Amer, 1985). *Nummulites perforatus bayharensis*, *Discocycline oliscus*, *Nummulites globules*, *Discocyclina dispance*, *Sphaerogypsina* sp. and *Nummulites atacicus* (Karim, 1977).

Age: The age of the Avanah Formation was considered as Middle – Upper Eocene (Amer, 1977; Taufiq and Domas, 1977; Hagopian and Veljupek, 1977; Youkhanna and Hradecky, 1978; Buday, 1980 and Al-Hashimi and Amer, 1985), whereas Mohi Ad-Din *et al*. (1977) and Jassim and Buday in Jassim and Goff (2006) claimed Middle Eocene age.

Depositional Environment: The Avanah Formation represents the shoal facies as demonstrated by the dominant occurrence of *Nummulites* and *Discocyclina* species (Middle Eocene) (Taufiq and Domas, 1977 and Hagopian and Veljupek, 1977). It represents semi restricted environment with high salinity represented by the *Alveolina*, *Coskinolina* and miliolids (Upper Eocene) (Henson, 1950 in Bellen *et al*., 1959 and Amer, 1977), whereas Jassim and Buday in Jassim and Goff (2006) claimed that the formation was deposited as an isolated carbonate shoal, associated with a paleoridge along the northeastern shore line of the basin during a high stand of sea level.

Lower Contact: In the type locality, the Avanah Formation is underlain by Khurmala Formation, the contact is probably unconformable. In Mushurah, Atshan and Qara Chouq anticlines, the lower contact of the formation is not exposed (Taufiq and Domas, 1977; Mohi Ad-Din *et al*., 1977 and Hagopian and Veljupek, 1977, respectively). In Sinjar vicinity, Avanah Formation occurs always as tongues within Jaddala Formation, therefore, its lower contact is always conformable with Jaddala Formation, the contact was based on the bottom of the first nummulitic limestone bed (Ma'ala, 1977), and the same case was considered by Al-Sammarai and Al-Mubarak (1978) in Qara Chouq anticline.

2.2.4. Pila Spi Formation (Middle – Late Eocene)

Type Locality: The Pila Spi Formation was "introduced by Lees (1930) from Pila Spi area; near Darbandi Khan Dam (Fig.6), it was redefined by Wetzel (1947) and amended by Bellen (1957)" (Bellen *et al*., 1959), the type locality is defined by the following coordinates (Bellen *et al*., 1959):

Longitude 45° 11' 00" E
Latitude 35° 12' 30" N

However, Bellen *et al*. (1959) chose a supplementary type section, because the original type section is inundated by the reservoir of the Darbandi Khan Dam. The supplementary type section at Kashti in the Baranan Dagh is defined by the following coordinates:

Longitude 45° 42' 10" E
Latitude 35° 06' 35" N

Exposure Areas: Although the contact between the Low Folded Zone and the High Folded Zone is represented almost by the top of the Pila Spi Formation, but still very restricted exposures of the formation exist within the Low Folded Zone. It is exposed in the core of Khweleen, Kiwa Charmula, Maqloub, Ba'shiqa, Ain Al-Safra, Dahqan, Qara Wais and Aj Dagh anticlines, which are very close and parallel to the aforementioned contact (Figs.2 and 3). The subsurface extension of the formation is also very limited to the marginal part in the contact with the High Folded Zone, therefore, it was struck in few oil wells, like Demir Dagh, Cham Chamal, Taq Taq, K 24, 29, 40, 52, 80, 86, 94, 101, 116, 117, 125, 149 and 163 (Fig.6).

Lithology: The Pila Spi Formation, in the type locality consists of two parts: The lower part consists of white, well bedded, porous, bituminous, poorly fossiliferous limestones with algal or shell sections. The upper part consists of light greyish white, well bedded, bituminous, chalky and crystalline limestone with bands of white chalky marl and chert nodules towards the top (Bellen *et al*., 1959). In the supplementary type section, dolomitic and chalky limestone, with a few less dolomitized bands, chert intercalations, with traces of subooliths and rare concentrations of gastropod debris form the bulk of the formation (Bellen *et al*., 1959). In the southern limbs of Ba'shiqa and Ain Al-Safra anticlines, the formation consists of alternation of white, hard, thickly bedded, very porous, recrystallized lagoonal limestone and white or light grey, hard dolomitic limestone, the upper part is characterized by thickly well bedded nature with many horizons of brown to black chert nodules (Hagopian and Veljupek, 1977). In Maqloub, and the northern limbs of Ain Al-Safra and Ba'shiqa anticlines, the formation consists of greyish white and yellowish grey in color, hard, fine crystalline, porous, thickly well bedded dolostone, with dark brown chert nodules in the uppermost part. Some marl and marly limestone layers occur too (Barwary, 1983). In Dahqan anticline, the formation consists of white, well bedded; thickly bedded to massive, porous, splintery, hard, partly fossiliferous, fine to medium crystalline dolostone, with chert nodules and iron oxides concretions (Taufiq and Domas, 1977).

Remark: In the core of the Middle Dome of Qara Chouq anticline, Hagopian and Veljupek, (1977) mapped a sequence similar to the Pila Spi Formation, though not precisely identified.

Thickness: The thickness of the Pila Spi Formation in the type locality is 85 m and in the supplementary type section is 189 m (Bellen *et al*., 1959). In Ba'shiqa and Ain Al-Safra anticlines, the exposed thickness is about 135 m (Hagopian and Veljupek, 1977), in Maqloub anticline it is 115 m (Barwary, 1983), near Dahqan anticline the exposed thickness is about 140 m (Taufiq and Domas, 1977).

Fossils: The following fossils were recorded, by different authors in Pila Spi Formation: Chilostomellids, miliolids, peneroplids, all indeterminable (Bellen *et al*., 1959), *Alveolina* sp., *Rhapdionina urensis* HENSON, *Spirolina* sp., *Bigenerina* sp., *Somalina* sp., rotaliids, miliolids, bryozoa, and algae (Al-Hashimi and Amer, 1985).

Age: The age of the Pila Spi Formation is considered as Middle – Upper Eocene (Amer, 1977; Hagopian and Veljupek, 1977; Youkhanna and Hradecky, 1978; Buday, 1980 and Al-Hashimi and Amer, 1985), whereas Jassim and Buday in Jassim and Goff (2006) claimed Middle Eocene age.

Depositional Environment: The Pila Spi Formation represents typical restricted to semi-restricted (lagoonal) marine platform facies of hypersaline marine conditions; demonstrated by the occurrences of miliolids, peneroplids, within its dolomitic limestone rocks (Al-Hashimi and Amer, 1985).

Lower Contact: In the type locality, the Pila Spi Formation is underlain by Gercus Formation, the contact is sometimes gradational through interfingering, sometimes appears to be marked by a conglomerate, whereas in the supplementary type section it is underlain unconformably by the Gercus Formation, which shows intercalations of Sinjar Formation, the contact is marked by a conglomerate (Bellen *et al*., 1959). In Dahqan anticline, the lower contact of the formation is not exposed (Taufiq and Domas, 1977), in Maqloub, Ain Al-Safra and Ba'shiqa anticlines, the formation is underlain conformably by the Gercus Formation, the contact was based on the bottom of the first dolostone bed (Hagopian and Veljupek, 1977 and Barwary, 1983).

2.3. Oligocene

At the end of Eocene, the main intraplate basin became narrower due to the tilting of west Arabia, and uplift of the High Folded Zone. The eastern shore line receded to the southwest boundary of the Low Folded Zone. The closed Neo-Tethys was narrow seaway in which clastics and carbonates were deposited. The Oligocene basin was relatively narrow, thick fringing reefs developed along the western and eastern shorelines of the basin. Thin marls were deposited in the centre of the basin, which was starved of sediment supply (Jassim and Buday in Jassim and Goff, 2006).

The exposures of Oligocene Epoch in the Iraqi Low Folded Zone have very limited extensions, only in Qara Chouq, Aj Dagh and Qara Wais anticlines. This is because the Neo-Tethys was a narrow seaway forming reef back reef and fore reef basins. However, Oligocene rocks may occur on the top of the Pila Spi Formation in many areas, but not differentiated. The Oligocene sequence is represented by eight exposed formations, these are described, hereinafter.

Remarks:

1) According to the executed Regional Geological Mapping of the Low Folded Zone, the Ibrahim Formation was not found to be exposed on surface. However, Abawi and Maroof (1988) in Ismail (2005) mentioned that the formation is exposed in Sharaf Al-Deen vicinity within the northern limb of Sinjar anticline with a thickness of 72.5 m, and claimed Middle – Late Oligocene age for the formation. Moreover, they suggested that the mentioned locality to be a supplementary type section for the Ibrahim Formation. The authors are not in accordance with them, because Ma'ala (1977) hardly could miss such a thickness during execution of the Regional Geological Mapping of Sinjar anticline, with a group of well experienced working geologists and paleontologists.

2) Recently, some Oligocene formations were recognized from other localities, such as Aj Dagh, and Sagirma Dag, southwest of Sulaimaniyah (Khanqa *et al*., 2009).

3) Sissakian and Fouad (2012) found some Oligocene formations overlying the Pila Spi Formation south of Qara Dagh, in Qara Wais and Aj Dagh anticlines, and they might be present more southeast and northwest wards**,** overlying the Pila Spi Formation, along the contact between Low Folded and High Folded Zone.

2.3.1. Palani Formation (Early Oligocene)

Type Locality: The Palani Formation was first described by Bellen in 1956 from Kirkuk structure in oil well K 85 (Fig.6) as the type locality, which is defined by the following coordinates (Bellen *et al*., 1959):

Longitude	44°	25'	28"	E
Latitude	35°	26'	42"	N

Exposure Areas: According to Bellen *et al*. (1959), the Palani Formation is exposed only in Northern Dome of Qara Chouq anticline, especially near Palani village. Al-Sammarai and Al-Mubarak (1978), however, did not ascertain the presence of the formation, during the Regional Geological Mapping of the involved vicinity. Jassim and Buday in Jassim and Goff (2006) mentioned the presence of the formation depending on Bellen *et al*. (1959). Its subsurface extension in the Low Folded Zone is clear, it was struck in many oil wells, like Makhoul, Bai Hassan 3, K 85, and 175, Qalian, Gusair, Gullar, Qara Chouq (Fig.6).

Remark: Buday (1980, p. 224) included the Palani Formation within the Lower – Upper Eocene cycle, moreover he considered the formation to be identical in age and lithology wise with Jaddala Formation, therefore, he recommended to abolish the formation, and he didn't mention it within the stratigraphic column of Iraq. Moreover, he mentioned that Ditmar *et al*. (1971, p. 77 – 81) are in accordance with his suggestion. However, Jassim and Buday in Jassim and Goff (2006) claimed the presence of the formation and claimed Late Eocene – Early Oligocene age for the formation.

Lithology: The Palani Formation, in the type locality consists of dolomitized, globigerinal marly limestones (Bellen *et al*., 1959).

Thickness: The thickness of the Palani Formation in the type locality is about 64 m. Because the formation was not found in the Low Folded Zone, as surface exposures, therefore no thickness records are available.

Fossils: The following fossils were recognized in the Palani Formation: *Globigerina ampliapertura* BOLLI, *G. ciperoensis* BOLLI, *G. praebulloides* BLOW, *Globorotalia nana* BOLLI, *Chilogumbelina* sp., *Lenticulina* sp. and *Bolivina* sp.

Age: Early Oligocene age is claimed for the Palani Formation by the following authors: Jassim *et al*. (1984), the age estimation was based on the stratigraphic position of the formation, between the underlying Jaddala Formation and the overlying and interfingering Sheikh Alas Formation, Early – early Middle Oligocene (Al-Hashimi and Amer, 1985) whereas Ditmar *et al*. (1971) claimed Late Eocene – Early Oligocene age for the formation. However, Buday (1980) claimed Lower – Upper Eocene age for the formation. Moreover, Jassim and Buday in Jassim and Goff (2006) claimed Late Eocene – Early Oligocene age for the formation.

Depositional Environment: The Palani Formation was deposited in an outer shelf basinal environment passing up into a slope environment (Majid and Vizer, 1986 in Jassim and Goff, 2006).

Lower Contact: The lower contact of the Palani Formation, in the type locality with the underlying Jaddala Formation is unconformable (Bellen *et al*., 1959). Because the formation was not found in the Low Folded Zone, as surface exposures, therefore no records for the lower contact are available.

Remarks:

1) Although the Palani Formation was not recorded during the Regional Geological Mapping in Qara Chouq vicinity (Hagopian and Veljupek, 1977 and Al-Sammarai and Al-Mubarak, 1978), but the authors prefer to mention it within the Oligocene sequence, because the paleontological study (Al-Hashimi and Amer, 1985) of the involved vicinity proved the presence of the formation. The authors believe that Hagopian and Veljupek (1977) and Al-Sammarai and Al-Mubarak (1978) have not recognized the exposures of the formation from the other similar Oligocene formations, due to very large lithological similarity between them. It is worth mentioning that the formation was struck in Qara Chouq oil well (Bellen *et al*., 1959) (Fig.6).

2) Al-Mutwali and Al-Banna (2002) in Ismail (2005) and Al-Banna *et al*. (2010) mentioned that the Palani Formation is exposed in Sinjar anticline with a thickness of 4 and 10 m, respectively. The authors are not in accordance with them, because they have discussed the presence of the formations with Al-Omari who also denied the presence of the formation, based upon paleontological evidences. (Dr. Farouk Al-Omari, personal communication, 2010).

2.3.2. Sheikh Alas Formation (Early Oligocene)

Type Locality: The Sheikh Alas Formation was first described by Bellen in 1956, the type locality is in Qara Chouq anticline near Sheikh Alas village (Bellen *et al*., 1959) it is defined by the following coordinates (Fig.6):

Longitude	43°	35'	30"	E
Latitude	35°	54'	38"	N

Exposure Areas: The Sheikh Alas Formation is exposed only in the core of the Northern dome of Qara Chouq anticline and in the deeply cut valleys in the Central Dome of Qara Chouq anticline (Figs.2 and 3). However, its subsurface extension is wider in the Low Folded Zone, it is struck in many oil wells, like Ain Zala, Gusair, Qalian, Bai Hassan 3 and K 109 (Fig.6).

Lithology: The Sheikh Alas Formation, in the type locality, consists of dolomitic and recrystallized limestone, generally porous and occasionally rubbly (Bellen *et al*., 1959). In the Central Dome of Qara Chouq anticline, the formation consists of brownish grey, thickly bedded to massive, hard, dolomitized, porous, recrystallized and nummulitic limestone (Hagopian and Veljupek, 1977). In the Southern Dome of Qara Chouq anticline, the formation consists of whitish grey, very hard, massive at the lower part and thickly bedded at the upper part, compacted, dolomitic and recrystallized nummulitic limestone (Al-Sammarai and Al-Mubarak, 1978).

Thickness: The thickness of the Sheikh Alas Formation in the type locality is 26 m (Bellen *et al*., 1959), in the central Dome of Qara Chouq anticline, it is about 35 m (Hagopian and Veljupek, 1977) and in the Southern Dome of Qara Chouq anticline, it ranges between (10 – 17) m (Al-Sammarai and Al-Mubarak, 1978).

Fossils: The following fossils were recognized in Sheikh Alas Formation: *Nummulites intermedius* (D'ARCHIAC), *N. vascus* JOLY and LEYMERE, *Heterostigina* sp., *Operculina complanata* (SCHLUMBERGER), *Rotalia viennoti* GREIQ, *Borelis pygmaeus* HANZAWA, corals, algae and mollusca (Karim, 1977; Al-Biaty, 1978 and Al-Hashimi and Amer, 1985).

Age: Early Oligocene age is claimed for the Sheikh Alas Formation by the following authors Al-Biaty (1978), Jassim *et al*. (1984) and Al-Hashimi and Amer (1985). However, Jassim and Buday in Jassim and Goff (2006) claimed Late Eocene age when *Lepidocyclina* (*Eulepidina*) is absent; otherwise, the age is Early Oligocene.

Depositional Environment: The Sheikh Alas Formation represents deposition in normal warm marine environment of shoal facies (shelf depth). This facies changes laterally into the inner shelf facies of Shurau Formation (Bellen *et al*., 1959), whereas Jassim and Buday in Jassim and Goff (2006) claimed that the lower part of the formation was deposited in a fore slope environment, and the upper part in a lagoonal environment. Majid and Vizer (1986) in Jassim and Goff (2006) claimed that it passes vertically and laterally into the reefal facies of the Shurau Formation.

Lower Contact: The lower contact of the Sheikh Alas Formation, in the type locality is unconformable with the underlying Palani Formation (Ditmar *et al*., 1971), whereas, in Qara Chouq anticline it is underlain conformably by Avanah Formation, the contact was taken at the base of the first appearance of brown, massive and nummulitic limestone (Al-Sammarai and Al-Mubarak, 1978).

2.3.3. Shurau Formation (Early Oligocene)

Type Locality: The Shurau Formation was first described by Bellen in 1956; its type locality is in Kirkuk structure, oil well K 109 (Fig.6), which is defined by the following coordinates (Bellen *et al*., 1959):

Longitude 44° 18' 55" E
Latitude 35° 33' 08" N

Exposure Areas: The Shurau Formation is exposed only in the deeply cut valleys and core of the Northern Dome of Qara Chouq anticline (Figs.2 and 3). However, its subsurface extension is wider in the Low Folded Zone, since it was struck in many oil wells, like Ain Zala, Gusair and K 109 (Fig.6).

Lithology: The Shurau Formation, in the type locality consists of porous coralline limestone, followed by grey, dense limestone (Bellen *et al*., 1959). In the deeply cut valleys of the Central Dome of Qara Chouq anticline, the formation consists of brownish grey, porous, coralline and reefal limestone, overlain by grey, thinly to thickly bedded, occasionally recrystallized limestone with abundant miliolids (Hagopian and Veljupek, 1977). In the Southern Dome of Qara Chouq anticline, the formation consists of whitish grey to white, very hard, massive, recrystallized, coralline limestone, with abundant miliolids (Al-Sammarai and Al-Mubarak, 1978).

Thickness: The thickness of the Shurau Formation in the type locality is 18 m (Bellen *et al*., 1959), in the deeply cut valleys of the Central Dome of Qara Chouq anticline it is about 15 m (Hagopian and Veljupek, 1977), and in the Southern Dome of Qara Chouq anticline it ranges between (7 – 10) m (Al-Sammarai and Al-Mubarak, 1978).

Fossils: The following fossils were recognized in Shurau Formation: *Archaias operculiniformis* HENSON, *Peneroplis evolutus* HENSON, *P. thomasi* HENSON, *Praerhapydionina delicata* HENSON, *Austrotrillina howchini* (SCHLUMBERGER), *A. paucialveolata* GRIMSDALE, *A. globulina* (Al-Hashimi and Amer, 1985), *Rotalia viennoti* GREIG, miliolids and algae (Behnam, 1977; and Al-Sammarai and Al-Mubarak, 1978).

Age: Early Oligocene age is claimed for the Shurau Formation by the following authors: Al-Hashimi (1974); Al-Biaty (1978); Jassim *et al*. (1984); Al-Hashimi and Amer (1985) and Jassim and Buday in Jassim and Goff (2006).

Depositional Environment: The Shurau Formation is deposited in an inner shelf zone of warm quiet marine platform reef and back reef facies (Bellen *et al*., 1959; Al-Biaty, 1978; Al-Hashimi, 1984; Jassim *et al*., 1984; Al-Hashimi and Amer, 1985 and Jassim and Buday in Jassim and Goff, 2006).

Lower Contact: The lower contact of Shurau Formation, in the type locality is conformable with the underlying Sheikh Alas Formation (Bellen *et al*., 1959), also in Qara Chouq anticline it is underlain conformably by Sheikh Alas Formation, the contact was taken at the base of the first thinly bedded, grey, recrystallized limestone, or the top of the last nummulitic limestone (Hagopian and Veljupek, 1977 and Al-Sammarai and Al-Mubarak, 1978).

2.3.4. Tarjil Formation (Middle Oligocene)
Type Locality: The Tarjil Formation was first described by Bellen in 1956 from Kirkuk structure in oil well K 85 (Fig.6) as the type locality, which is defined by the following coordinates (Bellen *et al*., 1959):

Longitude 44° 25' 28" E
Latitude 35° 26' 42" N

Exposure Areas: The Tarjil Formation is exposed only in the southern limb of the Southern Dome of Qara Chouq anticline (Figs.2 and 3). However, its subsurface extension is more wide in the Low Folded Zone, since it was struck in many oil wells, like Qalian, Kor Mor, Najmah, Qara Chouq, Bai Hassan, K 85 and 152, Gullar, Gusair and Makhoul (Fig.6).

Remark: Al-Mutwali and Al-Banna (2002) in Ismail (2005) and Al-Banna *et al*. (2010) mentioned that the Tarjil Formation is exposed in Sinjar anticline with a thickness of 197 m and 147 m (in Jaddala section), respectively, and consists of white marly limestone. The authors are not in accordance with them, because such a thickness could not be missed during the Regional Geological Mapping, which was executed by Ma'ala (1977) with a group of well experienced filed geologists and paleontologists.

Lithology: The Tarjil Formation, in the type locality consists of slightly dolomitized, marly limestone (Bellen *et al*., 1959). In Qara Chouq anticline, the formation consists of yellow to yellowish grey and brown to brownish grey, very hard, thinly to thickly bedded, recrystallized and fossiliferous limestone (Al-Sammarai and Al-Mubarak, 1978).

Thickness: The thickness of the Tarjil Formation in the type locality is 100 m (Bellen *et al*., 1959), in Qara Chouq anticline it is about 30 m (Al-Sammarai and Al-Mubarak, 1978).

Fossils: The following fossils were recognized in the Tarjil Formation from Qara Chouq area: *Globigerina ampliapertura* BOLLI, *G. ciperoensis* BOLLI, *G. selli* (BORSETTI), *Globorotalia opima* BOLLI, *Gl. nana* BOLLI, *Nummulites intermedius* (D'ARCHIAC), *Lepidocyclina (Eulipidina) dilitata* MICHELOTTI, *Lenticulina* sp., *Rotalia viennoti* GREIC and algae (Abdul-Munium and Jawi, 1978 and Al-Hashimi and Amer, 1985).

Age: Middle Oligocene age was claimed for the Tarjil Formation by the following authors: Abdul-Munim and Jawi (1978) and Al-Hashimi and Amer (1985), whereas Jassim and Buday in Jassim and Goff (2006) claimed Early Oligocene depending on the presence of *Nummulites intermedius,* as stated by Bellen *et al*. (1959).

Depositional Environment: The Tarjil Formation with its mixed fauna of planktonic, benthonic and larger foraminifera with algae and bryozoa; indicate that it was deposited in shelf margin (Henson, 1950 in Bellen *et al*., 1959; Al-Hashimi, 1978; Abdul-Munim and Jawi, 1978, and Al-Hashimi and Amer, 1985). Whereas, Jassim and Budayin Jassim and Goff (2006) claimed that the formation was deposited in outer shelf environment, as stated by Bellen *et al*. (1959).

Lower Contact: The lower contact of Tarjil Formation, in the type locality is unconformable with the underlying Palani Formation (Bellen *et al*., 1959), whereas in Qara Chouq anticline it is underlain unconformably by Jaddala Formation, the contact was based on the bottom of breccia (1.5 m thick) (Al-Sammarai and Al-Mubarak, 1978).

2.3.5. Baba Formation (Middle Oligocene)

Type Locality: The Baba Formation was first described by Bellen in 1956 from Kirkuk structure in oil well K109 (Fig.6) as the type locality, which is defined by the following coordinates (Bellen *et al*., 1959):

Longitude	44°	18'	55"	E
Latitude	35°	33'	08"	N

Exposure Area: The Baba Formation is exposed in Qara Chouq anticline, only in deep cut valleys (Figs.2 and 3). The subsurface extension of the Baba Formation is almost clear; it was struck in many oil wells, like K 109, Qara Chouq, Gullar, Gusair, Ain Zala, Qalian, and Adaiyah (Fig.6).

Lithology: The Baba Formation in the type locality consists of "ruby limestone and limestone containing Lepidocyclina" (Bellen *et al*., 1959). In the Central Dome of Qara Chouq anticline, the formation consists of brown to pinkish brown, porous, fairly hard, thinly to thickly bedded dolomitic limestone, with abundant nummulites (Hagopian and Veljupek, 1977). In the Southern Dome of Qara Chouq vicinity, the formation consists of whitish grey and white, very hard, compacted, thinly to thickly bedded, massive in the middle part, chalky limestone (Al-Sammarai and Al-Mubarak, 1978).

Thickness: The thickness of the Baba Formation in the type locality is 20 m (Bellen *et al*., 1959), in Bira Braza village; along Qara Chouq anticline it is 35 m; decreases eastwards to 25 m (Hagopian and Veljupek, 1977), in Qara Chouq anticline it ranges between (7 – 22) m and (20 – 30) m; in the Northern and Southern Domes, respectively (Al-Sammarai and Al-Mubarak, 1978).

Fossils: The following fossils were recorded in Baba Formation by many authors (Bellen, 1956 in Bellen *et al*., 1959; Karim, 1977; Al-Biaty, 1978 and Al-Hashimi and Amer, 1985). *Nummulites fichteli*, *Lepidocyclina elephanta* LEMOINE and DOUVILLE, *L. morgan*i LEMOINE and DOUVILLE, *Rotalia viennoti* GREIC, *Heterostegina* sp., *Operculina* sp., *Praerhapydionina delicata* HENSON, *Archaias kirkukensis* HENSON, *Borelis pygmaeus* HANZAWA, *Meandropsina anahensis* HENSON and coralline algae.

Age: The following ages were claimed for the Baba Formation by different authors: early Late Oligocene (Bellen *et al*., 1959), Middle Oligocene (Karim, 1977; Al-Hashimi and Amer, 1985 and Jassim and Buday in Jassim and Goff, 2006).

Depositional Environment: The Baba Formation represents reef – fore reef facies (Bellen, 1956 in Bellen *et al*., 1959; Karim, 1977 and Al-Hashimi and Amer, 1985), whereas, Jassim and Buday in Jassim and Goff (2006) claimed that the formation was deposited in fore reef environment.

Remark: Recently, based on the sequence stratigraphic analysis of the Oligocene succession, in Western Iraq, the Baba Formation represents a shelf margin edge deposited in the interior parts of a ramp-like setting. The crowded larger *Lepidocyclina* spp. qualify a stressed environment, prevailed during Early Chattian time and caused by lower rates of marine water invasion and lower rate of subsidence (Al-Twaijri, 2000).

Lower Contact: The Baba Formation, in the type locality is underlain, unconformably by the Shurau Formation (Bellen *et al*., 1959), in the Central Dome of Qara Chouq anticline it is underlain conformably by Shurau Formation; the contact was based on the top of the last ruby limestone or the bottom of the first nummulitic limestone (Hagopian and Veljupek, 1977), whereas in the Southern Dome of Qara Chouq anticline, it is underlain conformably by Tarjil Formation, the contact was based on the bottom of the first appearance of massive, porous, and chalky limestone (Al-Sammarai and Al-Mubarak, 1978).

2.3.6. Bajwan Formation (Late Oligocene)

Type Locality: The Bajwan Formation was first described by Bellen in 1956 from Kirkuk structure in oil well K109 (Fig.6) as the type locality, which is defined by the following coordinates (Bellen *et al*., 1959):

Longitude	44°	18'	55"	E
Latitude	35°	33'	08"	N

Exposure Areas: The Bajwan Formation is exposed only in the Central and Northern Domes, and northeastern limb of the Southern Dome of Qara Chouq anticline (Figs.2 and 3). However, its subsurface extension is wider in the Low Folded Zone, since it was struck in many oil wells, like Qalian, Adaiyah, Ain Zala, Butmah, Gusair, Gullar, K 109 and Bai Hassan (Fig.6).

Remark: According to Bellen *et al*. (1959), the Bajwan Formation is exposed in Aj Dagh and Darbandi Sagirma, southwest of Qara Dagh. Because geological mapping does not cover these localities; therefore, the available geological maps were compiled from interpretation of aerial photographs (Ibrahim, 1984) and did not show Bajwan Formation in the aforementioned vicinities. However, Khanqa *et al*. (2009) mentioned the possible occurrence of Anah/ Ibrahim formations in the aforementioned locations, instead of Bajwan Formation.

Lithology: The Bajwan Formation, in the type locality consists of miliolids limestone, alternating with more porous, partly dolomitized, rotalid – algal reef limestone, with fairly abundant coral fragments, some thin marly interbeds occur too (Bellen *et al*., 1959). In the Central Dome of Qara Chouq anticline, the formation consists of light creamy color, hard, crystalline limestone with abundant miliolids; alternated with strings of bluish green marl, this succession is overlain by brown, coralline, dolomitic reefal limestone (Hagopian and Veljupek, 1977). In the Southern Dome of Qara Chouq anticline, the formation consists of two parts: The lower part consists of light grey, very hard, massive, porous, recrystallized and coralline limestone. The upper part consists of creamy and white, very hard, splintery, thickly bedded, recrystallized limestone, with abundant miliolids. In the Northern Dome, green marl occurs with the succession (Al-Sammarai and Al-Mubarak, 1978).

Thickness: The thickness of the Bajwan Formation in the type locality is 40 m (Bellen *et al*., 1959), in the Central Dome of Qara Chouq anticline, it is 20 m (Hagopian and Veljupek, 1977), in Qara Chouq anticline, it is 10 m and 43 m; in the Northern and Southern Domes, respectively (Al-Sammarai and Al-Mubarak, 1978).

Fossils: The following fossils were recognized in Bajwan Formation: *Praerhapydionina delicate* HENSON, *Archaias kirkukensis* HENSON, *Austrotrillina howchini* (SCHLUMBERGER), *Borelis pygmae*us HANZAWA, *Peneroplis thomasi* HENSON, *P. evolutus* HENSON, *Meandropsina anahensis* HENSON and coralline algae (Karim, 1977; Al-Biaty, 1978 and Al-Hashimi and Amer, 1985).

Age: The age of Bajwan Formation is Middle Oligocene (Bellen *et al*., 1959; Karim, 1977; Al-Hashimi and Amer, 1985), whereas Jassim and Buday in Jassim and Goff (2006) claimed Late Oligocene age for the formation.

Depositional Environment: The Bajwan Formation represents back reef facies (Henson, 1950; Bellen, 1956 in Bellen *et al*., 1959; Karim, 1977 and Al-Hashimi and Amer, 1985). According to Jassim and Buday in Jassim and Goff (2006), the formation represents reef – back reef environment.

Lower Contact: The lower contact of Bajwan Formation, in the type locality is conformable with the underlying Baba Formation (Bellen *et al*., 1959). In Qara Chouq anticline, the contact with the underlying Baba Formation is also conformable; the contact was based on the bottom of the first appearance of massive, recrystallized and coralline limestone (Hagopian and Veljupek, 1977, and Al-Sammarai and Al-Mubarak, 1978).

2.3.7. Azkand Formation (Late Oligocene)

Type Locality: The Azkand Formation was first described by Bellen in 1956 from Azkand valley in the Southern Dome of Qara Chouq anticline, about 6 Km N 60° E of the Azkand village (Fig.6) (Bellen *et al*., 1959), the coordinates were not defined.

Exposure Areas: The Azkand Formation is exposed only in Qara Chouq anticline (Figs.2 and 3). Its subsurface extension in the Low Folded Zone is clear; it was struck in many oil wells, like K 109, Kor Mor, Gusair, Ain Zala, Alan and Adaiyah (Fig.6).

Remark: Recently, some Oligocene formations were recognized from other localities, such as Aj Dagh, Qara Wais and Sagirma Dagh (Khanqa *et al*., 2009 and Sissakian and Fouad, 2012).

Lithology: The Azkand Formation, in the type locality consists generally of massive, dolomitic and recrystallized limestones (Bellen *et al*., 1959), in Qara Chouq anticline it consists of whitish grey, massive, very hard, recrystallized and dolomitic limestone, with large Lepidocyclina in the middle part. The upper 10 m consists of white, very hard, thickly bedded to massive, oolitic limestone, with reddish brown ferruginous patches (Al-Sammarai and Al-Mubarak, 1978).

Thickness: The thickness of the Azkand Formation in the type locality is about 100 m, whereas in Qara Chouq anticline it is about 110 m (Al-Sammarai and Al-Mubarak, 1978).

Fossils: The following fossils were recorded in the Azkand Formation: *Miogypsinoides complanatus* (SCHLUMBERGER), *M. dehaarti* (VAN DER VLERK), *Lepidocyclina* (*Nephrolepidina*) *morgan*i LEMOINE, *Lepidocyclina* sp., *Austrotrillina howchini* (*SCHLUMBERGER*), *A. paucialveolata* GRIMSDALE, *Rotalia viennoti* GREIG, *Heterostegina antillae* CUSHMAN, *Peneroplis thomasi* HENSON, *P. evolutus* HENSON, *Nummulites vascus* JOLY and LEYMERIE, algae and miliolids (Al-Biaty, 1978 and Al-Hashimi and Amer, 1985). *Nummulites intermedius* (D'ARCHIAC), *N. vascus* JOLY and LEYMERE, *Heterostegina assilinoides* BLANKENHORN, *Operculina complanata* (SCHLUMBERGER), *Rotalia viennoti* GREIQ, *Borelis pygmaeus* HANZAWA, Corals, algae and mollusca (Op. cit).

Age: Late Oligocene age is claimed for the Azkand Formation by the following authors: Bellen *et al*. (1959); Al-Biaty (1978); Buday (1980); Jassim *et al*. (1984) and Jassim and Buday in Jassim and Goff (2006).

Depositional Environment: The Azkand Formation represents mainly a fore slope facies of marine platform (fore reef facies), where larger foraminifera and algae were prevailed (Al-Biaty, 1978; Al-Hashimi and Amer 1985 and Jassim and Buday in Jassim and Goff, 2006).

Lower Contact: The lower contact of the Azkand Formation, in the type locality and in the whole Qara Chouq anticline with the underlying Baba Formation is unconformable (Bellen *et al*., 1959 and Al-Sammarai and Al-Mubarak, 1978).

2.3.8. Anah Formation (Late Oligocene)

Type Locality: The Anah Formation was introduced by Bellen in 1956, the type locality is located 15 Km east of Nahiyah village, west of Anah, along the Euphrates River (Fig.6); it is defined by the following coordinates (Bellen *et al*., 1959):

Longitude 43° 37' 25" E
Latitude 34° 58' 00" N

Exposure Areas: The Anah Formation is exposed only in Qara Chouq anticline (Figs.2 and 3). The subsurface extension of the Anah Formation in the Low Folded Zone is clear, it was struck in many oil wells, like Adaiyah 1, Ain Zala, Gusair 1, and K 109 (Fig.6).

Remark: According to Al-Banna (1997), the Anah Formation is exposed in Butmah East anticline. During the Regional Geological mapping carried out by Taufiq and Domas (1978), in Butmah anticline, the base of the Fatha Formation was not found (Not exposed) (Fig.2), therefore, the assumption of Al-Banna (1997) is doubtful, moreover the formation is not encountered in all drilled oil wells in Butmah anticline (I.P.C., 1963).

Lithology: The Anah Formation, in the type locality consists of "grey, breccious, recrystallized, detrital and coralline limestone" (Bellen *et al*., 1959). In the crestal part of the Qara Chouq anticline, the formation consists of light grey, thickly bedded, coralline limestone overlain by creamy to grey, splintery, well bedded, shelly, recrystallized reefal limestone (Hagopian and Veljupek, 1977). In Qara Chouq anticline, the formation consists of creamy and whitish grey recrystallized, dolomitized, very hard, splintery, thickly bedded to massive, occasionally chalky, and shelly limestone (Al-Sammarai and Al- Mubarak, 1978).

Thickness: The thickness of the Anah Formation, in the type locality is 45 m (Bellen *et al*., 1959), in the Central Dome of Qara Chouq anticline, it is 30 m (Hagopian and Veljupek, 1977), in Qara Chouq anticline, it is 32 m in the Southern Dome, and ranges between (6 – 8) m in the Northern Dome (Al-Sammarai and Al-Mubarak, 1978).

Fossils: The following fossils were recorded in Anah Formation by Bellen *et al*. (1959); Raji (1977) and Buday (1980): *Miogypsinoides complanatus* (SCHLUMBERGER), *Archaias asmaricus* SMOUT and EAMES, *A. Hensoni* SMOUT and EAMES, *A. kirkukensis* HENSON, *Peneroplis thomasi* HENSON, *P. evolutus* HENSON, *Austrotrillina howchini* (*SCHLUMBERGER*), *A. paucialveolata* GRIMSDALE, *Borelis pygmaeus* HANZAWA, *Lepidocyclina* sp., *Rotalia viennoti* GREIG, *Meandropsina anahensis* HENSON, *Praerhapydionina delicata* HENSON, *Heterostegina* sp., *Dentritina* sp., *Subterraniphyllum thomasi*, and corals.

Age: The age of Anah Formation is Late Oligocene (Bellen *et al*., 1959), whereas Karim (1977); Al-Biaty (1978) and Jassim and Buday in Jassim and Goff (2006) claimed Late or Uppermost Oligocene age for the formation.

Depositional Environment: The depositional environment of the Anah Formation represents reef – back reef facies (Bellen, 1956 in Bellen *et al*., 1959; Buday, 1980; Karim, 1977; Al-Biaty, 1978 and Jassim and Buday in Jassim and Goff, 2006).

Remark: The second Upper Oligocene Cycle, the Azkand Formation, which is followed by the Anah Formation, was developed in a transgressive system tract (transgressive phase); in its lower part (Azkand Formation), and a high system tract (Anah Formation); in its upper part. The filling of the shallowing basin is indicated by a maximum flooding surface, which is indicated by colonial corals dominated sequence (Al-Twiajiri, 2000). The shallowing upward cycle could be inferred within the deposition of the Azkand Formation too, where it was developed through the older *Miogypsinoides* – *Lepidocyclina* faunal zone and the younger *Miogypsinoides* faunal zone of Bellen (1956) in Bellen *et al*. (1959).

Lower Contact: The Anah Formation, in the type locality is underlain conformably by the Azkand Formation (Bellen *et al*., 1959). In Qara Chouq anticline, it is underlain by Bajwan Formation, the contact is marked by (2 – 4) m thick basal conglomerate (Hagopian and Veljupek, 1977 and Al-Sammarai and Al-Mubarak, 1978).

2.4. Early – Middle Miocene

The Savian movements caused development of broad and shallow basins in which carbonates were deposited, with small closed basins in which evaporates were deposited. The five formations of this epoch are exposed only in restricted areas, except the last one, which is the Fatha Formation, where it covers considerable parts of the Low Folded Zone (Figs.2, 3, 4 and 5). The sequence is represented by five formations, these are:

2.4.1. Serikagni Formation (Early Miocene)

Type locality: The Serikagni Formation was introduced by Bellen in 1955, the type locality is at Bara village in Sinjar mountain (Fig.6), which is defined by the following coordinates (Bellen *et al*., 1959):

Longitude	41°	29'	00"	E
Latitude	36°	20'	30"	N

Exposure Areas: The Serikagni Formation is exposed only in Sinjar anticline (Fig.2). However, the subsurface extension of the formation is wider, since it was struck in many oil wells, like Sasan 1, Qalian 1, Ibrahim 1, Adaiyah 1, Jambur, Pulkhana 1, Injana 5, Himreen 1 (Fig.6).

Lithology: The Serikagni Formation in the type locality consists of globigerinal, chalky limestone with few more calcareous bands (Bellen *et al*., 1959). In Sinjar anticline, Ma'ala (1977) recognized four lithofacies, these are: **1)** White to whitish grey thinly bedded marly limestone alternated with thin beds of yellowish and brownish grey sandy limestone. This succession is overlain by conglomerate (0.2 – 2 m thick) and calcareous sandstone (0.5 – 1 m thick). The conglomerate consists of angular to subrounded chert fragments (30 – 50 cm) and well rounded limestone pebbles (5 – 10 cm), cemented by calcareous and ferruginous materials. **2)** Whitish and greenish grey, well bedded marly limestone alternated with greenish grey, thinly bedded marl. **3)** Whitish grey, thinly bedded limestone, the middle part consists of massive white limestone. **4)** White, thinly bedded marly limestone alternated with grey, thinly bedded hard, fine crystalline limestone.

Remark: Ma'ala (1977) mentioned that the Euphrates Formation forms tongues within the Serikagni Formation and is present between the aforementioned second and third lithofacies.

Thickness: The thickness of the Serikagni Formation in the type locality is 150 m (Bellen *et al*., 1959). It is 305 m and 150 m in the eastern and western parts of Sinjar Mountain, respectively (Ma'ala, 1977).

Fossils: The following fossils were recognized in the Serikagni Formation by Amer (1977 and 1979) and Al-Hashimi and Amer (1985): *Globigerina praebulloides* BLOW, *G. venezuelana* HEDBERG, *Globorotalia kugleri* BOLLI, *Gl. archeomenardii* BOLLI, *Globigerinoides primordius* BLOW, *Gs. trilobus* (REUSS), *Gs. immaturus* LEROY, *Gs. subquadratus* BRONNIMANN, *Gs. sacculiferous* (BRADY), *Gs. sicanus* DESTEFANE, *Catapsydrax stainforthi* BOLLI, LOEBICH and TAPPAN and *Globoquadarina dehiscense* CHAPMAN.

Age: The age of the Serikagni Formation is Early Miocene (Amer, 1977 and 1979; Ma'ala, 1977; Al-Hashimi and Amer, 1985 and Jassim and Buday in Jassim and Goff, 2006).

Depositional Environment: The depositional environment of the Serikagni Formation is deep water, basinal facies of warm sea with normal salinity (upper bathyal zone) (Amer, 1977 and 1979 and Al-Hashimi and Amer, 1985).

Lower Contact: The Serikagni Formation in the type locality is underlain unconformably by Jaddala Formation, the unconformity is demonstrated by the absence of Oligocene rocks

(Bellen *et al*., 1959). In Sinjar anticline, it is underlain unconformably by Jaddala Formation, the contact was based on the bottom of a conglomeratic limestone and chert, in Goulat anticline, calcareous sandstone is present instead if the conglomerate (Ma'ala, 1977).

2.4.2. Euphrates Formation (Early Miocene)

Type Locality: The Euphrates Formation was introduced by De Boechkh *et al*. (1929) and was amended by Bellen in 1957, the type locality is along wadi Fhaimi, near the police post (Fig.6), it is defined by the following coordinates (Bellen *et al*., 1959):

Longitude	42°	08'	09"	E
Latitude	34°	15'	58"	N

Remark: It is worth to mention that the type locality of the Euphrates Formation is inundated by Haditha Dam Lake. Moreover, the chosen type locality by Bellen *et al*. (1959) is not a representative one. Jassim *et al*. (1984) recommended a supplementary type section at wadi Chab'bab, in Anah vicinity (Fig.6), for the Lower and Middle Units (A and B) and another supplementary type section, at wadi Rabi, in Anah vicinity (Fig.6) for the Upper Unit (C). However, the Upper Unit (C) was found to be another formation, which was named as Nfayil Formation (Sissakian *et al*., 1997).

Exposure Areas: The Euphrates Formation is exposed in Dahqan, Ain Zala, Butmah, and Mushurah anticlines (Taufiq and Domas, 1977); it is exposed as tongues within the Serikagni Formation in Sinjar vicinity (Ma'ala, 1977). It is exposed west of Mosul vicinity in Alan, Atshan, and Sheikh Ibrahim anticlines (Mohi Ad-Din *et al*., 1977). It is exposed along the southwestern limb of Ain Sifni anticline (Hagopian *et al*., 1982), it is interfingering always with the Dhiban Formation in Makhoul anticline (Al-Mubarak and Youkhanna, 1976), it is also exposed in Qara Chouq anticlines (Al-Samarrai and Al-Mubarak, 1978) (Figs.2, 3 and 4). It is also exposed overlying the Oligocene rocks, which overlie the Pila Spi Formation in many localities, like Aj Dagh, Darbandi Bazian, Sagirma, (Khanqa *et al*., 2009) and Qara Wais anticlines. The subsurface extension of the Euphrates Formation is clear, with very wide extension, since it was struck in many oil wells, like Qalian, Gullar, Gusair, Ain Zala, Butmah, Alan, Ibrahim, Adaiyah, Atshan, Najmah, Qaiyarah, Qasab, Hibbarah, Najmah, Qara Chouq, Makhoul, Pulkhana, Injana, Himreen, Jambur, Cham Chamal, Kor Mor (Fig.6).

Remark: In Maqloub, Ba'shiqa and Ain Al-Safra anticlines, Barwary (1983) recognized *Miogypsina* spp. in the limestone pebbles of the basal conglomerate of the Fatha Formation, which is underlain unconformably by Pila Spi Formation; he believes that the presence of this fossil may indicate the presence of the Euphrates Formation overlying the Pila Spi Formation. The authors confirm this assumption and believe that the Euphrates Formation is exposed there, but not differentiated in the field from the underlying Oligocene rocks and Pila Spi Formation, due to the large lithological similarity.

Lithology: The Euphrates Formation in the type locality consists of "Shelly, chalky, well bedded recrystallized limestone" (Bellen *et al*., 1959). The supplementary type section proposed by Jassim *et al*. (1984) consists of: **1) Lower Unit (A)** consists of 20 m of basal conglomerate, with subrounded limestone boulders and pebbles, mainly derived from Anah Formation. The conglomerate is followed by 10 m of recrystallized, fossiliferous limestone, changing to coralline limestone. **2) Middle Unit (B)** consists of alternation of hard limestone and pseudoolitic limestone. In Makhoul anticline, the formation consists of pale grey and brownish grey, hard, thickly bedded to massive; in the lower part and thinly bedded; in the upper part, slightly bituminous limestone, with some sulfur crystals (Al-Mubarak and

Youkhanna, 1976). "In Dahqan anticline, the formation consists of white to pale grey, moderately hard, massive to poorly bedded, fossiliferous, and finely crystalline dolostone. In Butmah anticline, it consists of white, fine to medium crystalline, oolitic dolostone. In Mushurah anticline, it consists of yellowish grey, thinly bedded to massive, hard, cavernous, slightly fossiliferous dolostone with one bed (5.5 m thick) of green calcareous claystone" (Taufiq and Domas, 1977). In Sinjar vicinity, it consists of three layers (0.3 – 1 m thick, each) of grey, hard, fine crystalline, fossiliferous limestone, the limestone layers are separated by green marly limestone layers (5 – 10 m thick) (Ma'ala, 1977). "In west of Mosul vicinity, the formation consists of grey to brown, hard, recrystallized, bedded to massive dolomitic limestone, with some chert nodules. The middle part consists of grey to whitish grey, very hard, thinly bedded, locally fossiliferous and cavernous limestone. The upper part consists of grey to pink and light grey, recrystallized, fossiliferous, well bedded dolomitic limestone, the uppermost part is brecciated" (Mohi Ad-Din *et al*., 1977). In Ain Sifni anticline, the formation consists of yellowish white and grey, fossiliferous, recrystallized, well bedded, hard to very hard, sandy to silty limestone with very rare chert nodules (Hagopian *et al*., 1982). In the Central Dome of Qara Chouq anticline, the formation consists of basal conglomerate with pebbles up to 15 cm in size, overlain by grey and brownish grey, crystalline, fossiliferous, locally dolomitized, thinly to thickly bedded and hard limestone with rare chert nodules (Hagopian and Veljupek, 1977). In Qara Chouq structure, the formation consists of yellowish grey, hard, thinly bedded; in the lower part and thickly bedded; in the upper part, recrystallized, fossiliferous limestone, occasionally shelly and chalky (Al-Sammarai and Al-Mubarak, 1978).

Remark: In Butmah anticline, a gypsum bed of 5 m thickness was mapped overlying the Euphrates Formation; it might represent the Dhiban Formation, since it is encountered in nearby oil wells like Ain Zala 2 and Gullar 1 (Taufiq and Domas, 1977).

Thickness: The thickness of the Euphrates Formation in the type locality is 8 m (Bellen *et al*., 1959) and in the supplementary type section is 110 m (Jassim *et al*., 1984). In Dahqan anticline it is 16 m, in Butmah anticline the exposed thickness is 15 m, in Mushurah it is 70 m (including the Jeribe Formation) (Taufiq and Domas, 1977). In Makhoul anticline, it is 27 m (with the Dhiban Formation) (Al-Mubarak and Youkhanna, 1976). In Ain Sifni anticline, it ranges between (2.5 – 18) m (Hagopian *et al*., 1982). In Sinjar anticline, it ranges between (2 – 30) m (Ma'ala, 1977); in Mosul vicinity, it ranges between (26 – 50) m (Mohi Ad-Din *et al*., 1977). In the Central Dome of Qara Chouq anticline, it ranges between (20 – 30) m (Hagopian and Veljupek, 1977), in Qara Chouq structure it is 13 m and 15 m in the Northern and Southern Domes, respectively (Al-Sammarai and Al-Mubarak, 1978).

Fossils: The following fossils were recognized in the Euphrates Formation by different authors in different localities:*Peneroplis evolutus* HENSON, *P. farsensis* HENSON, *Archaias* sp., *Robulus* sp., *Quinqueloculina akneriana* D'ORBIGNY, *Triloculina* sp., *Cythereis* sp., *Cyprideis* sp., *Hydrobia* sp., *Macoma* sp., *Miogypsina globulina* MICHELOTTI, and *Borelis melo melo* FICHTEL and MOLL. *Triloculina asymetrica* SALD, *T. asperula* CUSHMAN, *Quinqueloculina acuta* HUSSEN, *Spiroloculina sp*., *Elphidium advantum* CUSHMAN, *Bolivina shukrii* SOAYA, *Bolimina ovata* D'ORBIGNY, *Cibicides lobatulus* WALKER, *Ostrea latimarginata* UREBENBURG, *Ostrea verieti* DESHAYES, *Clausinella* sp.and *Chlamus* c.f. *varia* LINNE (Al-Biaty, 1978 in Makhmour area). *Turritella angulara* BROCCHI, *Murex* sp., *Actaeon* sp., *Conus* sp., *Ficus conditus* (BRONGNIART), *Glycymeris pilosus* LINNAEUS, *Arca turonica* DUJARDIAN, *Phacoides* c.f. *Columbella* LAMARCK, *Divericella* sp., *Cardium* sp., *Chama gryphoides* UNNAEUS, *Modiolus*. *increassatus*

D'ORBIGNY. *Modiolus invrassatus* D'ORBIGNY, *Tapes vetulus* BAST, *Trochus nefa* KCLESNIKOV *Corbula gibba* OLIVI, *Divercella ornata* AGASSUZ, *Cardium facetum* ZHIZHCHENKO, *Modiolus conditus* MAYER and *Glycymeris pilosus* LINNAEUS.

Age: The age of the Euphrates Formation, depending on the aforementioned fossils is Early Miocene (Early – Late Burdigalian) confirmed by the presence of *Miogypsinaglobulina* and *Miogypsina intermedia*. All the involved authors agree upon this age.

Depositional Environment: The depositional environment of the Euphrates Formation is marine, warm tropical to subtropical, with reef – back reef, near shore (10 – 50) m depth (Jassim *et al*., 1984).

Lower Contact: The Euphrates Formation, in the type locality is underlain unconformably by Anah Formation (Bellen *et al*., 1959). In Dahqan anticline, the Euphrates Formation is underlain unconformably by the Pila Spi Formation; the contact was based on the top of the last chert bearing limestone. In Mushurah anticline, it is underlain unconformably by the Avanah Formation (no details of the contact was mentioned), whereas in Mushurah and Butmah anticlines the base of the Euphrates Formation is not exposed (Taufiq and Domas, 1077). West of Mosul vicinity, the lower contact of the formation is not exposed except in Atshan anticline; there, the formation is underlain unconformably by Avanah Formation; the contact is marked by 15 m thick breccia (Mohi Ad-Din *et al*., 1977). In Ain Sifni anticline, the formation is underlain unconformably by Pila Spi Formation, the contact is marked by a conglomerate bed (about 2 m thick); the pebbles are mainly of Pila Spi Formation, when the conglomerate is absent, then the contact is based on the bottom of the first grey claystone or marl (Hagopian *et al*., 1982). In Makhoul anticline, it is underlain conformably by the underlying Kalhur Gypsum, the contact was based on the bottom of the thick limestone bed (Al-Mubarak and Youkhanna, 1976). In Sinjar anticline, it is developed as tongues within the Serikagni Formation (Ma'ala, 1977). In Qara Chouq structure, it is underlain unconformably by Anah Formation, the contact is marked by (2 – 3) m thick basal conglomerate (Hagopian and Veljupek, 1977, and Al-Sammarai and Al-Mubarak, 1978).

Remark: In Makhoul anticline, at many deeply cut valleys, Al-Mubarak and Youkhanna (1976) recognized a thick gypsum sequence and mapped it as the "Kalhur Gypsum" representing the underlying rocks of the Euphrates Formation. The gypsum is white, massive, interbedded with two thin beds (about 40 – 50 cm; each) of grey, hard bedded, fine crystalline limestone. The exposed thickness of the "Kalhur Gypsum" is about 10 m. In the authors opinion, the so called "Kalhur Gypsum" is a part of the Dhiban Formation, although Al-Mubarak and Youkhanna (1976) explained the reason for their claim, which depends on the thickness of the "Kalhur Gypsum" (about 10 m). They claimed that no such thickness is present in Dhiban Formation, and because the Dhiban Formation interfingers only with the upper part of the Euphrates Formation. The present authors attributed their opinion to the absence of "Kalhur Gypsum" in the nearby vicinities and at many drilled oil wells in near by surroundings, in which no "Kalhur Gypsum" was encountered. Its supposed location bellow the Euphrates Formation (Al-Mubarak and Youkhanna, 1976) could be explained by the assumption that the recognized gypsum is not bellow the bottom of the Euphrates Formation, since the bottom of the gypsum (Kalhur Gypsum) is not exposed and most possibly below the gypsum; the Euphrates Formation still may be present (in subsurface). Therefore, the authors believe that the gypsum belongs to the Dhiban Formation.

2.4.3. Dhiban Formation (Early Miocene)
Type Locality: The Dhiban Formation was introduced by Henson in 1940 and amended by Bellen in 1957, the type locality is near Umm ad Dhiban, 1400 m east of a ruined caracole, in Sinjar vicinity (Fig.6); it is defined by the following coordinates (Bellen *et al*., 1959):

Longitude 41° 21' 32" E
Latitude 36° 16' 25" N

Exposure Areas: The Dhiban Formation is exposed as tongues between Jeribe and Serikagni formations, in Sinjar vicinity (Ma'ala, 1977), and in Makhoul vicinity, it interfingers with the upper part of the Euphrates Formation (Al-Mubarak and Youkhanna, 1976) (Figs.2 and 3). The subsurface extension of the Dhiban Formation is almost clear it was struck in many oil wells, like Sasan, Ain Zala, Gullar, Mushurah, Hibbarah, Jawan, Khanuga, Qaiyarah, Najmah, Injana, Himreen, Qumar (Fig.6).

Remark: In Butmah anticline, a gypsum bed of 5.5 m thick was mapped overlying the Euphrates Formation, doubtfully represents the Dhiban Formation (Taufiq and Domas, 1977).

Lithology: The Dhiban Formation in the type locality consists of "thick beds of gypsum, interbedded with thin beds of marl and brecciated and recrystallized limestone" (Bellen *et al*., 1959). In Makhoul vicinity, the formation consists of white, massive anhydrite, and it is present as thin horizons or lenses (Al-Mubarak and Youkhanna, 1976). In Sinjar anticline, the formation consists of thick beds of gypsum interbedded with yellowish grey marly limestone and fine crystalline limestone (Ma'ala, 1977).

Thickness: The thickness of the Dhiban Formation in the type locality is 72 m (Bellen *et al*., 1959); in Sinjar anticline, it ranges between (65 – 100) in Jeribe mountain, and 40 m as exposed thickness in Sinjar and Goulat mountains (Ma'ala, 1977); in Makhoul anticline it is 27 m (with the Euphrates Formation) (Al-Mubarak and Youkhanna, 1976).

Fossils: No fossils were recognized in the Dhiban Formation.

Age: The age of the Dhiban Formation as indicated from its stratigraphic position is Early Miocene **(**Amer, 1977; Ma'ala, 1977; Al-Sammarai and Al-Mubarak, 1978; Buday, 1980 and Jassim and Buday in Jassim and Goff, 2006).

Depositional Environment: The Dhiban Formation was deposited under lagoonal – evaporitic condition (Amer, 1977 and Behnam, 1977)**,** whereas Jassim and Buday in Jassim and Goof (2006) considered that the formation was deposited in basin-centered Sabkhas and salines.

Lower Contact: The Dhiban Formation, in the type locality, is underlain conformably by Euphrates Formation (Bellen *et al*., 1959), in Makhoul anticline it is always interfingering with the Euphrates Formation (Al-Mubarak and Youkhanna, 1976), in Sinjar vicinity it is developed as tongues within the Jeribe Formation or underlain conformably by Serikagni Formation, the contact is sharp due to lithological change (Ma'ala, 1977).

2.4.4. Jeribe Formation (Middle Miocene)
Type Locality: The Jeribe Formation was introduced by Damensin in 1936, then was defined by Bellen in 1957 from Sinjar Mountain, near Jaddala village, it is defined by the following coordinates (Bellen *et al*., 1959) (Fig.6):

Longitude 41° 41' 00" E
Latitude 36° 18' 00" N

Exposure Areas: The Jeribe Formation is exposed in Sinjar anticline, west of Mosul vicinity; in Atshan, Nuwaigeet and Sheikh Ibrahim anticlines, also in Mushurah, Alan, Qara Chouq, and Makhoul anticlines (Figs.2 and 3). The subsurface extension is wider, since it was struck in many oil wells, like Mushurah, Gullar, Ain Zala, Butmah, Alan, Sasan, Ibrahim, Adaiyah, Hibbarah, Qaiyarah, Sadid, Qasab, Qalian, Najmah, Qara Chouq, Bai Hassan, Jambur, Cham Chamal, Kor Mor, Pulkhana, Injana, Himreen (Fig.6).

Remarks:

1) In Mashurah anticline, Taufiq and Domas (1977) mapped a carbonate sequence of 70 m thick, they considered the sequence as Euphrates and Jeribe formations, but they could not differentiate them in the field.

2) From reviewing the data of the aforementioned oil wells, it is clear that the Jeribe Formation was encountered in many oil wells, but not on surface exposures. In the authors opinion, the reason is the large similarity between the lithology of the Jeribe and Euphrates formations, therefore, the Jeribe Formation most probably was grouped with the Euphrates Formation during the geological mapping of the Low Folded Zone.

Lithology: The Jeribe Formation, in the type locality consists of "Limestone, recrystallized and dolomitized, generally massive, with beds of (3 – 6) feet (0.3 – 2.6 m) in thickness. The top is obscured; however, it is capped by 50 feet (15.5 m) of gravels. The gravels almost certainly replace the anhydrite, which normally exist at the base of the Lower Fars Formation" (Bellen *et al*., 1959). In Makhoul anticline, the formation consists of brownish grey and white, very hard, thinly bedded; in the lower part and thickly bedded to massive; in the upper part, fossiliferous limestone (Al-Mubarak and Youkhanna, 1976). In Sinjar vicinity, the formation consists of four main facies, from bottom to top: **1)** Yellowish grey to whitish grey, very hard, thickly bedded, fossiliferous limestone, which is underlain by (1.5 – 2) m thick basal fragmented limestone. The thickness of this facies is 24 m. **2)** Alternation of dolomitic limestone and chalky limestone, both are laminated to thinly bedded. The thickness of this facies is 39 m. **3)** Whitish to yellowish grey, bedded to massive conglomeratic limestone. The gravels are rounded to angular, up to 10 cm in size, and highly fossiliferous. The thickness of this facies is 38 m. **4)** Yellowish grey, hard, fossiliferous limestone, occasionally with aphanitic and fossiliferous limestone. Locally, this succession is alternated with laminated calcareous sandstone. The thickness of this facies is 25 m (Ma'ala, 1977). In west of Mosul vicinity, the formation consists of white to grey, fossiliferous, dolomitic limestone interbedded with whitish grey, oolitic, bedded, chalky and shelly, hard limestone, with chert nodules (Mohi Ad-Din *et al*., 1977). In the Central Dome of Qara Chouq anticline, the formation consists of white, chalky, oolitic, shelly, marly limestone; which includes rare chert nodules, interbedded with white to light grey, thinly to thickly bedded, hard dolomitic limestone, whereas in Alan anticline it consists of light grey, fossiliferous, fine crystalline dolostone (Hagopian and Veljupek, 1977). In Qara Chouq structure, the formation consists of whitish grey to yellowish grey, very hard, thinly bedded; in the lower part and thickly bedded to massive; in the upper part, recrystallized and dolomitic limestone, occasionally dolomitic and oolitic (Al-Sammarai and Al-Mubarak, 1978).

Thickness: The thickness of the Jeribe Formation, in the type locality is 73 m (Bellen *et al*., 1959), in Makhoul anticline it is 18 m (Al-Mubarak and Youkhanna, 1976), in Sinjar anticline it ranges between (100 – 126) m (Ma'ala, 1977), west of Mosul vicinity it ranges between (25 – 50) m (Mohi Ad-Din *et al*., 1977), in the Central Dome of Qara Chouq anticline it ranges between (18 – 25) m (Hagopian and Veljupek, 1977), in Qara Chouq structure it is

31 m and 26 m in the Northern and Southern Domes, respectively (Al-Sammarai and Al-Mubarak, 1978).

Fossils: The following fossils are recorded from Jeribe Formation by Amer (1977); Karim (1977) and Al-Biaty (1978): *Borelis melo melo* (FITCHEL and MOLL), *Borelis melo curdica* REICHEL, *Peneroplis farsensis* HENSON, *Meandropsina anahensis* HENSON, *Amphistegina* sp., *Elphidium* sp., *Ammonia beccarii* (LINNE), *Dentritina* sp.,miliolids, algaeandshell fragments.

Age: The age of Jeribe Formation is Middle Miocene, as agreed upon by all the involved authors.

Depositional Environment: The Jeribe formation is homogenous in lithology and in faunal assemblage's content. It reflects a restricted environment on marine platform, mainly of lagoonal facies, of calm and warm water, with relatively high salinity (Henson, 1950; Bellen *et al*., 1959 and Al-Hashimi and Amer, 1985). According to Al-Mubarak and Youkhanna (1976), the depositional environment of the formation was shallow, near shore warm marine.

Lower Contact: The Jeribe Formation in the type locality is underlain unconformably by the Serikagni Formation (Bellen *et al*., 1959), in Makhoul anticline, it is conformably underlain by the Dhiban Formation; the contact was based on the top of the last anhydrite bed (Al-Mubarak and Youkhanna, 1976). West of Mosul vicinity, it is conformably underlain by the Euphrates Formation; the contact is not sharp and clear, therefore, both formations were mapped together; however, the contact was proved paleontologically, except in Alan anticline where the contact is marked by semi-brecciated limestone (Mohi Ad-Din *et al*., 1977). In the Central Dome of Qara Chouq anticline, the contact is not sharp and problematic; either conformable or unconformable with the underlying Euphrates Formation, locally a conglomerate bed is developed (Hagopian and Veljupek, 1977). In Qara Chouq structure, it is underlain by Euphrates Formation (Al-Sammarai and Al-Mubarak, 1978). In Sinjar vicinity, it is conformably underlain by Dhiban Formation, the contact is based on the top of the last gypsum bed, when the Dhiban Formation is not developed, then Jeribe Formation is underlain unconformably by Serikagni Formation (Ma'ala, 1977).

Remark: The authors are not in accordance with the probable unconformable contact, which was mentioned by Hagopian and Veljupek (1977) between Jeribe and Euphrates formations, due to the conglomeratic nature of the rocks in the contact. This could be due to a local tectonic affect or due to diagenetic processes, like dolomitization.

2.4.5. Fatha Formation (Middle Miocene)

The Fatha Formation was formerly known as the Lower Fars Formation, it was introduced by Busk and Mayo in 1918, without mentioning the type locality. However, Ion *et al*. (1951) in Bellen *et al*. (1959) described the formation from Agha Jari oil field of southwest Iran (Bellen *et al*., 1959). Jassim *et al*. (1984) introduced the name of Fatha Formation, which was adopted by the geologists of GEOSURV since 1984. However, Al-Rawi *et al*. (1992) announced, officially the name of the Fatha Formation. It is worth mentioning that the name of the Lowe Fars Formation is abandoned in Iran, and renamed as Gachsaran Formation.

Type Locality: The type locality of the Fatha Formation is in Makhoul Range, it is defined by the following coordinates (Fig.6) (Jassim *et al*., 1984 and Al-Rawi *et al*., 1992):

Longitude 43° 21' 15'' E
Latitude 35° 10' 00'' N

It is worth to mention that Al-Rawi *et al*. (1992) adopted the same aforementioned type locality and they suggested a supplementary type locality in oil well Gillabat 3.

Exposure Areas: The Fatha Formation is exposed widely in the Low Folded Zone (Figs.2, 3, 4 and 5), whereas its subsurface extension is wider, since it is present wherever the younger formations (Injana, Mukdadiya and Bai Hassan) are exposed.

Lithology: The Fatha Formation consists of cyclic sediments, each ideal cycle consists of green marl, limestone and gypsum, however, in the upper half part of the formation, reddish brown claystone is present over the green marl, moreover, in the uppermost parts; reddish brown clastics are developed within the cycles too. The cycles, however may be incomplete in many areas, then one of the main constituents might be absent. The three main constituents show large variations in their characteristics and thickness, manifesting the basin configuration, in certain areas. Moreover, the main constituents exhibit lateral and vertical variations, even in a short distance.

Many authors introduced different subdivisions for the rocks of the Fatha Formation, however, the most used and applicable one is that introduced by Al-Mubarak and Youkhanna (1976); latter on it was used almost in all parts of the Low Folded Zone, although some modifications were introduced in many localities. This was either due to the possibility of introducing farther details; in some localities in some units; like Unit A, west of Mosul vicinity, where Mohi Ad-Din *et al*. (1977) subdivided the Unit A into four subunits, or due to large similarities between the units, like Unit E and F. The two units were grouped together almost all over the Low Folded Zone. Therefore, only the details of the units, as described by Al-Mubarak and Youkhanna (1976) are presented hereinafter, with general description for the main constituents of the formation, with many remarks as presented by different authors from different localities.

According to Al-Mubarak and Youkhanna (1976), the Fatha Formation in Makhoul – Mosul area was divided into two members: Lower and Upper Members, farther more each member was subdivided into three units: A, B and C, for the former and D, E and F for the latter. However, the last two units were merged together during the mapping of the majority of the Low Folded Zone. The six units are described briefly, hereinafter; it is worth mentioning that the thickness of each unit is not mentioned, because it is highly variable even within a local area.

Unit A: This unit is characterized by the dominance of thick gypsum beds, usually (2 – 3) cycles are developed. Occasionally, the gypsum is replaced by limestone or bitumen and sulphur. Locally, each cycle consists of two thick gypsum beds alternated by two thick limestone beds, which occasionally are alternated with thin green marl. The contact of this unit with the overlying Unit B is based on the bottom of thick massive gypsum, or on the top of the second thick limestone bed of Unit A.

Unit B: This unit is characterized by very thick gypsum beds (usually more than 10 m) alternated with very thin (20 – 25 cm) limestone beds. The contact of this unit with the overlying Unit C is based on the bottom of a thick massive limestone, or on the top of the last thick gypsum bed of Unit B.

Unit C: This unit is characterized by its mono-lithology; being consists of limestone beds only**.** The limestone is pale grey to white, highly fossiliferous, thinly well bedded to massive, very hard, splintery, scarp forming, occasionally bituminous or chalky, cavernous; the cavities are filled by secondary calcite. Very rarely, thin green marl and/ or gypsum horizons may occur as sandwiched between the limestone beds. The contact of this unit with the overlying Unit D is based on the bottom of thick massive gypsum, or on the top of the last thick limestone bed of Unit C.

Remark: This unit forms the contact between the Lower and Upper Members of the Fatha Formation; it is a well-recognizable marker in the field and very clearly traceable in aerial photographs and Landsat images, locally as well as in topographic maps at scale of 1: 25000.

Unit D: This unit is characterized by cyclic nature (about 8 – 12 cycles were recorded in different localities), each cycle consists of gypsum, green marl, reddish brown claystone and limestone, moreover, it is a gypsum dominant unit, where the gypsum beds are very thick; up to 40 m in Pulkhana anticline (Sissakian, 1978). Local variations are common, as the absence (very rarely) of the main constituents or lateral lithological changes. This unit was father subdivided into two subunits, namely Subunit D1 and Subunit D2, a well recognizable limestone bed (1 – 1.5 m thick); in the field forms the contact between the two subunits. It was mapped almost everywhere in the Low Folded Zone. The claystone beds in the uppermost part may contain lenses and/ or horizons (0.5 – 2 m thick) of reddish brown or green sandstone. The contact of this unit with the overlying Unit E is based on the bottom of a thick (6 – 8 m thick) reddish brown claystone bed, within Unit E.

Unit E: This unit is characterized by thick claystone (6 – 8 m) and gypsum (5 – 8 m) beds and thin limestone (0.1 – 0.7 m) beds, usually (2 – 3) cycles are developed. The reddish brown claystone beds changes upwards to green marl, in the uppermost parts; sandstone lenses and/ or horizons (0.5 – 1 m thick) may occur. The contact with the overlying Unit F is not sharp; it was based on the bottom of the first thin (2 – 5 m thick) reddish brown claystone bed.

Unit F: This unit is characterized by thick gypsum beds that range between (8 – 20) m and its cyclic nature, usually (3 – 6) cycles are developed, each cycle consists of relatively thin (2 – 5 m) reddish brown claystone and green marl, limestone (0.2 – 0.4 m thick); occasionally is absent, and gypsum. In the uppermost parts, the claystone beds contain lenses and/ or thin horizons (0.15 – 2 m) of reddish brown or greenish grey siltstone and sandstone, which very rarely include thin beds (0.5 – 1 m) of white gypsum.

Remarks:

1) As it is clear from the description of the aforementioned contact, between Units E and F, the contact is not sharp and clear, and then it could be easily missed in the filed. Therefore, the two units were merged together in the whole area of the Low Folded Zone, during the regional geological mapping, and were called as Unit E and F.

2) In Makhoul structure, a **Transitional Zone** is mapped as a separate unit in the lower part of the Fatha Formation. It consists of two parts: Lower part consists of white, massive gypsum interbedded with two thin horizons (30 – 50 cm, each) of brownish grey, very hard bituminous limestone and crystalline limestone. The upper part consists of white, hard, thinly bedded to massive intraclastic limestone (Al-Mubarak and Youkhanna, 1976).

3) West of Mosul vicinity**,** Mohi Ad-Din *et al*. (1977) subdivided the **Unit A** of the Fatha Formation into four subunits, which are developed only in this part of the Low Folded Zone**.** The four subunits are described briefly hereinafter.

Subunit A1 (Limestone – Claystone), consists of two parts: Lower part, consists of yellowish green, thinly bedded and fossiliferous marl interbedded with green, fossiliferous and hard marly limestone. Grey, bituminous limestone is often present, which includes lenses of gypsum up to 5 m thick. The upper part consists of greyish white, thinly bedded, intraclastic limestone. The thickness of this subunit ranges between (25 – 50) m.

Subunit A2 (Gypsum), consists of white, compacted and massive gypsum, the thickness of this subunit ranges between (8 – 20) m.

Subunit A3 (Gypsum – Limestone), consists of cyclic deposits, each cycle consists of yellowish green marl, yellowish green, oolitic limestone and whitish grey, hard gypsum; occasionally includes thin beds and/ or nodules of halite, chert nodules up to 10 cm, and bitumen. The thickness of this subunit ranges between (50 – 90) m.

Subunit A4 (Marly Limestone), consists of light grey, thinly bedded, fossiliferous limestone, mainly dolomitic and recrystallized, occasionally bituminous and oolitic. Locally, the limestone is interbedded with yellowish and grayish green, fossiliferous marly limestone. The thickness of this subunit ranges between (8 – 20) m.

4) The aforementioned subdivisions of Mohi Ad-Din *et al*. (1977) are not applicable in Mosul vicinity, east, and southwards, because the subunits decrease in thickness and merge to each other to form the normal **Unit A**. This is due to the effect of Mosul High, which had deceased the depth of the basin.

5) In the north of Mosul city, at Masr'ra anticline and the eastern part of Alan anticline, the whole Lower Member of the Fatha Formation consists of carbonate rocks interbedded with marl, with thickness of 52 m and 33m, respectively. Therefore, the informal **Units A, B** and **C** are not distinguishable and were not mapped (Hagopian and Veljupek, 1977). Moreover, they claimed that north of Mosul city at Ba'shiqa, Ain Al-Safra and Numrood vicinities, the Fatha Formation was mapped as "**Undifferentiated Unit**" with thickness ranges between (25 – 35) m, because the informal units are not developed and the reddish brown claystone (mudstone) prevails in the whole sequence. Therefore, they believe that the sequence there is equivalent to the Upper Member of the Fatha Formation.

6) The authors are not in accordance with the aforementioned assumption of Hagopian and Veljupek (1977). Because the absence of the Lower Member of the Fatha Formation, in the aforementioned area, means the presence of an unconformity that had eroded the Lower Member of the Fatha Formation. However, no such event was recorded elsewhere within the Fatha Formation during Middle Miocene. Therefore, the authors believe that the Fatha Formation is fully exposed, but with special development, which represents the marginal part of the depositional basin, in which the reddish brown clastics prevail and the gypsum becomes very rare; if not totally absent, as it is the case farther northwards of the involved area (in the High Folded Zone). This is also attributed to the effect of the Mosul High, which isolated the involved area from the main depositional basin, as an open marine basin, not affected by dominant lagoons.

7) Along the extreme marginal area between the Low Folded and High Folded Zones, along the southwestern limbs of Safin and Bana Bawi anticlines (from Salah Al-Deen to Koi Sanjaq) Sissakian and Youkhanna (1979) mapped the Fatha Formation as one unit, because the informal units introduced by Al-Mubarak and Youkhanna (1976) are not developed in the area involved. There, the Fatha Formation consists of cyclic deposits, the ideal cycle consists of reddish brown claystone, limestone and gypsum, but usually the gypsum is absent or thin, some reddish brown siltstone and sandstone also occur in the uppermost parts of the formation. The claystone forms the main constituents of the formation, the thickness of the beds ranges between (1 – 35) m. The limestone beds are the second main constituent and range in thickness between (0.1 – 12) m, exceptionally reaches 20 m in Koi Sanjaq area at the lowermost part of the formation. The gypsum forms minor constituent and ranges in thickness between (1 – 5) m, usually (1 – 3) horizons occur within the whole formation. It is worth mentioning, that this special development of the Fatha Formation continues southeast wards along the contact between Low Folded and High Folded Zones.

8) In Maqloub, Ba'shiqa and Ain Al-Safra anticlines, Barwary (1983) mapped the Fatha Formation as one unit; because not all the aforementioned informal units are developed in the involved area. He mentioned that the formation consists of normal cyclic sediments of marl, limestone and gypsum with subordinate reddish brown claystone, siltstone and sandstone, the last three components increase in the upper part of the formation. He also considered that the exposed part of the formation represents the Upper Member of the Fatha Formation, because the reddish brown claystone is present in the lower part of the formation. The authors are not in accordance with this assumption due to the same mentioned reason in **Remarks 5** and **6**.

9) In Ain Sifni anticline, Hagopian *et al*. (1982) mapped the Fatha Formation as one unit, not all the aforementioned informal units are developed in the involved area. They mentioned that the formation consists of normal cyclic sediments of marl, limestone and gypsum with subordinate reddish brown claystone, siltstone and sandstone, the last three components increase in the upper part of the formation.

10) In Hammam Al-Aleel vicinity, south of Mosul city, Ma'ala *et al*. (1987) used five limestone markers (**M1 – M5**) in subdividing the Fatha Formation into informal units, during the detailed geological mapping forwarded for native sulphur investigation. Fouad *et al*. (1992) and Fouad (2002 and 2004) used the same subdivisions of Ma'ala *et al*. (1987) instead of those informal units introduced by Al-Mubarak and Youkhanna (1976). However, they did not correlate the five markers with the existing informal units introduced by Al-Mubarak and Youkhanna (1976). However, they mentioned that the first 2 markers (**M1** and **M2**) belong to the Lower Member, whereas the remaining 3 markers (**M3, M4** and **M5**) belong to the Upper Member of the Fatha Formation.

Because each of the main constituents of the Fatha Formation was described in each locality within the Low Folded Zone by different authors, the present authors have summarized the description of each rock type as mentioned hereinafter.

Gypsum: White and different tones of grey, occasionally green, pink, pale yellow colors may occur due to impurities, medium hard to hard, thickly bedded to massive and very rarely are thinly bedded; then have wavy lamination, occasionally nodular and banded. Locally, the beds are transformed to limestone (post gypsum limestone, Al-Mubarak and Youkhanna, 1976 and Ma'ala *et al*., 1987) or replaced very rarely by travertine or bitumen, and include sulphur crystals, mainly medium to coarse crystalline; some of the beds are granular, with "Chicken wire" texture or banded, also, may show variation to satin spar and/ or alabaster. The thickness of the individual beds is very wide, it ranges between (1 – 15) m and rarely reaches to 40 m; like in north of Kifri town (Sissakian, 1978). Locally, lens-forming gypsum was described, by different authors.

Remark: In the authors' opinion, the described lens form gypsum represents a karst phenomenon, where parts of the gypsum beds are karstified leading to lens form. Moreover, the karst cavities are filled with the overlying weathered materials of marl or claystone beds. This was also described by some authors as lateral changes of the gypsum to marl and/ or claystone. Very good and clear example occurs along Baghdad – Mosul road cuts, south of Mosul city.

Limestone: Light grey, white and pale brown in color, thinly to thickly bedded, hard to very hard, fossiliferous, occasionally recrystallized, fine crystalline, bituminous, splintery, very rarely with sulphur crystals. The thickness of the limestone beds within the cycles is thin, the thickness of the individual beds ranges between (0.1 – 1.5) m, except in Unit C where the thickness of the limestone beds ranges between (4 – 15) m.

Marl: Pale to olive green and yellowish green, soft to fairly hard, papery to thinly bedded, usually conchoidally fractured, occasionally includes gypsum nodules and thin fossiliferous marly limestone interlayers, fractures are filled by secondary gypsum. The thickness of the marl beds within the cycles is thin, the thickness of the individual beds ranges between (0.5 – 3) m, however, locally more thicknesses were recorded, like in north of Mosul and in Masar'ra anticline (Hagopian and Veljupek, 1977).

Claystone: Reddish brown, pale brown and rarely purple in color, soft to fairly hard, thinly to thickly bedded, usually conchoidally fractured, in the uppermost parts of the formation the beds include reddish brown siltstone or fine grained sandstone. The thickness of the claystone beds within the cycles is highly variable, the thickness of the individual beds ranges between (0.5 – 8) m, however, locally more than 35 m was recorded in Salah Al-Deen – Koi Sanjaq vicinity (Sissakian and Youkhanna, 1979).

Replaced Limestone: Many beds of replaced limestone were found within the Fatha Formation in different localities, they originally were gypsum beds. They are light grayish white, brownish white and creamy in color, semi bedded to massive, hard to very hard, splintery, cavernous; cavities are usually filled by brown and yellowish brown secondary calcite crystals. Secondary growth of calcite crystals is very common, they are needle like; arranged in pyramidal or bipyramidal shapes, radial growth is very rare; the length of the crystals ranges between (1 – 20) cm. Occasionally, bitumen was found with the replaced limestone, as pure bitumen or as bituminous limestone; with tetrahedral crystals and small limonitic lenses (Ma'ala *et al*., 1987). Clear gradual change from gypsum to limestone; with the presence of sulphur crystals were observed in the field. The degree of the replacement of gypsum to limestone differs in different localities, this leads to total or partial replacement. Occasionally, green and yellowish green marl is associated with the replaced limestone. In areas where replaced limestone were found, usually oil and bitumen seepages occur with strong H_2S smell, like in Pulkhana anticline; near a main reverse fault. The replaced limestone is usually found in Units D, and E and F, in the former case; the replacement is not total, whereas in the latter, it is totally replaced and no gypsum traces could be find. Three types of replaced limestone were found: **1)** Pillow like bodies, **2)** Sinter forms and **3)** Isolated hills (Ma'ala *et al*., 1987).

Sulphur: It is present in enormous amounts in the Fatha Formation, in the area from Mosul towards south until Fatha. The details are mentioned by different authors, among them are: Ma'ala *et al*. (1987); Fouad *et al*. (1992); Fouad (2002 and 2004); Al-Bassam (2007).

Thickness: The thickness of the Fatha Formation in the type locality is 445 m (Jassim *et al*., 1984 and Al-Rawi *et al*., 1992). Because great differences occur in the thickness of the formation within different parts of the Low Folded Zone, therefore, the measured thicknesses are tabulated in details in Table (2).

Fossils: The following fossils were recorded in the Fatha Formation by different authors: *Ammonia beccarii* LINNE, *Elphidium* sp., *Quinqueloculina* sp., *Pyrgo* sp., *Spiroloculina* sp., *Clausinella* sp., *Modiolus* sp., *Paracypris* sp., *Ostrea* sp. algae and bryozoa (Behnam, 1976; Amer, 1977; Al-Biaty, 1978; Buday, 1980 and Al-Hashimi and Amer, 1985).

Age: The age of the Fatha Formation is Middle Miocene as agreed upon by all involved authors. Mahdi (2007) however, claimed Early Miocene (Burdigalian) age for the Fatha Formation.

Depositional Environment: The depositional environment of the Fatha Formation as agreed upon by all involved authors was closed lagoon of hypersaline condition. However, in areas where the Fatha Formation was mapped as "Undifferentiated", the lagoons were not closed, and were in direct contact with the open sea.

Table 2: Thicknesses of the Fatha Formation in the Low Folded Zone

Anticline	Thickness (m)	Anticline	Thickness (m)	Vicinity	Thickness (m)
Qara Chouq, Middle Dome Southern Dome	163 242	Qalian + Hammam Al-Aleel + Nuwaigeet + Lazzaga	150 – 181	Fatha	444
				Salah Al-Ddeen	310
				Degala	100
Qara Boutak	210	Chia Surkh*	762	Koi Sanjaq	200
Bai Hassan	77	Alan	80	Mishraq*	209
Avanah Dome*	72	Sheikh Ibrahim	446	Mosul	70
Baba Dome*	71	Masar'ra	117	SE Duhok	183
Naft Khana*	200	Ishkaft	350		
Damir Dagh	188	Gillabat	700		
Kor Mor	1322	Pulkhana*	300		
MakhoulRange	214 – 336	Ain Zala	325		
Gullar	459	Mushurah	220		
Butmah	392	Ba'shiqa	35		
Gusair	355				

*Exposed thickness, only

Lower Contact: The Fatha Formation; in the type locality is underlain conformably by the Euphrates Formation (Jassim *et al*., 1984 and Al-Rawi *et al*., 1992). In Makhoul – Mosul vicinity, the formation is underlain conformably by the Jeribe Formation; the contact is based on the bottom of the first massive gypsum bed (Al-Mubarak and Youkhanna, 1976). In Himreen anticline, the bottom of the formation is not exposed. However, Abdul Lateef (1976) reported about a thick bituminous and splintery limestone below the Fatha Formation in Al-Fudhul Dome, doubtfully it might belong to the Euphrates Formation, but paleontological study did not ascertain that; due to obliterated fossils. West of Mosul vicinity, the formation is underlain unconformably by the Jeribe Formation, the contact was based on a horizon (3 – 4 m thick) of green to light green, semi-brecciated, fairly hard, massive clayey limestone with gypsiferous materials. In Nuwaigeet anticline, the contact is based on the first appearance of gypsum bed, in Alan anticline the contact is based on the first appearance of claystone or marl. In Atshan and Sheikh Ibrahim anticlines, angular unconformity was supposed (Mohi Ad-Din *et al*., 1977). In Maqloub, Ba'shiqa and Ain Al-Safra anticlines, Pila Spi Formation underlies the formation unconformably; the contact is marked by a basal conglomerate bed, which consists of dolostone pebbles of different sizes, rounded, subrounded and subangular shapes, cemented by calcareous materials (Barwary, 1983). In Ain Sifni anticline, the Euphrates Formation underlies the formation unconformably, the contact is marked by a conglomerate; and when it is absent, then the last limestone bed, which is overlain by grey claystone is considered as the contact (Hagopian *et al*., 1982). In Sinjar vicinity it is underlain unconformably by the Jeribe Formation, the contact is based at the base of a conglomerate and sandy marl, which is underlain directly by an oyster-bearing horizon (Ma'ala, 1977). In Khanaqeen vicinity, the lower contact of the formation with the underlying formations is unconformable, although Euphrates and Jeribe formations are exposed in the involved area. But, Youkhanna and Hradecky (1978) mentioned that the Fatha Formation is underlain unconformably by Oligocene formations, the contact is marked by about 1.5 m thick basal conglomerate that includes pebbles up to 1 m of Oligocene rocks, except in Bezniyan anticline, where the contact was based on the bottom of the first oolitic limestone above the Anah Formation. In Salah Al-Deen – Koi Sanjaq vicinity, the lower contact of the formation with the underlying Pila Spi Formation is unconformable and marked by a conglomerate bed, about (1 – 4) m thick. The pebbles are mainly of limestone of the Pila Spi Formation cemented by red and green clayey and calcareous materials, the size of the pebbles range between (3 – 8) cm. In areas where the conglomerate is missing the contact is based on the bottom of the first reddish brown claystone overlying the limestones of the Pila Spi Formation (Sissakain and Youkhanna, 1979).

Remarks:

1) Although Ma'ala (1977) considered unconformable contact between the Fatha Formation and the underlying Jeribe Formation in Sinjar anticline, but the authors believe that the contact is conformable, as it is the case in the all-surrounding areas, where the two formations are exposed. Moreover, the authors may attribute the claim of Ma'ala (1977) concerning local absence of Dhiban Formation between Euphrates and Jeribe formations, is related to the basin configuration and not to a stratigraphic break.

2) West of Mosul vicinity, also Mohi Ad-Din *et al*. (1977) considered unconformable contact between the Fatha Formation and the underlying Jeribe Formation, but the authors believe that the contact is conformable, not only depending on the paleontological evidences, but even from the given lithological description for the nature of the contact. Concerning the angular unconformity between the two formations, the authors are not in accordance with Mohi Ad-Din *et al*. (1977) opinion, and they attribute that to structural configuration of the beds as their position is concerned in the anticlines, besides the different mechanical behavior of the beds of the two formations during folding, due to difference in competency.

3) In Ain Sifni anticline, Hagopian *et al*. (1982) considered unconformable contact between the Fatha and Euphrates formations, the authors are not in accordance with this assumption, because normal contacts are recorded between the two formations in many locations, though a conglomerate bed marks the contact. This could be attributed to very local hiatus in the basin.

4) In Khanaqeen vicinity, unfortunately Youkhanna and Hradecky (1978) did not mention the details why the Fatha Formation is underlain by Oligocene formations, although Euphrates and Jeribe formations are exposed in the area involved. According to the authors' opinion, the contact is obscure, due to the structural complexity and the development of conglomeratic beds in both Euphrates and Jeribe formations; as mentioned by Youkhanna and Hradecky (1978). These conglomeratic beds might hinder the contact and made it obscure. However, a structural contact due to tectonic disturbances could not be excluded.

5) It is worth mentioning that within majority parts of the Low Folded Zone, GEOSURV geologists mapped the abandoned **Middle Fars Formation** as a separate map able unit and it is presented on geological maps at scale of 1: 25 000 and 1: 20 000. However, Jassim *et al*. (1984) merged the formation with the ex-Upper Fars Formation and renamed them together as the Injana Formation. Jassim *et al*. (1986 and 1990), Sissakian (2000) and Sissakian and Fouad (2012) adopted this idea during the compilation and updating of the Geological Map of Iraq at scale of 1: 1000 000. The abandoned Middle Fars Formation had almost the same characters of the ex-Upper Fars Formation, in its cyclic nature of sediments, the characters of the main constituents; reddish brown claystone, grayish green marl, reddish brown siltstone, reddish brown sandstone and yellowish grey limestone, usually (4 – 7) cycles were mapped, the thickness of the formation ranges between (25 – 150) m. The formation has the same depositional environment and fossils content of the Injana Formation, with early Late Miocene age. The lower contact of the formation with the underlying ex-Lower Fars Formation was based on the top of the last thick gypsum bed, whereas the upper contact with the overlying ex-Upper Fars Formation was based on the top of the last nodular limestone bed followed by coarse clastics, both contacts were supposed to be conformable.

6) From the senior author's field observations, the ex-Middle Fars Formation was not mapped, in different parts of the Low Folded Zone, exactly as the same stratigraphic sequence. West of Mosul vicinity (Mohi Ad-Din *et al*., 1977) and between Tuz Khurmatu and Kalar vicinity (Sissakian, 1978), thin gypsum beds were mapped within the formation. Moreover, the aforementioned lower and upper contacts are not so sharp and most probably confusing, especially the described "last nodular limestone bed", which was considered as the contact between ex-Middle and ex-Upper Fars formations. However, many limestone horizons were recorded in the lower part of the ex-Upper Fars Formation, which could be easily missed as the contact between the ex-Middle Fars and ex-Upper Fars formations.

7) In the eastern parts of the Low Folded Zone, south of Qara Dagh anticline, the Fatha Formation is not underlain by the Pila Spi Formation (Jassim *et al*., 1986 and 1990; Sissakian, 2000 and Ma'ala, 2007). There, the Fatha Formation is underlain conformably by a sequence, which consists of Oligocene and Early Miocene rocks (Khanqa *et al*., 2009). This special sequence was not mapped separately when it exists; it was mapped as the Fatha Formation (Ibrahim, 1984). From the field observations of the senior author, the sequence occurs on the top of the Pila Spi Formation in Darbandi Bazian gorge and extends northwestwards passing through Haibat Sultan Mountain, but it is not developed more northwestwards till west of Salah Al-Deen, along Permam anticline. Farther northwestwards, it appears again but not continuously. However, in Aj Dagh and Qara Wais anticlines, south of Qara Dagh Mountain, the Fatha Formation is underlain by Oligocene formations, with thin beds of Euphrates Formation (Sissakian and Fouad, 2012).

2.5. Late Miocene – Pleistocene

During the Late Miocene – Pliocene major thrusting occurred during the collision of the Sanandaj – Sirjan Zone with the Arabian Plate (Neo-Tethyan terrains), causing the end of the marine phase and beginning of the continental phase. Consequently, the High Folded and Imbricate Zones were uplifted, folded and faulted. A major foredeep (within the foreland) formed in the nowadays Low Folded Zone, which was filled by continental molasse sediments that increased in size continuously, due to continuous and intensely increasing of the High Folded Zone. The erosion products of the High Folded Zone were laid down in the foredeep as continental molasse sediments that represent the end of the last marine phase and begging of the continental phase. Those sediments were continuously folded due to the last phase of the Alpine Orogeny.

During Early Pleistocene, the Alpine Orogeny reached its climax; the sediments of the Bai Hassan Formation also reached their climax in the size of the pebbles and the thickness of the individual conglomerate beds. Quaternary sediments developed in different geomorphological forms and units.

The Late Miocene – Pleistocene time is represented by three formations, which have very wide coverage areas in the Low Folded Zone, especially east of the Tigris River (Figs.2, 3, 4 and 5).

2.5.1. Injana Formation (Late Miocene)

The Injana Formation was formerly known as the Upper Fars Formation, it was introduced by Busk and Mayo in 1918, without mentioning the type locality. However, Ion *et al*. (1951) described the formation from Agha Jari oil field of southwest Iran (Bellen *et al*., 1959). The formation was later on abandoned in Iran (James and Wynd, 1968 in Jassim and Goff, 2006). Jassim *et al*. (1984) introduced the name of Injana Formation, which was adopted by the geologists of GEOSURV since 1984. However, Al-Rawi *et al*. (1992) announced, officially the name of the Injana Formation. Moreover, the formation in Iran is renamed as Mishan Formation.

Type Locality: The type locality of the Injana Formation is along the northeastern limb of Himreen South anticline at Injana, near the old police station along Baghdad – Kirkuk road; it is defined by the following coordinates (Jassim *et al*., 1984) (Fig.6):

Longitude 44° 38' 10" E
Latitude 34° 32' 00" N

It is worth to mention that Al-Rawi *et al*. (1992) adopted the same aforementioned type locality and they suggested a supplementary type section in oil well Gillabat 1, which is defined by the following coordinates:

Longitude 44° 48' 04" E
Latitude 34° 35' 19" N

Exposure Areas: The Injana Formation is one of the widest spread formations in the Low Folded Zone. It extends northwest wards from Badra vicinity; along the Iraqi – Iranian borders to Sinjar vicinity; at the extreme northwestern part of the involved area (Figs.2, 3, 4 and 5). It is exposed almost in all anticlines of the area, forming continuous belts around them, except those anticlines that exhibit thrusting of their northeastern limb over the southwestern one, and then they are not exposed in the latter limb. An exceptional case is in north of Sinjar anticline, where the formation covers the whole Rabee'a Plain and extends north of the Tigris River and covers a wide plain until Duhok city. The subsurface extension of the Injana Formation is clear. It extends everywhere within the area, under Mukdadiya Formation, as well as under thick polygenetic sediments, which fill the trough of some synclines (Figs.2, 3, 4 and 5).

Lithology: The Injana Formation, in the type locality consists of alternation of red, brown and grey claystone, siltstone and sandstone, with rare fresh water thin limestone and gypsum horizons, in the lowermost part (Jassim *et al*., 1984 and Al-Rawi *et al*., 1992). In all exposure areas, the formation has the same lithological characters, it consists of cyclic repetition of claystone, siltstone and sandstone, and the cycles are coarsening upwards. Locally, in the lowermost part of the formation, (2 – 3) thin horizons of fresh water limestone and gypsum, and/ or selenite may occur, the thickness ranges between (15 – 100) cm.

Because each of the main constituents of the Injana Formation was described in each locality within the Low Folded Zone by different authors, the present authors have summarized the description of each rock type; as mentioned hereinafter.

Claystone: Reddish brown, pale brown, brownish grey, yellowish green, violet and purple in color, soft to fairly hard, thinly bedded to massive, conchoidally fractured, usually silty and very rarely sandy, fractured and jointed; fractures and joints are filled by secondary gypsum and/ or calcite; occasionally black staining of Mg; forming vein shapes occur too. The thickness of the individual bed ranges between (0.5 – 30) m.

Siltstone: Reddish brown, light brown, light greenish grey, olive green and blue in color, fairly hard to hard, thinly to thickly bedded, usually calcareous and occasionally clayey or sandy, includes detrital fragments of carbonate, quartz, feldspar and volcanic rock fragments, the matrix forms (25 – 40) % of the rock . The thickness of the individual bed ranges between (0.2 – 2) m.

Sandstone: Reddish brown, dull brown, greyish brown, grey, light greenish grey, olive green, blue in color, fine grained in the lower parts and becomes coarser upwards, cemented by calcareous and sandy materials; rarely gypsiferous. Quartz, mica, dark minerals, and volcanic and metamorphic rock fragments are the main constituents. Beds are thinly to thickly bedded; occasionally massive, fairly hard to hard; in the uppermost parts some friable beds occur too, occasionally clayey, silty, and calcareous, and very rarely contain chert pebbles (less than 2 cm), thin conglomerate horizons may occur in the uppermost part of the formation too. Rich in sedimentary structures, like cross bedding, graded bedding with very fine pebbles (less than 2 cm) especially in the uppermost parts, ripple marks, load cast, flute cast, mud balls, very rarely rain prints, worm tubes or burrows, honey-comb, pot holes, whirl balls (10 – 20 cm in size) and channeling. The thickness of the individual bed ranges between (0.3 – 15) m, but occasionally may reach 25 m.

Remark: Bitumen occurs in the uppermost parts of the formation in the eastern parts of the Low Folded Zone, between Tuz Khurmatu and Kifri towns.

Thickness: The thickness of the Injana Formation in the type locality is 620 m (Jassim *et al*., 1984 and Al-Rawi *et al*., 1992). Because great differences occur in the thickness of the formation within different parts of the Low Folded Zone, therefore the measured thicknesses are tabulated in details in Table (3).

Fossils: The fossils within the major parts of the Injana Formation are very rare or not well preserved; gastropods and pelecypods were reported in the type locality (Jassim *et al*., 1984 and Al-Rawi *et al*., 1992).

Age: The age of the Injana Formation is not definitely established. Al-Naqib (1959) and Bellen *et al*. (1959) assigned the formation (Upper Fars) to Late Miocene age. This age assignment was based on its stratigraphical position, rather than on its fossils content. Jassim *et al*. (1984) and Al-Rawi *et al*. (1992) considered the age of the Formation as Late Miocene based on the stratigraphic position, too. All geologist of GEOSURV and all workers have agreed upon this age.

Table 3: Thicknesses of the Injana Formation in the Low Folded Zone

Anticline	Thickness (m)	Anticline and/ or vicinity	Thickness (m)
Chia Surkh *	800	West of Mosul	150*
Quaratu	1200	Pulkhana Ant.*	890
Bezniyan	1000	Salah Al-Deen	450
Naft Khana	700	Degala	200
Qara Chouq, Northern Dome	46	Taq Taq Ant.*	150
Qara Chouq, Southern Dome	141	Mishraq Ant.*	130
Qara Boutak	300	Duhok*	200
Bai Hassan	398	Ishkaft Ant.	383
Avanah Dome	365	Quwair Ant.	120
Baba Dome	153	Demir Dagh Ant.	402
Khanuga	130		

*Exposed thickness, only
Ant. = Anticline

Depositional Environment: The lower part of the Injana Formation has been interpreted as shallow water to sub-continental environment. This interpretation is based on the presence of limestone bearing pelecypods, gastropods and ostracods in the lowermost part of the formation (Yakta, 1977 in Jassim *et al*., 1984). Algae and miliolids were also mentioned, therefore, a supratidal environment for the lower part of the formation has been suggested (Jassim *et al*., 1984). Thus, the lower part of the formation seems to be transitional between the marine evaporitic Fatha Formation and the continental (fluvial) Injana Formation (Lawa, 1989).

Lower Contact: The lower contact of the Injana Formation in the type locality is conformable and gradational with the underlying Fatha Formation, it is based on the top of the last gypsum bed, or the bottom of the first thick reddish brown sandstone horizon (Jassim *et al*., 1984, and Al-Rawi *et al*., 1992). All other authors, who were working in all localities within the Low Folded Zone adopted the same contact. However, Barwary (1983) in Maqloub, Ba'shiqa and Ain Al-Safra anticlines used the last dolostone bed of the Fatha Formation as the contact between Fatha and Injana formations. Hagopian *et al*. (1982) in Ain Sifni anticline, also used different contact between the two formations, they considered the last grey olive green claystone bed as the contact, which also was considered by Ma'ala *et al*. (1987) in the detailed geological mapping of Hammam Al-Aleel vicinity.

Remark: It is worth mentioning that the details of the aforementioned contact are originally the details of the contact between ex-Upper and ex-Lower Fars formations (Bellen *et al*., 1959).

2.5.2. Mukdadiya Formation (Late Miocene – Pliocene)

The Mukdadiya Formation was formerly known as the Lower Bakhtiari Formation, it was introduced by Busk and Mayo in 1918, without mentioning the type locality. However, Ion *et al*. (1951) described the formation from Agha Jari oil field of southwest Iran (Bellen *et al*., 1959). Jassim *et al*. (1984) introduced the name of Mukdadiya Formation, which was adopted by the geologists of GEOSURV since 1984. However, Al-Rawi *et al*. (1992) announced, officially the name of the Mukdadiya Formation. It is worth mentioning that the name of Lower Bakhtiari is abandoned in Iran, and it is renamed as Agha Jari Formation.

Type Locality: The type locality of the Mukdadiya Formation is along the northeastern limb of Himreen South anticline in Mukdadiya; near Himreen Lake, it is defined by the following coordinates (Jassim *et al*., 1984) (Fig.6). It is worth mentioning that Al-Rawi *et al*. (1992) adopted the same aforementioned type locality:

Longitude 45° 01' 50" E
Latitude 34° 02' 10" N

Exposure Areas: The Mukdadiya Formation is one of the widest spread formations in the Low Folded Zone. It extends northwest wards from northeast of Amara city; along the Iraqi – Iranian borders to Tigris River (except small exposures in the northern limb of Sinjar anticline), along the involved area (Figs.3, 4 and 5). It is exposed almost in all anticlines of the area forming a continuous belt around them, except those anticlines that exhibit thrusting of their northeastern limb over the southwestern one, and then they are not exposed in the latter limb. The subsurface extension of the Mukdadiya Formation is clear. It extends everywhere within the area until east of the Tigris River (except small exposures in the northern limb of Sinjar anticline); under Bai Hassan Formation, as well as under thick polygenetic sediments, which fill the trough of some synclines.

Lithology: The Mukdadiya Formation, in the type locality consists of alternation of coarse sandstone; the sandstone is occasionally pebbly, claystone and siltstone (Jassim *et al*., 1984 and Al-Rawi *et al*., 1992). Generally, in all exposure areas within the Low Folded Zone, the formation has the same lithological characters, it consists of cyclic repetition of sandstone, siltstone and claystone, the cycles are fining upwards; some of the sandstone beds are pebbly. The sandstone beds predominate in the lower part of the formation, whereas the claystone beds predominate in the upper part. The main color of the rocks is grey, the pebbles within the pebbly sandstones are up to 6 cm, but usually are (1 – 2) cm in size, mainly of chert, quartz, carbonates, and subordinate igneous and metamorphic rocks.

Because each of the main constituents of the Mukdadiya Formation was described in each locality within the Low Folded Zone by different authors, the present authors have summarized the description of each rock type; as mentioned hereinafter.

Sandstone: Light and dark grey, light greenish grey, light yellowish grey, light brown, in color, but the grey tone is the most abundant, coarse grained in the lower parts and becomes medium to coarse grained upwards, poorly sorted, cemented by calcareous materials; rarely gypsiferous. Quartz, mica, dark minerals and few rock fragments are the main constituents. Beds are thickly bedded; occasionally massive, fairly hard to hard; locally friable beds occur too, occasionally clayey, silty, and calcareous. Rich in sedimentary structures, like clay balls of variable sizes (not more than 15 cm), cross bedding, ripple marks, load cast, flute cast, groove cast, very rarely rain prints, channeling, and limonitic concretions. Some of the sandstone beds are pebbly; pebbles are either scattered or in form of lenses that did not exceed few meters. Pebbles are mainly of silicates, with subordinate limestone, igneous and metamorphic rocks, the size of the pebbles range between few millimeters up to 6 cm; occasionally may reach 10 cm or slightly more. The pebbly sandstone beds are common in the lower and upper parts, whereas in the middle part are rare or totally absent. The thickness of the individual bed ranges between (0.5 – 12) m, but occasionally may reach 40 m.

Claystone: Light brown, brownish grey, rarely yellowish and greenish grey, soft to fairly hard, thinly bedded to massive, conchoidally fractured, usually silty and sandy, fractured and jointed; fractures and joints are filled by secondary gypsum forming vein shapes. The thickness of the individual bed ranges between (0.5 – 40) m, exceptional case occurs in Tuz Khurmatu, where the thickness reaches about 100 m (Sissakian, 1978).

Siltstone: Light brown, light grey, reddish brown, and rarely yellowish grey and greenish grey in color, fairly hard to hard, thinly to thickly bedded, occasionally clayey, sandy and calcareous. The thickness of the individual bed ranges between (0.2 – 7) m.

Remark: Bitumen and Bentonite occur in the lower part of the formation, the latter is found in many localities within the claystone beds, it is light brown, grey and light pink in color, with greasy texture and not more than 1 m in thickness. These occurrences are found between Tuz Khurmatu and Kifri towns, in Qara Tappa town and in Himreen South anticline.

Thickness: The thickness of the Mukdadiya Formation in the type locality is 2000 m (Jassim *et al*., 1984 and Al-Rawi *et al*., 1992). Because great differences occur in the thickness of the formation within different parts of the Low Folded Zone, therefore, the measured thicknesses are tabulated in details in Table (4).

Table 4: Thicknesses (m) of the Mukdadiya Formation in the Low Folded Zone

Anticline	**Thickness (m)**	**Anticline and/ or vicinity**	**Thickness (m)**
Naft Khana	2200	Bai Hassan Ant.	456
Quaratu	1500	Avanah Dome	352
Chia Surkh	650	Baba Dome	200
Bezniyan	1100	West of Mosul	20*
Qara Chouq Northern Dome	42*	Pulkhana Ant.	925
Qara Chouq Southern Dome	200	Salah Al-Deen	660
Qara Boutak	394	Taq Taq Ant.	1000
Halwa	30*	Quwair Ant.	65*
Zar'rariya	50*	Khurmala Ant.	680

*Exposed thickness, only
Ant. = Anticline

Fossils: The fossils within the major parts of the Mukdadiya Formation are very rare or not well preserved. The horse *Hipparion* sp. was recorded by Bellen *et al*. (1959). Gastropods and pelecypods are reported in the type locality (Al-Rawi *et al*., 1992). Many Vertebrate remains (mastodons and other mammals) were found within the sandstone beds and studied by the Iraqi – French team, Buffetant and Thomas (1981). Raji (1978) recorded some fresh water ostracods, charophytes and bryozoans.

Age: The age of the Mukdadiya Formation is not definitely established. Al-Naqib (1959) and Bellen *et al*. (1959) assigned the formation (Lower Bakhtiari) to Late Miocene age. This age assignment was based on its stratigraphical position, rather than on its fossils content. Buffetant and Thomas (1981), claimed Late Miocene age (8 Ma) for the lower part of the formation. Jassim *et al*. (1984) and Al-Rawi *et al*. (1992) considered the age of the formation as Late Miocene – Pliocene based on the stratigraphic position, too. All geologist of GEOSURV and almost all workers have agreed upon this age.

Depositional Environment: The Mukdadiya Formation has been deposited in fluvial environment in a rapidly subsiding foredeep basin, as indicted from the pattern of sedimentation and cyclicity and fossil remains (Jassim *et al*., 1984).

Lower Contact: The lower contact of the Mukdadiya Formation in the type locality is conformable and gradational with the underlying Injana Formation; it is based on the base of the first pebbly sandstone bed (Jassim *et al*., 1984 and Al-Rawi, *et al*., 1992). All other authors in all localities; within the Low Folded Zone and elsewhere adopted the same contact.

Remarks:

1) It is worth mentioning that the aforementioned details of the contact are originally the details of the contact between ex-Lower Bakhtiari and ex-Upper Fars formations (Bellen *et al*., 1959).

2) The first pebbly sandstone bed, which is considered as the contact between Injana and Mukdadiya formations, in the whole area of the Low Folded Zone usually disappears locally and reappears again after a considerable distance; along the dip direction, then it will be not along the same stratigraphical horizon. This may lead to much confusion, such as assuming the presence of an oblique fault that has shifted the contact. From the senior author's field experience, the true contact is the lateral continuation of the first pebbly sandstone bed that may change to a coarse grained sandstone bed. However, in majority of such cases the same pebbly sandstone bed reappears again along the same stratigraphic horizon after a few hundred meters or even few kilometers.

2.5.3. Bai Hassan Formation (Pliocene – Pleistocene)

The Bai Hassan Formation was formerly known as the Upper Bakhtiari Formation, it was introduced by Busk and Mayo in 1918, without mentioning the type locality. However, Ion *et al*. (1951) described the formation from Agha Jari oil field of southwest Iran (Bellen *et al*., 1959). Jassim *et al*. (1984) introduced the name of Bai Hassan Formation, which was adopted by the geologists of GEOSURV since 1984. However, Al-Rawi *et al*. (1992) announced, officially the name of the Bai Hassan Formation. It is worth mentioning that the name of Upper Bakhtiari Formation is abandoned in Iran, and it is renamed as Bakhtiari Formation.

Type Locality: The type locality of the Bai Hassan Formation is in Bai Hassan anticline, northwest of Kirkuk city (Jassim *et al*., 1984) (Fig.6). It is worth mentioning that Al-Rawi *et al*. (1992) adopted the same aforementioned type locality.

Longitude 43° 40' 15" E
Latitude 34° 40' 15" N

Exposure Areas: The Bai Hassan Formation is one of the widest spread formations in the Low Folded Zone. It extends northwest wards from northeast of Amara city; along the Iraqi – Iranian borders to Tigris River; along the involved area (Figs.3, 4 and 5). It is exposed almost in all anticlines of the area; except west of the Tigris River forming a continuous belt around them. Those anticlines, however, that exhibit thrusting of their northeastern limb over the southwestern one, the formation is not exposed in the latter limb. The subsurface extension of the Bai Hassan Formation is clear. It extends everywhere within the area except west of the Tigris River, under thick polygenetic sediments, which fill the trough of some synclines.

Lithology: The Bai Hassan Formation, in the type locality consists of alternation of conglomerate, claystone and sandstone (Jassim *et al*., 1984 and Al-Rawi *et al*., 1992). The formation has almost similar lithological constituents, with exceptional slight changes in particular details; therefore, the present authors, in this paper, give a general description for the main constituents.

Because each of the main constituents of the Bai Hassan Formation was described in each locality within the Low Folded Zone by different authors, the present authors have summarized the description of each rock type; as mentioned hereinafter.

Conglomerate: The conglomerate beds consist of gravels of different sizes that range between few millimeters to 35 cm; exceptionally may reach 50 cm, the size increases in the middle part of the formation, then decreases again in the upper parts. The pebbles are mainly of silicate and carbonate, with subordinate igneous and metamorphic rocks. The thickness of the individual bed ranges from 5 m; in the lower parts to 50 m; in the upper parts, exceptionally may reach about 100 m. The pebbles are subrounded to well rounded, varicolored, elongated, semispherical and disc shaped, cemented by calcareous and sandy materials, locally gypsiferous. Occasionally, grey, coarse grained sandstone lenses and/ or beds (up to 4 m; some are pebbly); may occur within the individual bed. Among the sedimentary structures present in the conglomerate beds are cross bedding, lenses of sandstones, channeling and clay balls, all with different sizes.

Sandstone: Light and dark grey, light greenish grey, light yellowish grey, light brown, in color, but the grey tone is the most abundant, usually coarse grained, cemented by calcareous and sandy materials; rarely gypsiferous. Quartz, mica, dark minerals and few rock fragments are the main constituents. Beds are thickly bedded; occasionally massive, fairly hard to hard; locally friable beds occur too, occasionally contain clay balls of variable sizes (not more than 35 cm), rich in sedimentary structures, like cross bedding, ripple marks, load cast, flute cast, groove cast, and channeling. Some of the sandstone beds are pebbly; pebbles are mainly of silicates and carbonates with subordinate igneous and metamorphic rocks, the size of the pebbles range between few millimeters up to 10 cm; occasionally may reach 20 cm or slightly more. The thickness of the individual bed ranges between (0.5 – 10) m, but occasionally may reaches 20 m. It is worth mentioning that many beds exhibit erosional contact with the overlying conglomerate beds, indicating fluvial and alluvial fan deposition style.

Claystone: Light reddish brown, pale brown and very rarely grey in color; exceptionally yellowish white and yellowish green colors may occur, soft to fairly hard, conchoidally fractured, when silty; then exhibits spheroid fracturing pattern, very rarely contains fine pebbles. Beds are fractured and jointed; fractures and joints are filled by secondary gypsum forming vein shapes, very rarely fine conglomerate horizon may occur within the claystone bed. The thickness of the individual bed ranges from 10 m, in the lower part to about 150 m, in the uppermost part of the formation.

Siltstone: Light grey, reddish brown, and rarely yellowish grey and greenish grey in color, fairly hard to hard, thinly to thickly bedded, occasionally clayey, sandy and calcareous. The thickness of the individual bed ranges between (0.2 – 3) m.

Thickness: The thickness of the Bai Hassan Formation in the type locality is 638 m (Jassim *et al*., 1984 and Al-Rawi *et al*., 1992). Because great differences occur in the thickness of the formation within different parts of the Low Folded Zone, therefore the measured thicknesses are tabulated in details in Table (5).

Table 5: Exposed thicknesses of the Bai Hassan Formation in the Low Folded Zone

Anticline and/ or vicinity	Thickness (m)	Anticline	Thickness (m)
Khanaqeen	1880	Gillabat	200
Qara Chouq, Northern Dome	30	Pulkhana	930
Qara Chouq, Southern Dome	50	Qumar	350
Salah Al-Deen	1000	Barda Sur	360
Bai Hassan Ant.	790	Qara Boutak	1000
Kirkuk Structure, Avanah Dome	485	Taq Taq	2500
Kirkuk Structure, Baba Dome	335	Dibagah	250

Fossils: Fossils in the Bai Hassan Formation are very rare, but some smooth ostracods, charophytes, bryozoa and *Mammalian* boneswere recorded by Behnam (1976) and Raji (1978).

Age: The age of the Bai Hassan Formation is not precisely defined yet, however, Pliocene age was claimed by Bellen *et al*. (1959). Buday (1980) also claimed Pliocene age for the formation, but he did not excluded uppermost Miocene for the lower part and early Pleistocene for the upper part. Pliocene – Pleistocene was claimed by Jassim *et al*. (1984) and Al-Rawi *et al*. (1992). All geologist of GEOSURV and all other workers have agreed upon this age.

Depositional Environment: The Bai Hassan Formation was laid down in a fluvio – lacustrine environment in a rapidly sinking foredeep, and might be considered as a typical fresh water molasses (Buday, 1980), and it was deposited in alluvial fans form; originated from the High Folded Zone and the Zagros Suture Zone (Jassim and Buday in Jassim and Goff, 2006).

Lower Contact: The lower contact of the Bai Hassan Formation in the type locality with the underlying Mukdadiya Formation is conformable and gradational, partly diachronous; it is based on the base of the first thick conglomerate bed (Jassim *et al*., 1984 and Al-Rawi *et al*., 1992). All other authors in all localities within the Low Folded Zone and elsewhere adopted the same contact.

Remarks:

1) It is worth mentioning that the aforementioned details are originally the details of the contact between ex-Upper Bakhtiari and ex-Lower Bakhtiari formations (Bellen *et al*., 1959).

2) The first conglomerate bed, which is considered as the contact between Mukdadiya and Bai Hassan formations; in the whole area of the Low Folded Zone usually disappears locally and reappears again after a considerable distance; along the dip direction, then it will be not along the same stratigraphical horizon. This may lead to much confusion, such as assuming the presence of an oblique fault that has shifted the contact. From the senior author's field experience, the true contact is the lateral continuation of the first conglomerate bed that may change to pebbly sandstone or even to a coarse grained sandstone bed. However, in majority of such cases the same conglomerate bed reappears again along the same stratigraphic horizon after a few hundred meters or even few kilometers.

3) In north of Khanaqeen vicinity, Youkhanna and Hradecky (1978) divided the Bai Hassan Formation into two members, Lower Member and Upper Member (Maidan Unit). The Lower Member has the same normal characters of the formation, whereas the Upper Member has special development and consists of coarse grained sandstone, conglomerate and claystone. The conglomerate beds are unusual, hence the cobbles reach up to 1 m in diameter and in the uppermost parts reach to 4 m, being mainly of limestones of Eocene and Oligocene formations and rarely of Maastrichtian age, with subordinate pebbles of chert and quartz that decrease in their amount upwards. Moreover, they claimed angular unconformable contacts not only with the underlying Lower Member, but also even with ex-Middle Fars Formation. It is worth mentioning that Jassim *et al*. (1984) called this member as "Bammu Conglomerate", which was adopted by Jassim *et al*. (1986 and 1990) and Sissakian (2000). However, Sissakian and Fouad (2012) abandoned this unit.

2.6. Quaternary Sediments

The Quaternary sediments are well developed in the Low Folded Zone, especially in the trough of wide synclines (Figs.2, 3, 4 and 5). Only the main types are reviewed, hereinafter:

2.6.1. Terraces (Pleistocene)

The Tigris, Greater Zab, Lesser Zab, Khazir – Goumal, Adhaim, Al-Wand, and Diyala Rivers have deposited many terrace levels, which have different extensions, thicknesses and heights from their riverbeds. Large streams and valleys, like Nareen Chai, Zghaytoon, Kifri Chai, Tuz Chai, Tawooq (Daqooq) Soo, Khassa Soo, Bastoora, Shalgha, Awaina, Qasab etc., have also developed their own terrace systems, which have almost the same characteristics of the terraces of the aforementioned rivers. Usually, (2 – 4) levels were reported from different localities, except in Duhok – Ain Zala vicinity, where Taufiq and Domas (1977) mapped ten levels of terrace of Tigris River. The height of the terraces from the river bed varies from (5 – 204) m, the older level being the highest; the highest level was recorded between Duhok and Ain Zala along the banks of the Tigris river. The thickness of terraces is also highly variable, it ranges between (2 – 35) m, and the thickest level was recorded along the Tigris River, between Duhok and Ain Zala. The composition of the terraces is almost uniform; the pebbles are composed of silicates and limestones with subordinate igneous and metamorphic rocks. The size of the pebbles varies between (1 – 35) cm, but exceptionally may reach 50 cm and more. The pebbles are sub rounded, rounded and well rounded, mainly of spheroidal, and disk shaped, some are rode shaped. The cementing materials are calcareous, sandy and gypsiferous. Usually they show cross bedding, graded bedding and channeling sedimentary structures. Very locally, they are tilted (3 – 12)° and faulted, indicating Neotectonic activity, as in Khanuga vicinity, NW of Baiji city.

Remarks:

1) The authors doubt about the recorded ten levels of terraces of the Tigris River by Taufiq and Domas (1977) in Duhok – Ain Zala vicinity, because no such accumulations were recorded elsewhere, not only within the Low Folded Zone, but also further northwards in the High Folded Zone. The authors believe that the recorded ten levels are not stratigraphically of different levels, they are repeated terrace levels in different localities alongside down stream, which means (3 – 4) levels occur and because they were recognized in different heights, therefore, were considered as different ten levels.

2) In areas where the Bai Hassan Formation is exposed, especially when horizontally lying in synclinal troughs, it is very difficult to differentiate the terraces from the conglomerates of the Bai Hassan Formation. Therefore, the authors believe that in certain localities, the terraces are mapped as conglomerates of Bai Hassan Formation and the reverse case exists too.

3) Usually, the oldest level is preserved as relics of some scattered gravels, which might be present in far distances and in elevated areas from the present river and/ or stream-beds, therefore, they could be easily missed, especially when the coverage area is small. The authors also believe that this may be is the reason why different levels of terraces; along side the same river are reported by different authors from different localities.

2.6.2. Polygenetic Sediments (Pleistocene – Holocene)

Polygenetic sediments are well developed in the wide synclinal troughs, especially when the youngest exposed rocks belong to Bai Hassan Formation. They are composed of different materials, like different rock fragments (limestone, gypsum, sandstone) and pebbles (derived mainly from Bai Hassan Formation, and partly from Mukdadiya Formation) of different sizes and shapes. They include sediments of different genesis, like alluvial, colluvial, residual, Aeolian, evaporates, therefore, the mapped contacts are always arbitrary. The thickness of the sediments is highly variable, it ranges between (< 1 – 15) m, exceptionally may be more, attaining few tens of meters, as in Kirkuk – Erbil Plain.

2.6.3. Calcrete (Pleistocene – Holocene)

Although calcrete is well developed in different parts of the Low Folded Zone, especially near the northern limits with the High Folded Zone, where Pila Spi Formation is exposed, but it is not well mapped and studied. The rock fragments are mainly limestone of Pila Spi Formation, cemented by clayey and calcareous materials, the size of the fragments and/ or pebbles ranges between (< 5 – 45) cm. The thickness may reach up to 10 m, but usually ranges between (1 – 5) m. They form horizontal cover above the tilted pre-Quaternary rocks, forming mesas of different dimensions and heights. Good example is along the Pila Spi ridge between Darbandi Khan and Khanaqeen (Sissakian, 2012).

Remark: The authors believe they are relics of old alluvial fan sediments, which are eroded and the remaining parts are still preserved. Good examples are near Cham Chamal, Degala, Bana Bawi, Permam, Darbandi Bazian, Darbandi Khan and Qara Dagh.

2.6.4. Gypcrete (Pleistocene – Holocene)

Gypcrete is well developed along anticlinal limbs, especially when the gypsum rocks of the Fatha Formation are the youngest exposed rocks, forming gentle slopes with a width of few hundred meters and thickness ranges between (<1 – 5) m. Moreover, they are also well developed in localities built-up by the Fatha Formation, then they have powder form (locally called Juss), light greyish white in color and more pure than in other localities, with less thickness; not more than 2 m. Occasionally, they are covered by thin veneer of sand sheets and scattered pebbles and rock fragments. The percentage of the SO_4 is highly variable, but is more in the latter aforementioned case. It is also very well developed, partly along the courses of the main streams and valleys, like Khassa Soo, Tawooq Soo, Tuz Chai, where the thickness attains few meters (3 – 8 m).

2.6.5. Alluvial Fan Sediments (Pleistocene – Holocene)

Alluvial fan sediments are well developed in many localities within the Low Folded Zone, like along the northern limb of Sinjar anticline; within Rabee’a Plain, and along the southwestern slopes of the continuous ridge of the Pila Spi Formation, forming "Bajada" (Sissakian, 2010). A special case is the alluvial fan of Qara Chouq anticline, near Makhmour town. The stages, composition, thickness, coverage areas are highly variable, but they are not well recorded. The thickness varies from (1 – 8) m, with coverage areas that range between (< 1 – 48) Km^2, the largest being in Sinjar anticline (Sissakian, 2011). The main composition of the constituents is limestone rock fragments, locally pebbles (derived from Bai Hassan Formation), the size of the fragments and pebbles ranges between (1 – 60) cm, exceptionally may reach 1 m; like in Sinjar alluvial fans (Sissakian, 2011). The rock fragments and pebbles are well cemented by sandy, calcareous, clayey and gypsiferous materials, locally are covered by thin veneer of gypcrete. Mainly, (1 – 2) stages are developed, but exceptionally reach 4 stages; like in Sinjar anticline within the Rabee'a Plain (Sissakian, 2011).

2.6.6. Bammu Conglomerate (Pleistocene – Holocene)

Jassim *et al*. (1984) introduced the Bammu Conglomerate instead of the Upper Member (Maidan Unit) of the Bai Hassan Formation in Khanaqeen vicinity (Youkhanna and Hradecky, 1978). It consists of very large blocks (up to 4 m) of limestones of different ages, almost without cement. Jassim *et al*. (1986 and 1990) adopted this term; Sissakian (2000) used the same term in Kalar vicinity. However, recent field observations and interpretations of high quality Landsat images revealed that they are mainly talus sediments and debris in Khanaqeen vicinity. Whereas, in Kalar vicinity, they are thrusted beds of Bai Hassan Formation on a thick sequence of the same formation. Therefore, the authors recommend abandoning the term of "Bammu Conglomerate". It is worth mentioning that Sissakian and Fouad (2012) also abandoned the term of Bammu Conglomerate, for the same aforementioned reason.

2.6.7. Flood Plain Sediments (Holocene)

Flood plain sediments are well developed along side the Tigris, Greater Zab, Lesser Zab, Khazir – Goumal, Adhaim and Diyala Rivers and large streams and valleys, like Nareen Chai, Zghaytoon, Kifri Chai, Tuz Chai, Tawooq Soo, Khassa Soo, Bastoora, Shalgha, Awaina etc. The thickness and width of the plains are highly variable, but usually the thickness ranges between (< 1 – 5) m, whereas the width ranges between (< 1 – 3) Km, exceptionally may reach more, locally, more than one level is developed. The composition of the sediments is almost similar, fine sand; silt and clay are dominant, with subordinate pebbles. Very special case is observed in flood plain sediments are along some main streams, like Khassa Soo, Tawooq Soo, Tuz Chai, Kifri Chai, especially when these streams leave the mountainous ranges. The sediments are thicker, up to 10 m, cemented by gypsiferous material, partly forming gypcrete. Recently, they under went river erosion, therefore, are preserved as relics along side the stream bank in form of cliffs.

2.6.8. Valley Fill Sediments (Holocene)

The main streams and valleys like Nareen Chai, Zghaytoon, Kifri Chai, Tuz Chai, Tawooq Soo, Khassa Soo, Bastoora, Shalgha, Awainat …etc. are filled by sediments, which are highly variable in composition, width and thickness. The width ranges between (< 0.1 – 1) Km, exceptionally may be slightly more, like in Tawooq Soo. The thickness ranges from (< 1 – 5) m, but may exceed more than 10 m. The main composition of the pebbles is carbonates and silicates with subordinate igneous and metamorphic rocks; the pebbles are rounded to subrounded, with average size of (1 – 20) cm, but may reach to 45 cm, spheroidal, disk and rode shaped. The finer size clastics; sand and silt form minor constituents, especially in streams and large valleys, whereas the clay fraction is very rare, if not totally absent.

2.6.9. Residual Soil (Holocene)

Residual soil covers considerable parts of the Low Folded Zone. The soil is brown to reddish brown, calcareous, gypsiferous, sandy, silty and clayey, with small rock fragments and pebbles of limestone and occasionally gypsum, which increase in size and abundance depth wards. The thickness is highly variable it ranges between (< 0.5 – 5) m, but exceptionally may reach more, especially when the uppermost parts of Bai Hassan Formation builds-up the area, because very thick claystone beds; up to 100 m thick, are developed in the formation.

2.6.10. Anthropogenic Sediments

Anthropogenic Sediments are very well preserved at different localities in the Low Folded Zone, like Nineveh ruins, which form an outstanding feature in Mosul city, forming the walls of the capital of the Assyrian Empery, which are totally covered by clayey silty soil, nowadays. Many other ruins are also totally covered by clayey and silty soil were discovered since 19^{th} and 20^{th} Centuries, like Numrud, Khursabad, Ashur Castle, and others. In all those ruins, limestone and gypsum were used in construction of the buildings, and the statues. Another features are Erbil and Kirkuk Castles, both are nowadays in form of isolated hills, almost circular in a flat terrain, on top of which old parts of both mentioned cities still do exist. Their height is about (15 – 25) m, whereas the diameter ranges from (1 – 3) Km. Other features are isolated hills, which are well distributed in straight alignment in Kirkuk – Erbil Plain, Mosul vicinity and other flat plains like near Tel Kaif, Tel Asquf .. etc. The heights differ from (10 – 25) m, with diameter ranges from (50 – 150) m, mainly with flat tops, some of them are of two levels. They were used as watching towers, during Assyrian Empery. Among them are Qush Tappa, Yarim Tappa, Yarmjah. All of them nowadays are covered by clayey silty soil, or originally were built by damping of soil to the required height. Some of them may represent ancient sites, which are buried now by recent sediments.

Some irrigation channels, like Nahir Al-Feel are outstanding features with straight alignments and two adjacent embankments, which are (2 – 5) m in height. The embankments exhibit parallel and constant spacing rills, which may indicate jointing, consequently indicating Neotectonic activity in the area involved.

RESULTS

The oldest exposed rocks in the Low Folded Zone (LFZ) are of **Late Cretaceous** age, belong to the Shiranish Formation; they are mainly marl and marly limestone, representing synrift sediments. Although the formation is exposed in Sinjar anticline and a very small outcrop in Qara Chouq anticline, but it is the only formation, which extends over all the LFZ area (Fig.7C). Both mentioned areas represent inverted grabens, as well as almost all other anticlines, especially in the western part of the LFZ. This is indicated from abnormal recorded thicknesses of the Shiranish Formation in oil wells (I.P.C., 1963) that attain for example 1359 m in oil well Mushurah 1.

During **Paleocene**, the Sinjar Formations was deposited in shallow water reef, forereef and lagoon environments, whereas Khurmala Formation was deposited in restricted lagoons, as indicated by its restricted exposures (Fig.7B and A). Both formations consist mainly of limestone.

During **Eocene**, a basin was formed and filled by open marine marls of Aaliji Formation, forming the first postrift sediments (Fig.8D). Ma'ala (1977) reported about the presence of tongues of Aaliji Formation within the Sinjar Formation. This could be explained by the presence of contact between the open marine and the neighboring reef complex environment in which Sinjar Formation was deposited. After gradual rise of the sea level, due to final phase of subduction, the carbonates of the Jaddala Formation were deposited in the open marine basin (foredeep), in the extreme western limits of the Low Folded Zone in Iraq (Fig.8C). Meanwhile, the molasse clastics of Gercus Formation were deposited in the foredeep at the extreme northern margins of the Low Folded Zone (Fig.8B). Alongside the foredeep, and within shallow lagoons; the Pila Spi Formation, and locally Avanah Formation were deposited, also in the extreme northern and northeastern margins of the LFZ area (Fig.8A), along a continuous ridge that formed an obstacle for the deposition of the Gercus Formation more southwards, in the present days of the LFZ area.

During **Oligocene**, great sea level drop was witnessed because the main intraplate basin became narrower due to the tilting of west Arabia, and uplift of the High Folded Zone. The Oligocene rocks form a complex reef system, including backreef – reef – forereef sediments, which are normally repeated in three cycles during Early, Middle and Late Oligocene. The shore line of the basin was extending towards northeast till the present day Qara Dagh Mountain and extends northwest wards alongside the present day contact between Low Folded and High Folded Zones (Fig.9A, B and C). The main constituent of Oligocene formations is limestone.

During **Early – Middle Miocene,** the Savian Orogeny caused development of broad and shallow basins in which carbonates of Serikagni, Euphrates and Jeribe formations were deposited, with wide closed basins (lagoons) in which evaporates of Dhiban and Fatha formations were deposited, with different extensions within the LFZ (Fig.9A, B, C and D).However, the Dhiban Formation has very restricted exposures as compared to those of the Fatha Formation.

During **Late Miocene – Pliocene**, a major thrusting occurred during the collision of the Sanandaj – Sirjan Zone with the Arabian Plate (Neo-Tethyan terrains), causing the end of the marine phase and beginning of the continental phase. Consequently, a major foredeep (within the foreland) formed in the Low Folded Zone, which was filled by continental molasse sediments of the Injana and Mukdadiya formations (Figs.2, 3, 4, and 5).

During **Pliocene – Pleistocene**, the Alpine Orogeny reached its climax; the sediments of the Bai Hassan Formation also reached their climax and were deposited in the continuously subsiding basin covering considerable parts of the LFZ (Figs.3, 4 and 5). Meanwhile, the main rivers deposited their own terraces in different levels. The synclinal troughs filled by polygenetic sediments, the oscillation of the climate contributed in forming of the gypcrete in vast areas (Fig.2 and 3).

During **Holocene**, the continuous folding was almost ceased and accompanied with continuous weathering and erosion gave-up to the nowadays landscape, with its different stratigraphic and geomorphological units, like flood plains, valley fill sediments, Aeolian forms, residual soil, anthropogenic sediments and others.

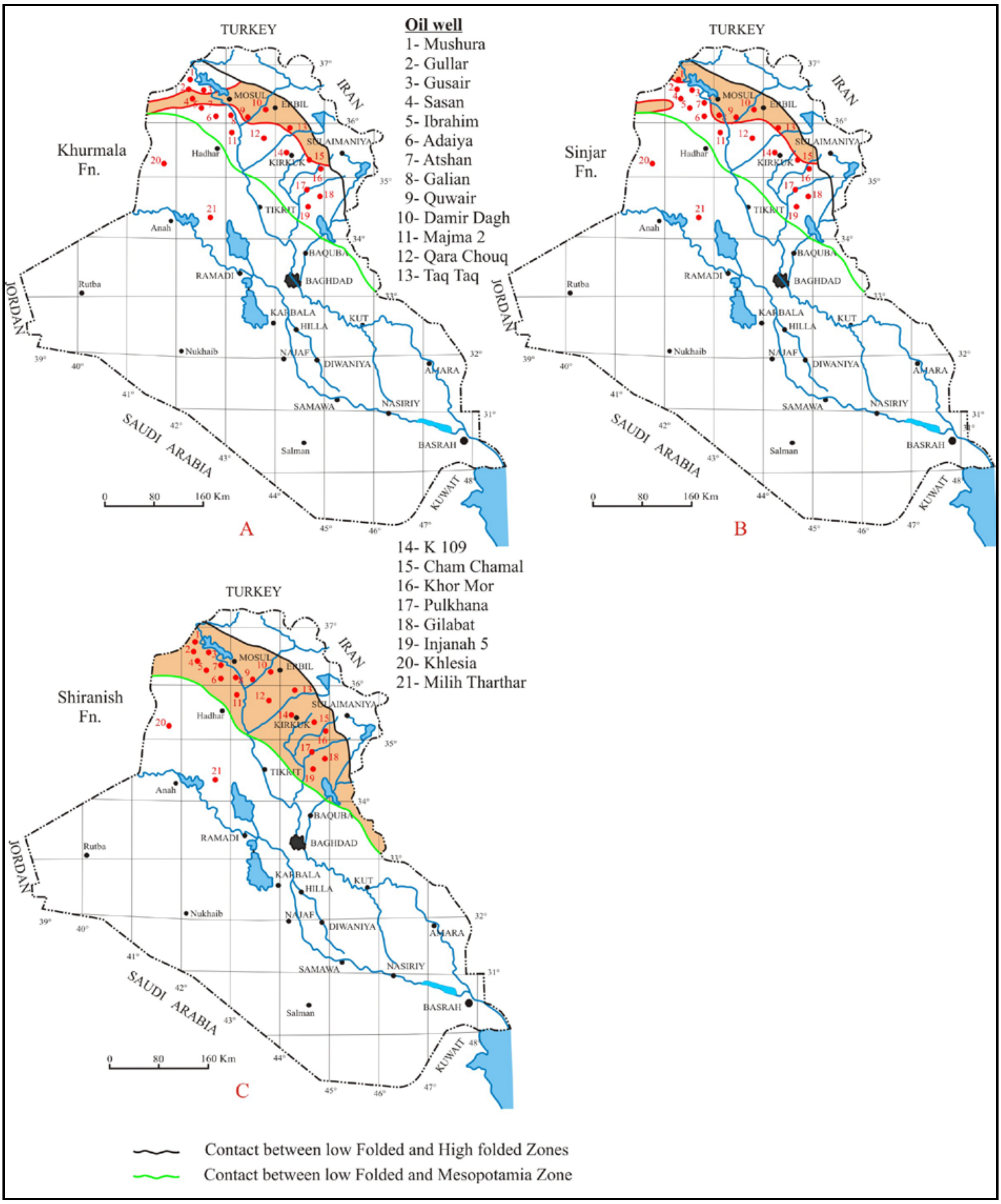

Fig.7 (A, B and C): Geographical distribution of Khurmala, Sinjar and Shiranish formations (Oil well data after I.P.C, 1963)

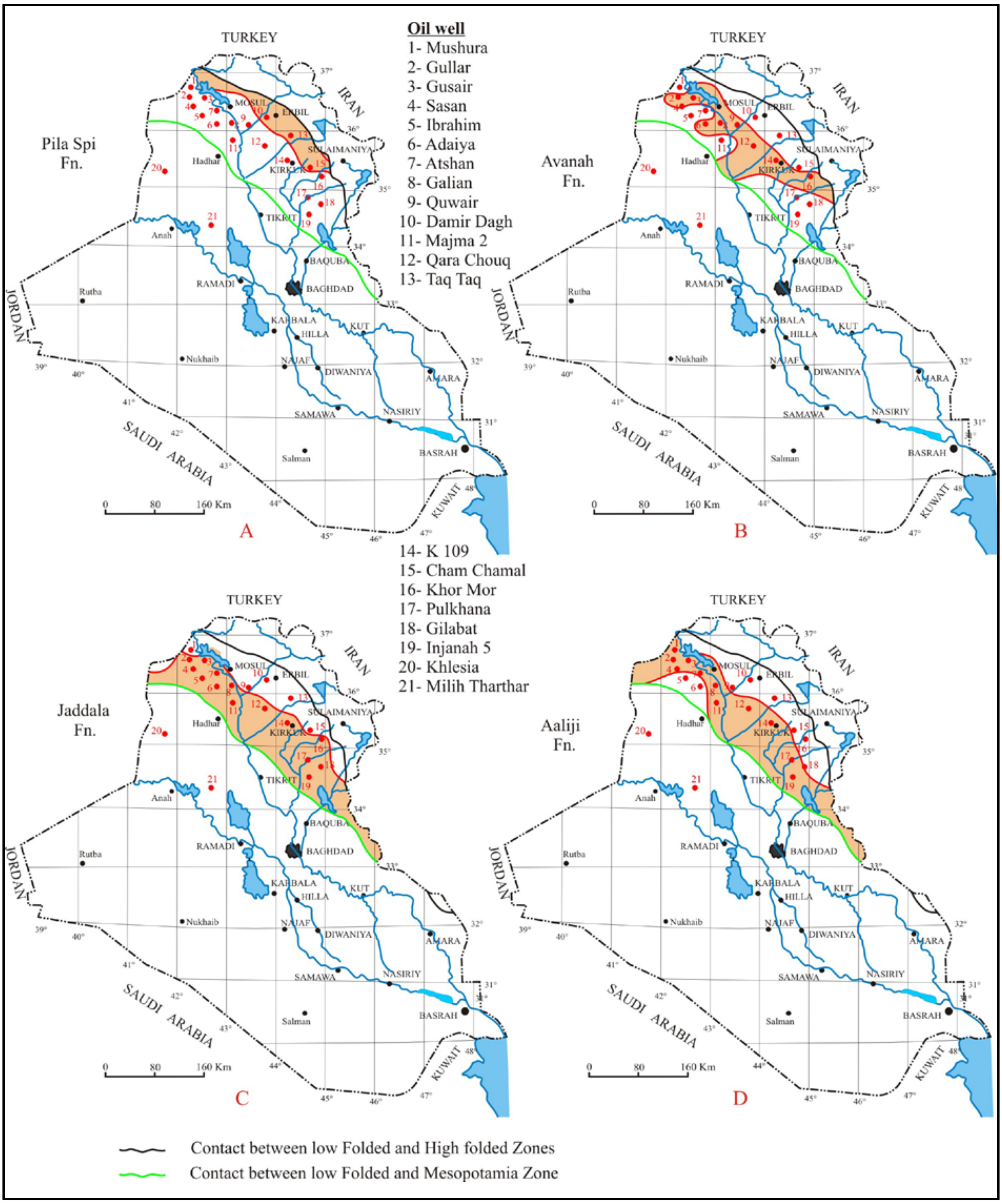

Fig.8 (A, B, C and D): Geographical distribution of Pila Spi, Avanah, Jaddala and Aaliji formations (Oil well data after I.P.C, 1963)

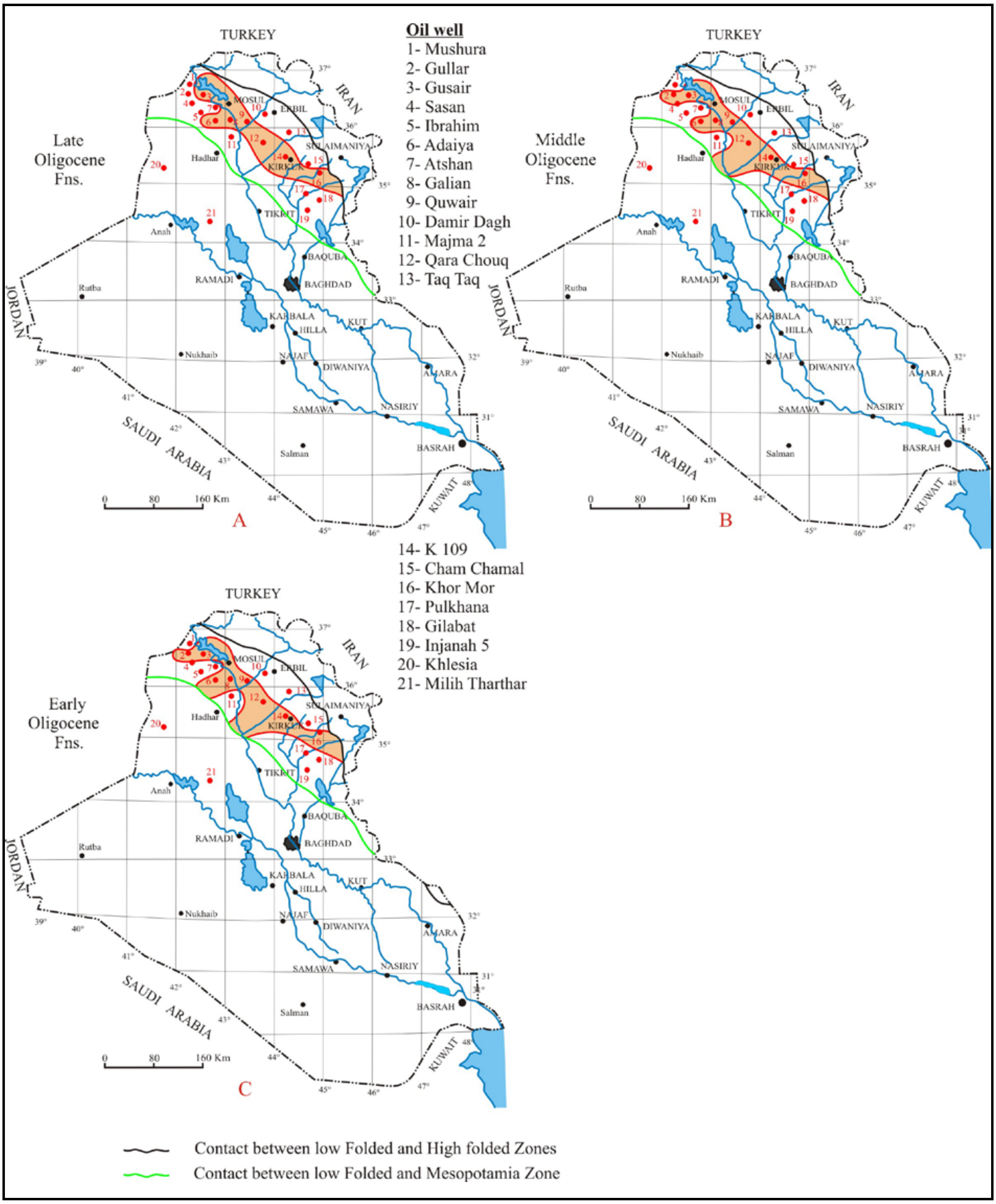

Fig.9 (A, B and C): Geographical distribution of Early, Middle and Late Oligocene formations (Oil well data after I.P.C, 1963)

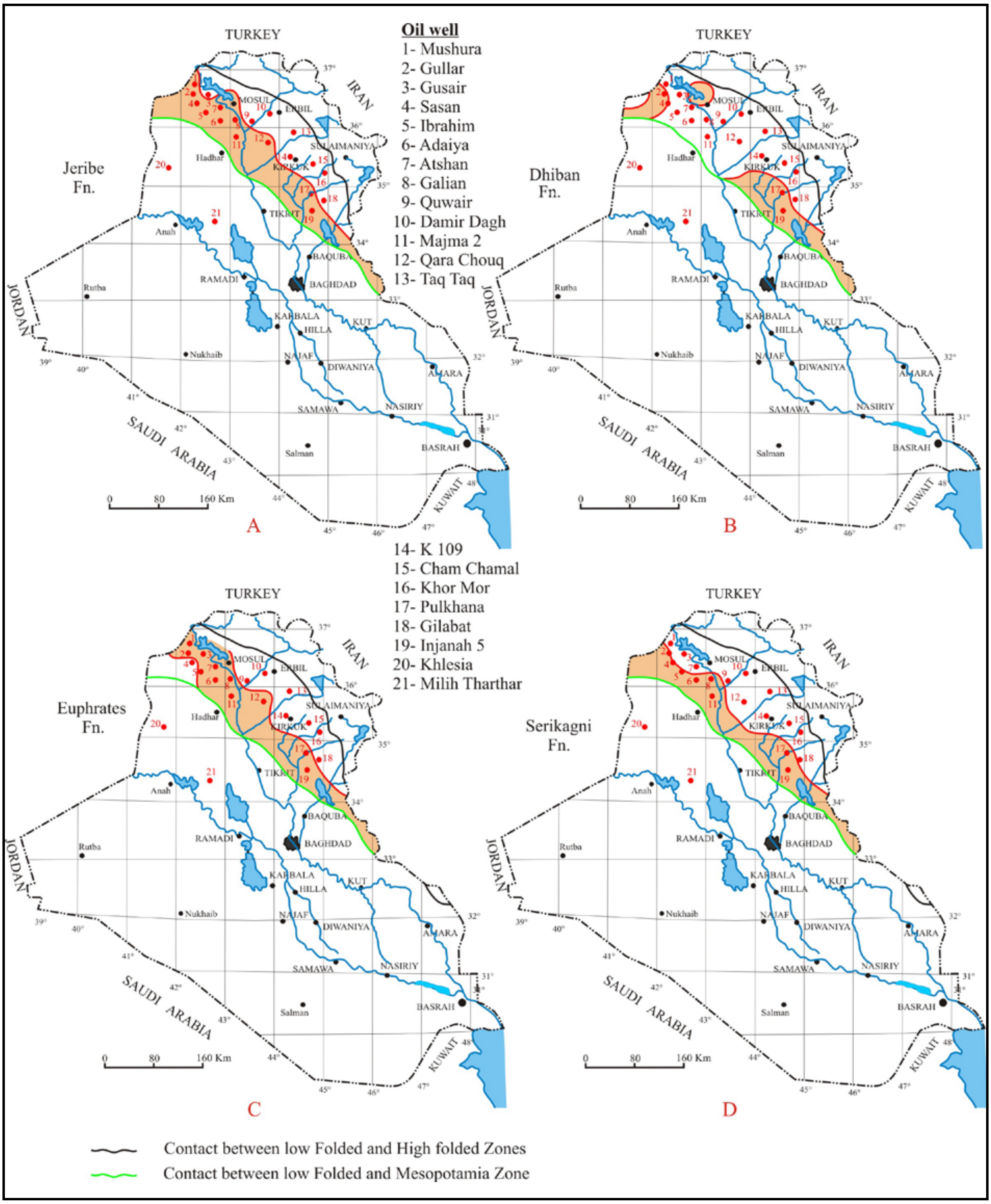

Fig.10 (A, B, C and D): Geographical distribution of Jeribe, Dhiban, Euphrates and Serikagni formations (Oil well data after I.P.C, 1963)

It is worth mentioning that the subsurface distribution of the formations, in the Low Folded Zone, which is illustrated in Figs. (7, 8, 9, and 10) depends mainly on the acquired subsurface data from the drilled oil wells during the last century (I.P.C., 1963). Therefore, the given limits for each formation might be not precise limits, because many formations were amended; age wise, and unfortunately, the recent discoveries are not mapped to indicate their geographical extensions. Therefore, it is not possible to amend the available geological maps in GEOSURV's archive. This case is mainly restricted to the Oligocene formations, where many authors (among them are Lawa, 1989; Al-Banna, 1997; Ismail, 2005; Khanqa *et al*., 2009, and Al-Banna *et al*., 2010) have recognized Oligocene formations in areas where GEOSURV's geologists were not recorded them during the regional and detailed geological mapping of the Iraqi territory, or even not mapped.

Concerning the surface and subsurface distribution of the Fatha, Injana, Mukdadiya and Bai Hassan formation, which are not illustrated in Figs. (7, 8, 9, and 10), they could be easily recognized from the presented geological map (Figs.2, 3, 4, and 5), since wherever the youngest formation, among the mentioned four formations is exposed, then the remaining older formations are exposed.

DISCUSSION

The oldest exposed rocks in the Low Folded Zone are of Late Cretaceous age. Therefore, the depositional history of the Late Cretaceous and onwards is discussed hereinafter.

During the **Late Cretaceous** (100.5 – 66 Ma), the Shiranish Formation was deposited, partly in continuously sinking basins in form of grabens forming synrift sediments, as indicated from the great difference in the recorded thicknesses in normal exposures; 225 m in the type section (Bellen *et al*., 1959) and 565 m; the exposed thickness in Sinjar anticline (Ma'ala, 1977). However, the thicknesses encountered in some oil wells, which were drilled, mainly in anticlinal structures (inverted grabens), like 1359 m in Mushurah 1; 1145 m in Injana 5; 867 m in Gullar 1, etc. are much higher. Those anticlines were previously grabens representing synrift basins (Fouad and Nasir, 2009), which were formed due to the climax of the obduction that occurred during the Late Campanian and Maastrichtian. This contributed to a major transgression across the whole Iraqi territory. Therefore, the Late Cretaceous rocks are the most wide spread rocks in the Iraqi territory. The continuous subsidence of the synrift basins (grabens) is also indicated from the type of the rocks encountered in the Shiranish Formation. In Sinjar anticline, Ma'ala (1977) described 405 m of intercalations of very hard intraformational fragments with marly limestone. Such rocks with such huge thickness are not recorded in the normal sequence of the formation out of the grabens. The presence of the intraformational fragments indicates the collapse of the fragments during the continuous subsiding of the grabens. By the end of the Maastrichtian (65 Ma), the subsidence of active grabens terminated and was followed by regional uplifting and development of region-wide unconformity (Fouad and Nasir, 2009). This is well evidenced by the absence of the Early – Middle Paleocene rocks in the involved area (Sissakian, 2000 and Sissakian and Fouad, 2012).

During the **Middle Paleocene – Early Eocene** (61.6 – 56.0 Ma), a foredeep (within the foreland) was developed, which was progressively migrating towards southwest, it occupied the entire area of the Low Folded Zone, almost extending from Mushurah, Mosul, Kirkuk and Chia Surkh (Fig.6). This basin was filled by the open marine marls of Aaliji Formation (Jassim and Buday in Jassim and Goff, 2006 and Fouad and Nasir, 2009), forming the first postrift sediments; followed by the deposition of Sinjar and Khurmala formations. The former was deposited in shallow water reef, forereef and lagoon environments, whereas the latter was deposited in restricted lagoons, as indicted by its restricted exposures, not only in the Low Folded Zone, but even northwards in the High Folded Zone, too. In Sinjar anticline, Ma'ala (1977) reported about the presence of tongues of Aaliji Formation within the Sinjar Formation. This could be explained by the presence of contact between the foredeep and the neighboring reef complex environment in which Sinjar Formation was deposited. This could be also attributed to the presence of transversal fault that divided Sinjar anticline into blocks?.

During the **Middle – Late Eocene** (47.8 – 38.0 Ma), the Neo-Tethys was narrowed and closed during the final phase of subduction. A foredeep basin (within the foreland) was developed southwest of the Low Folded Zone; this foredeep was separated from the basin to the southwest by a belt of nummulitic limestone shoals of Avanah Formation. The foredeep basin was located, partly, in the present day Low Folded Zone (Jassim and Buday in Jassim and Goff, 2006). After gradual rise of the sea level, the carbonates of the Jaddala Formation were deposited in the open marine basin, in the extreme western limits of the Low Folded Zone in Iraq. Meanwhile, the molasse clastics of Gercus Formation were deposited in the foredeep at the extreme northern margins of the Low Folded Zone. Alongside the foredeep, and within shallow lagoons; the Pila Spi Formation was deposited, also in the extreme northern and northeastern margins of the involved area, along a continuous ridge that formed an obstacle for the deposition of the Gercus Formation more southwards, in the present days Low Folded Zone area (Sissakian, 2000 and Sissakian and Fouad, 2012).

At the end of **Late Eocene** and during **Oligocene** (38.0 – 23.03 Ma), the main intraplate basin became narrower due to the tilting of west Arabia, and uplift of the High Folded Zone. Therefore, great sea level drop was witnessed; consequently, the eastern shore line receded to the southwest boundary of the Low Folded Zone. The closed Neo-Tethys was a narrow seaway in which carbonates were deposited. However, the Oligocene basin was not relatively so narrow, as claimed by Jassim and Buday in Jassim and Goff (2006). According to the new acquired data about the exposure limits of the Oligocene rocks, the shore line was extending more towards northeast until the present day Qara Dagh Mountain (Khanqa *et al*., 2009) and extends northwest wards alongside the present day contact between Low Folded and High Folded Zones. It is worth mentioning that Bellen *et al*. (1959) also claimed the presence of Oligocene exposures in the extreme northeastern margins of the Low Folded Zone at Aj Dagh and Sagirma Dagh, south and southeast of Sulaimaniyah, near Qara Dagh. Moreover, Sissakian and Fouad (2012) found that Oligocene rocks partly form the core of Aj Dagh and Qara Wais anticlines, south of Qara Dagh Mountain.

The **Oligocene** rocks form a complex reef system, including backreef – reef – forereef sediments, which are normally developed in three cycles during Early, Middle and Late Oligocene, respectively. However, not always, the three components are present in each cycle; this is attributed to the change in the basin configuration and upwards tectonic movement, which contributed in the oscillation of the eustatic sea level. Therefore, in a certain locality one or even two of the basic components of one cycle is missing. However, in certain areas the whole cycle is missing, which means non-deposition of Early or Middle or Late Oligocene cycle. This very complex system is clear from the surface exposures in Qara Chouq anticline and the acquired data from the oil wells (Al-Sammarai and Al-Mubarak, 1978 and I.P.C., 1963, respectively). Moreover, in some exposures, like in Atshan anticline, west of Mosul city, where Avanah Formation underlies the Euphrates Formation, the contact is marked by 15 m of breccia indicting the absence of Oligocene rocks (Mohi Ad-Din *et al*., 1978), whereas Oligocene rocks are present in Alan and Ibrahim anticlines (I.P.C., 1963), towards north and west of Atshan anticline, respectively. Moreover, they are present in Mishraq anticline, southeast of Mosul city, and were encountered in Al-Khafsan well (Ma'ala *et al*., 1987). This very complex situation of presence and/ or absence of the Oligocene rocks indicate the activity of Mosul High, which had uneven shape, as manifested on the irregular shape of the Oligocene basin, which gave very irregular surface and subsurface extensions of Oligocene formations (Fig.9A, B and C).

During the **Early – Middle Miocene** (23.03 – 11.63 Ma)**,** the Savian movements caused development of broad and shallow basins in which carbonates were deposited, with wide closed basins (lagoons) in which evaporates were deposited. However, the northwards extensions of the lagoons in which Fatha Formation was deposited, manifested different types of sediments. The primary component of the Fatha Formation, the gypsum, was not deposited in the extreme parts of the basin and even if was deposited, it forms thin layers as compared with those beds present in the central typical lagoonal part. Moreover, reddish brown clastics; claystone, siltstone and even fine sandstones were deposited within the Fatha Formation, forming the main constituent, especially in the top of the cycles; in the uppermost part of the formation. The authors believe that this is attributed to the basin configuration and sediments supply, where the environment for deposition of gypsum was not prevailing. It is worth mentioning that it is the same case as in the Western Desert, where the Fatha Formation passes to another formation; recently recognized by Sissakian *et al*. (1997) and called the Nfayil Formation. Therefore, the authors highly recommend this aspect for future studies, which may conclude for announcement of a new formation, instead of the Fatha Formation, in the extreme margins of the Low Folded Zone and within the High Folded Zone and farther northwards areas, and they recommend the name of "Sar Sang Formation".

The exposed Euphrates Formation, in the Low Folded Zone, has different lithological constituents as compared with those present in the type locality (Bellen *et al*., 1959) and the suggested supplementary type section too (Jassim *et al*., 1984). The authors believe it is another unrecognized formation, which interfingers with the true Euphrates Formation somewhere south of the Low Folded Zone. Therefore, they highly recommend this aspect for future studies, which may conclude for announcement of a new formation.

The **Middle Miocene**, in the Low Folded Zone, is characterized by vertical block movements, which were the main factor in the cyclicity and frequent isolation of the Middle Miocene Basin (Tucker and Shawket, 1980). Among the blocks is the Mosul Block, which has caused separation of the main depositional basin, in Mosul vicinity from the surrounding areas, into two parts. The northwestern one; in which abnormal thick sediments of the Fatha Formation were deposited, with very thick Unit A, as compared to other parts of the basin. The second part is in the south and southeast of Mosul; in which normal sediments of the Fatha Formation were deposited with the five informal units (Al-Mubarak and Youkhanna, 1976). In Mosul vicinity, due to the block movements, the five informal units are not developed with large decrease in the thickness of the formation, due to upward movements (Mohi Ad-Din *et al*., 1977).

The coverage areas of the Jeribe Formation were not well defined during the regional geological mapping of the Iraqi territory. This is attributed to the large lithological similarities between the rocks of the Euphrates and Jeribe formations. Therefore, when the Dhiban Formation is not developed, then the two formations are hardly differentiable in the field. This leads to a conclusion that in some localities, the Jeribe Formations was missed and mapped with the Euphrates Formation, as one unit.

During the **Late Miocene – Pliocene** (11.63 – 2.588 Ma), a major thrusting occurred during the collision of the Sanandaj – Sirjan Zone with the Arabian Plate (Neo-Tethyan terranes), causing the end of the marine phase and beginning of the continental phase. Consequently, a major foredeep (fresh water basin) formed in the Low Folded Zone, which was filled by continental molasse sediments. The size of the sediments was increased; continuously, due to continuous and intensely uplifting of the High Folded Zone; behind the Low Folded Zone. The erosion products were laid down in the foredeep as continental molasse sediments that represent the end of the last marine phase and the begging of the continental phase.

The Injana and Mukdadiya formations were deposited in the foredeep, continuously by huge braided rivers; their energy was increasing continuously with continuous uplifting of the Zagros Range, due to Alpine Orogeny. It is worth mentioning that Jassim *et al*. (1984) merge the abandoned Middle Fars Formation, which was mapped by GEOSURV's geologists separately during the regional geological mapping of the Iraqi territory, with the Injana Formation. The authors are in full accordance with merging of the two formations, because they have almost the same lithology, depositional environment and age, though precise age determination is not available for the both formations. However, the authors pay attention that not the same lower and upper contacts of the abandoned Middle Fars Formation were considered, in all coverage areas of the Low Folded Zone; during the regional geological mapping. Therefore, the present contact between Injana and underlying Fatha formations is not always on the same stratigraphic level. Hence, the authors suggest diachronous contact between the two formations.

The contact between the Injana and Mukdadiya formations suffers from stratigraphic problem too. Because a pebbly sandstone horizon marks the contact, the pebbly sandstone is not a well stratigraphic marker, it may disappear within hundred of meters along the strike, and appears again in a younger or older stratigraphic level, because it depends on the energy and shape of the stream that was carrying the sediments. This had caused, in different localities of the Low Folded Zone to mark different stratigraphic contacts between the two formations. Therefore, the contact should always be considered as a diachronous.

Six "**Burnt Hills**" exist within the Injana Formation in Injana vicinity; one is east of Baghdad – Kirkuk main road, whereas the other five are west of the road. They are aligned within a 3.5 Km long lineament, which is parallel to the main thrust fault of Himreen South anticline (NW – SE). The fused rocks are of claystone, underlain by sandstone, they include vanadium, and bitumen was found along the thrust fault plane (Basi and Jassim, 1974 in Ma'ala *et al*., 2006), and the flowing groundwater from the springs includes NaCl and Sr (Ma'ala *et al*., 2001, in Ma'ala *et al*., 2006). All these aspects are good indications for the presence of hydrocarbon seepages from depth along the fault plane (Ma'ala *et al*., 2006).

The presence of Bentonite in the Mukdadiya Formation, in Himreen and Pulkhana anticlines indicates volcanic activities in nearby areas. Zainal (1977) believes that, the bentonite is derived from the alteration of volcanic ash. Remnants of glass shards were identified in thin sections of the Qara Tappa bentonite. The fallen ash was precipitated during the Pliocene, because the Bentonite is present in the upper parts of the Mukdadiya Formation of Late Miocene – Pliocene age. This may be a good indication for the presence of volcanic activity in nearby areas of the Low Folded Zone, during Pliocene?.

During the **Pleistocene** (2.588 – 0.0117 Ma), the Alpine Orogeny reached its climax; the sediments of the Bai Hassan Formation also reached their climax in the size of the pebbles and the thickness of the individual conglomerate beds (Jassim *et al.*, 1984). The deposition mode was by extremely large braided rivers with extremely large energy in transporting maximum loads, which deposited the sediments in form of alluvial fans and deltas. Meanwhile, the main rivers, streams and valleys deposited their own terraces after continuous incision of their courses forming different terrace stages. The synclinal troughs filled by polygenetic sediments, the oscillation of the climate contributed in forming of the gypcrete in vast areas. Large parts along the main ridges and limbs of anticlines were covered by slope sediments, which partly were lithified and formed calcrete. The present thickness of the calcrete indicates very wet periods, which were able for deposition of such huge sediments. Moreover, locally they have the same inclination of the former slopes upon which they were deposited, indicating quiet depositional basins, which have not suffered from active folding. The folding started to decrease in its intensity after mid Pleistocene, but is still continuous.

During the **Holocene**, the continuous folding accompanied with continuous weathering and erosion gave-up to the nowadays landscapes, with their different stratigraphic and geomorphological units, like flood plains, valley fill sediments, residual soil, Aeolian forms and others. However, the presence of multi stage flood plains in some rivers, main streams and valleys indicate climatic oscillation between wet and dry seasons.

CONCLUSIONS

Concerning the stratigraphy of the Low Folded Zone, the following can be concluded:

- The oldest exposed rocks in the Low Folded Zone are of Shiranish Formation (Late Cretaceous) representing, in some cases synrift sediments. They are exposed widely in Sinjar anticline and very small exposure in the core of Qara Chouq Anticline.
- During the Middle Paleocene, a foredeep was developed, it was progressively migrating towards southwest; it occupied the entire present day Low Folded Zone area, extending from Mushurah, Mosul, Kirkuk to Chia Surkh, and extends in Iran. The open marine marls of Aaliji Formation, as well as Sinjar and Khurmala formations filled this basin.
- During the Late Paleocene – Eocene, the Neo-Tethys was narrowed and closed during the final phase of subduction. A foredeep basin was developed northeast of the Low Folded Zone area in which the first post rift sediments of the Aaliji Formation were deposited. This foredeep was separated from the basin to the southwest by a belt of nummulitic limestone shoals of Avanah Formation. To the south, Jaddala Formation was developed as postrift sediments, whereas to the north; Gercus (Molasse sediments) and Pila Spi (Lagoon sediments) formations were developed. The foredeep basin was located, partly, in the present day Low Folded Zone.
- At the end of the Eocene, the main intraplate basin became narrower due to the tilting of west Arabia, and uplift of the High Folded Zone. The eastern shore line receded to the southwest boundary of the Low Folded Zone. The closed Neo-Tethys was narrow seaway in which carbonates were deposited.
- The Oligocene basin was not so relatively narrow, as it was recorded by the previous works. This is evidenced by the presence of Oligocene rocks, both on surface and subsurface, as compared to the previously recognized rocks. A complex body of backreef – reef – forereef was deposited in three main cycles, which represent Early, Middle and Late Oligocene. However, the three cycles are not always present, indicating tectonic unrest and/ or basin configuration that had caused the absence of one or more cycles in certain areas.

- During the Early – Middle Miocene, the Savian movements caused development of broad and shallow basins in which carbonates of Serikagni and Euphrates formations were deposited, however, in small closed basins evaporates of Dhiban Formation were deposited. During Middle Miocene the marine transgression, extended westwards forming shallow basins, with carbonate deposits of Jeribe Formation, whereas in closed lagoons, which covered vast areas, evaporates and carbonates of the Fatha Formation were deposited, in cyclic nature, indicating cyclic oscillation of the sea level, due to vertical block movements.
- During the Late Miocene – Pliocene major thrusting occurred during the collision of the Neo-Tethyan terranes (Arabian Plate) with the Sanandaj – Sirjan Zone, causing the end of the marine phase and beginning of the continental phase. A major foredeep formed in the Zagros Foreland, which was filled by continental molasse sediments that increased in size continuously, due to continuous and intensely uplifting of the High Folded Zone; the erosion products, which were laid down in the foredeep represent Injana, Mukdadiya and Bai Hassan formations.
- During Pleistocene – Holocene, the present landforms started to develop, the main rivers and streams incised their river-beds forming terrace systems, usually (2 – 4) levels. Polygenetic sediments filled the synclinal troughs. Alluvial fans were developed along main mountain chains. Considerable parts are covered by residual soil due to weathering that was accelerated during wet phases, which prevailed many times. The main rivers, streams and valleys also exhibit a well developed system of flood plains and infilled valleys.

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