STRATIGRAPHY OF THE HIGH FOLDED ZONE

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ABSTRACT

The stratigraphy of the High Folded Zone (HFZ), in Iraq is reviewed. The oldest exposed rocks are Early Triassic in age, whereas the youngest are of Pliocene – Pleistocene age, which belong to the Bai Hassan Formation. The exposed stratigraphical column is represented by 36 formations, with 10 main types of Quaternary sediments, which have wide geographic extent and well preserved in the HFZ.

The Triassic, Jurassic, Cretaceous and Paleogene rocks are mainly of marine carbonates with some clastics. The Oligocene rocks form a complex of reef – backreef – forereef and are restricted almost in the eastern and western parts of the area, with restricted exposures in different parts. The Early and Middle Miocene rocks are mainly of marine origin, lagoonal carbonates and fairly developed evaporates, respectively, with restricted exposures. The Late Miocene – Pleistocene rocks, which represent the beginning of the continental environment, consist of molasse sediments, deposited in sinking foredeep, which had few separated and isolated basins. The Quaternary sediments are well developed, especially Pleistocene river terraces of different stages, alluvial fan sediments, calcrete and other different types. Glacier moraine sediments, may be present in Rawandooz – Galala vicinity.

For each exposed formation, the type locality, exposure areas, subsurface extension, main lithology (as described in form 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 by the present authors. The main tectonic events and the paleogeography of each era or period are reviewed briefly. Each formation is discussed, for the 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.

طباقيــة نطاق الطيات العالية

فاروجان خاجيك سيساكيان و بثينة سلمان الجبوري

المستخلص

تمت مراجعة طباقية نطاق الطيات العالية في العراق، تعود أقدم الصخور المتكشفة الى عصر الترياسي المبكر والأحدث تعود الى عصر البلايوسين – البلايستوسين المتمثلة بتكوين باي حسن. إن العمود الطباقي المتكشف في نطاق الطيات العالية يتمثل بستة وثلاثين تكوينا، إضافة الى عشرة أنواع رئيسية من ترسبات العصر الرباعي ذات الامتداد الجغرافي الواسع والسمك الكبير.

إن غالبية صخور الترياسي، الجوراسي، الطباشيري والباليوجيني هي صخور بحرية كاربوناتية مع بعض الصخور الفتاتية، بينما صخور الأوليگوسين تمثل صخور معقد الحيد وتتموضع في الجزئين الشرقي والغربي وفي أجزاء أخرى منتشرة في المنطقة. أما صخور المايوسين المبكر والأوسط هي في الغالب صخور بحرية كاربوناتية – لاغونية مع بعض الصخور الجبسية.

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إن صخور المايوسين المتأخر – البلايستوسين تمثل بداية البيئة القارية وتتمثل بترسبات المولاس الفتاتية المترسبة في الحوض العميق (foredeep basin) لأرض زاگروس الأمامي (Zagros Foreland). إن عدم ترسب صخور الأوليگوسين في جميع مناطق نطاق الإلتواءات العالية يمثل من أهم ظواهر عدم الترسيب (غير التوافقي)، حيث إنها تتركز في الأجزاء الشرقية ومناطق متفرقة من نطاق الإلتواءات العالية، وسبب ذلك هو نهوض المنطقة بشكل عام وحركات الصفيحة العربية. كما أن ترسيب صخور المولاس بداء من المايوسين المتأخر تمثل ظاهرة مهمة أخرى، حيث تشير الى تغير البيئة الترسيبية من البحرية الى القارية، بينما الترسبات القارية قبل هذا العصر قليلة في المنطقة، وسبب تغير البيئة هو تصادم الصفيحة العربية مع الصفيحة الاوروسية (الإيرانية). أما العصر الرباعي فيتمثل بشكل رئيسي بالترسبات الفيضية المختلفة وان بعضها متأثرة بالحركات البنيوية الحديثة وهناك أدلة عديدة لوجود واستمرار هذه الحركات، إضافة الى ترسبات المراوح الفيضية والكالكريت وأنواع أخرى. وقد تكون هناك بعض ترسبات الثلاجات (Moraine) في مناطق راوندوز – گلالة ؟ ايضا.

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, considerable amount of data were acquired concerning the stratigraphy of the High Folded Zone, in Iraq. These were mainly achieved through the regional geological survey, conducted by Iraq Geological Survey (GEOSURV), started in 1971 and was terminated in 1982. The second stage, of data collection, achieved through the detailed geological survey, which was conducted in very restricted parts. Through both aforementioned stages, many formations were amended and their ages, lithological constituents and relation with other formations were elucidated more clearly than before. Moreover, large parts of the High Folded Zone were covered by interpretation of aerial photographs, consequently geological maps at scale of 1: 100 000 were compiled (Ibrahim, 1984). Based on the regional geological survey data, GEOSURV compiled the Geological Map of Iraq, at scale of 1: 1000 000, 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, until then; utilizing the compiled and published series of geological maps at scale of 1: 250 000 (39 sheets). Sissakian and Fouad (2012) updated the geological map of Iraq; at scale of 1: 1000 000, to be the fourth issue depending on the most recent available data acquired from the detailed geological mapping, especially in Sulaimaniyah vicinity (Al-Shwaily *et al*., 2012). Moreover, Sissakian and Fouad during 2006 – 2012 did a lot of field checking in the northern and northeastern parts of the Iraqi territory to update the available maps and check other inadequate data; the authors in this paper already have utilized some of the recently acquired data.

This paper is an attempt to review and explain the stratigraphy of the Iraqi High Folded Zone, depending mainly on the regional and detailed geological surveys carried out by GEOSURV's geologists, beside many recently published articles by different authors; referred to in the text. It aims to elucidate the geology of the High Folded Zone. To prepare this paper, which represents GEOSURV's opinion, the best and final available data have been used.

LOCATION

The High Folded Zone covers small part of the Iraqi territory. Its coverage area is about 15827 Km². Its contact with the Low Folded Zone runs almost parallel to the first continuous ridge of the Pila Spi Formation, starting in the southeast from Sharwaldar Mountain along the Iraqi – Iranian international boundaries. Then extends northwards to Zimnaco Mountain; near Darbandi Khan, then extends northwestwards running parallel to Qara Dagh, Baranan, Haibat Sultan, Bana Bawi, Permam, Peris, Aqra, Dohuk and finally Bai Khair Mountains and extends inside Syria. Fouad (2012 and 2014) had defined the northeastern, northern and northwestern contact with the Imbricate Zone. Geographically, the contact starts from southeast of Halabja town and extends northwest wards. It passes through south of Chwarta, Mawat and Qalat Diza towns, then runs almost parallel to the main thrust fault of the Zagros Suture Zone, which extends more northwest wards crossing, north of Rawandooz, Merga Sur, Baiboo, north of Amadiya and Zakho towns (Fig.1).

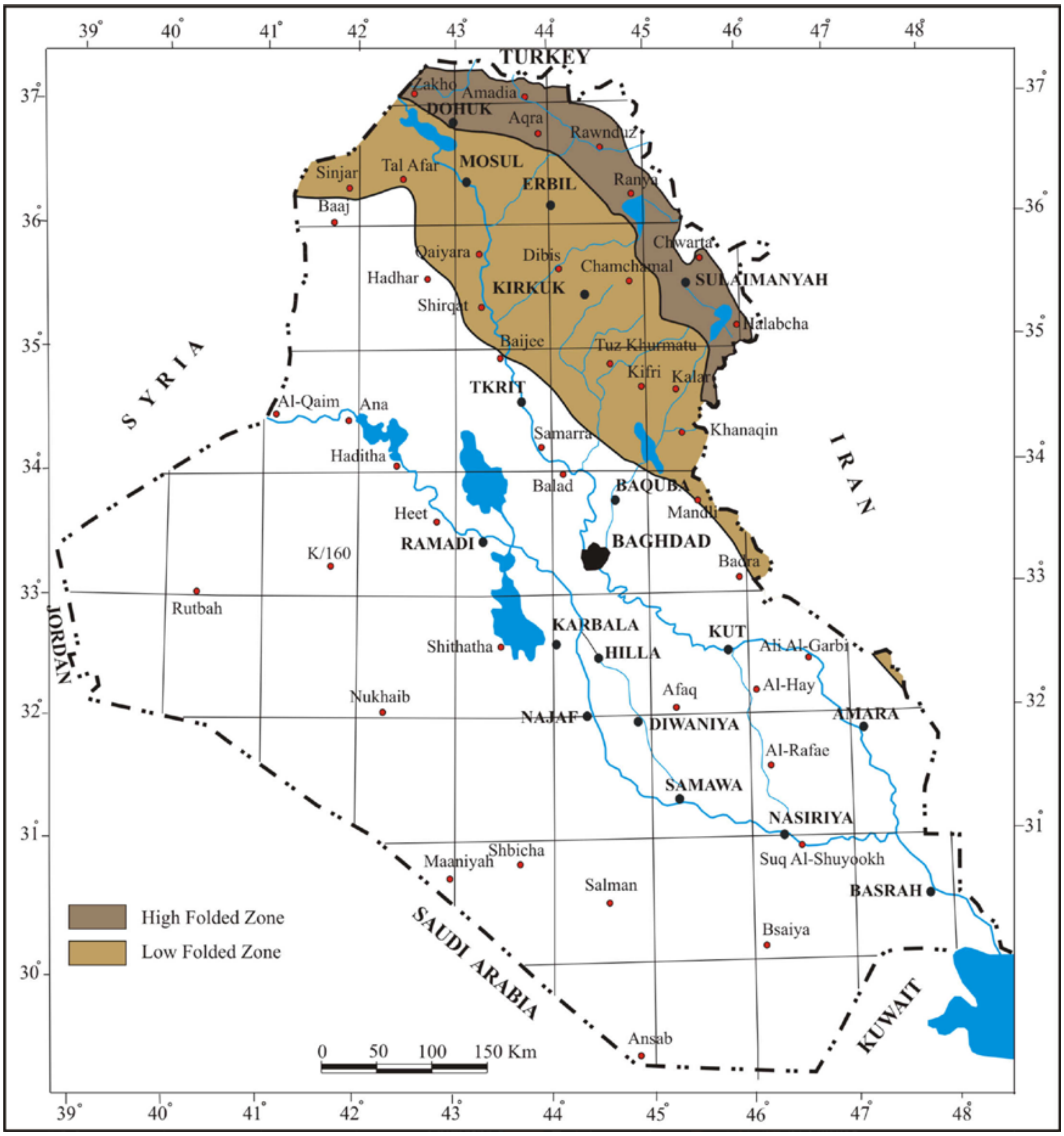

Fig.1: Location map of the High Folded Zone (after Fouad, 2012)

GENERAL TOPOGRAPHY

The High Folded Zone (HFZ) is characterized by different topographic natures. The nature of the topography reflects the type of the exposed rocks, their thicknesses and structur. Generally, two main different topographical parts could be recognized, this is mainly due to presence of longitudinal and narrow anticlines and synclines, with the Greater Zab, Lesser Zab, and Diyala (Sirwan) rivers that dissect the involved area. Darbandi Khan, Dokan and Dohuk lakes are within the area too. The two topographic parts are:

- **The elevated (mountainous) parts,** which consist of rocky surface dissected by numerous streams and valleys running either parallel to the main strike in NW – SE and SE – NW directions changing westwards to N – S, or perpendicular to the main strike in NE – SW direction. This part forms the area that covers the majority of the High Folded Zone.
- **The flat and undulatory parts,** form restricted areas with small coverage forming almost main plains, which are covered by clastics of different formations and Quaternary sediments. They are usually dissected by axial valleys and/ or streams, which run almost 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, like Shahri Zoor Plain, near Sulaimaniyah city, or form badland morphology, as in the southern part of the HFZ area.

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The High 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 affects have controlled the type of the exposed rocks, thicknesses, and surface and subsurface extensions of the formations.

In order to facilitate the description of the exposed geological formations in the High Folded Zone, they are divided, agewise 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 (if data is available), and lithology; as divided into members and/ or informal units, and as described by different authors from different localities; during execution of the geological mapping by Site Investigation Co. (1954 – 1958) and by GEOSURV (1971 – 2012). Moreover, fossils, age, depositional environment and the lower contact of each formation are mentioned too.

The names of some formations 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 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.

The adopted descriptions of the formations with their geographical distribution and other mentioned data is based on 18 regional and detailed geological survey reports of GEOSURV. 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: 20 000 and 1: 25 000), which were used in compilation of the published geological maps at scale of 1: 250 000. However, because the area of the High Folded Zone is not fully covered by geological mapping, therefore, the data presented in this article depends also on the available reports, Ph.D. and M.Sc. theses and published relevant articles. Moreover, geological maps at scale of 1: 100 000 prepared from interpretation of aerial photographs and visual interpretation of high quality Landsat and Quickbird images were used in compilation of the geological maps, and in writing of this article. Google Earth images also were used, occasionally for deducing ambiguous data and/ or areas where no adequate data are available. Moreover, in areas where no geological mapping was performed, the description of the formations depends on the available data of nearby areas. Therefore, in some formations, the list of the fossils, age, depositional environment, and lower contact are mentioned; as reported by Bellen *et al*. (1959), Jassim *et al*. (1984), Jassim and Goff (2006), and Aqrawi *et al*. (2010).

Sissakian (1995 – 1997) compiled many geological maps at scale of 1: 100 000 within the High Folded Zone, using aerial photographs, among them are Rawandooz, Qalat Diza, Zibar, Aqra, Koi Sanjaq, Ain Sifni, and Aqra, the maps are depoited in the archives of the Geology Department, GEOSURV. However, those areas were continuously checked in the field; using high quality Landsat and Quickbird images, the acquired data were confirmed also by some published articles and some post graduate theses, consequently, those compiled maps were updated and used by Sissakian and Fouad (2012) in compilation of the Geological Map of Iraq at scale of 1: 1000 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), Jassim and Buday in Jassim and Goff (2006) and Aqrawi *et al*. (2010). The established megasequences of the Sequence Stratigraphy by Sharland *et al*. (2001) are introduced in the described articles of the stratigraphy of the High Folded Zone. The mentioned time span for each period and epoch is based on the recently established "International Chronostratigraphic Chart" (Gradstein *et al*., 2012 and ICS, 2012).

Wherever the authors have found it necessary to give explanations, hints, comments concerning the descriptions and/ or ideas of previous authors, or when contradictions occure, for any reason, they 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. However, in the **DISCUSSION** part, critical reviews and discussions are given on some data, which contradicts the well known ideas and data, concerning the stratigraphy of the Iraqi territory.

Because deep wells in the area of the High Folded Zone are very rare, except the recently drilled oil wells by foreign oil companies working in the Iraqi Kurdistan Region, whose result are impossible to use, the subsurface extensions of the exposed formations are not well known. However, if the present data in the drilled deep wells in the neighboring Low Folded Zone provide any significant data for the subsurface extension, which are useful for this study, then they are already utilized and mentioned under the title "**Exposed Areas**" for each formation. Some field photos for the majority of the exposed formations are enclosed in the text too.

The exposed geological formations, from oldest to youngest are described hereinafter. A geological map, at scale of 1: 1000 000 (Fig.2) (Sissakian and Fouad, 2012), elucidates the geographical distribution of the formations. The location of the type localities and/ or sections is presented in Fig. (3), their reference numbers are mentioned in Table (1). It is worth to mention that the authors have utilized the presented data by Sissakian and Fouad, 2012), to elucidate the updated geological acquired data. The updated data depends on 37 performed field checks. In some areas, crucial changes were performed to the geology of the High Folded Zone. All these changes are presented in this article.

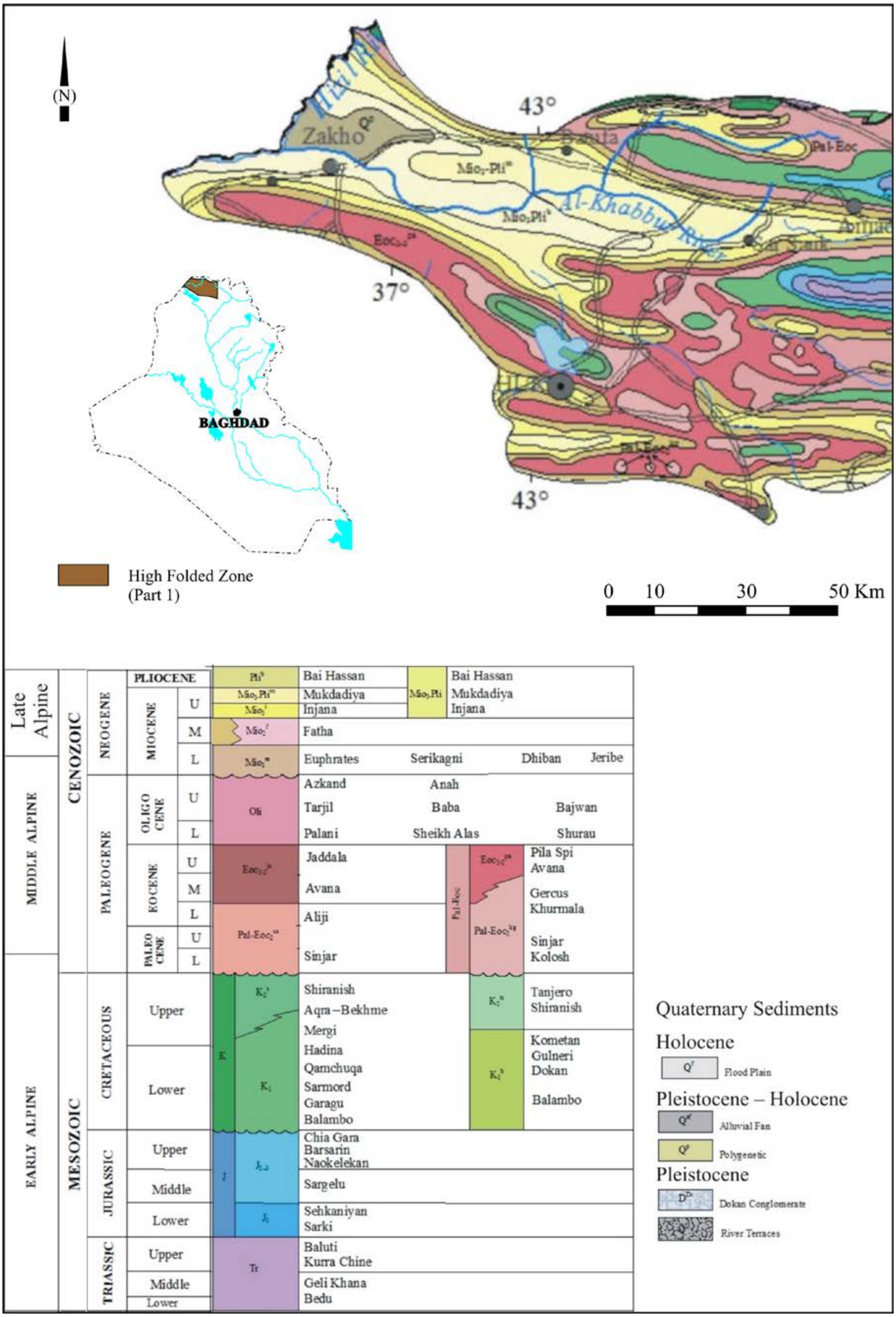
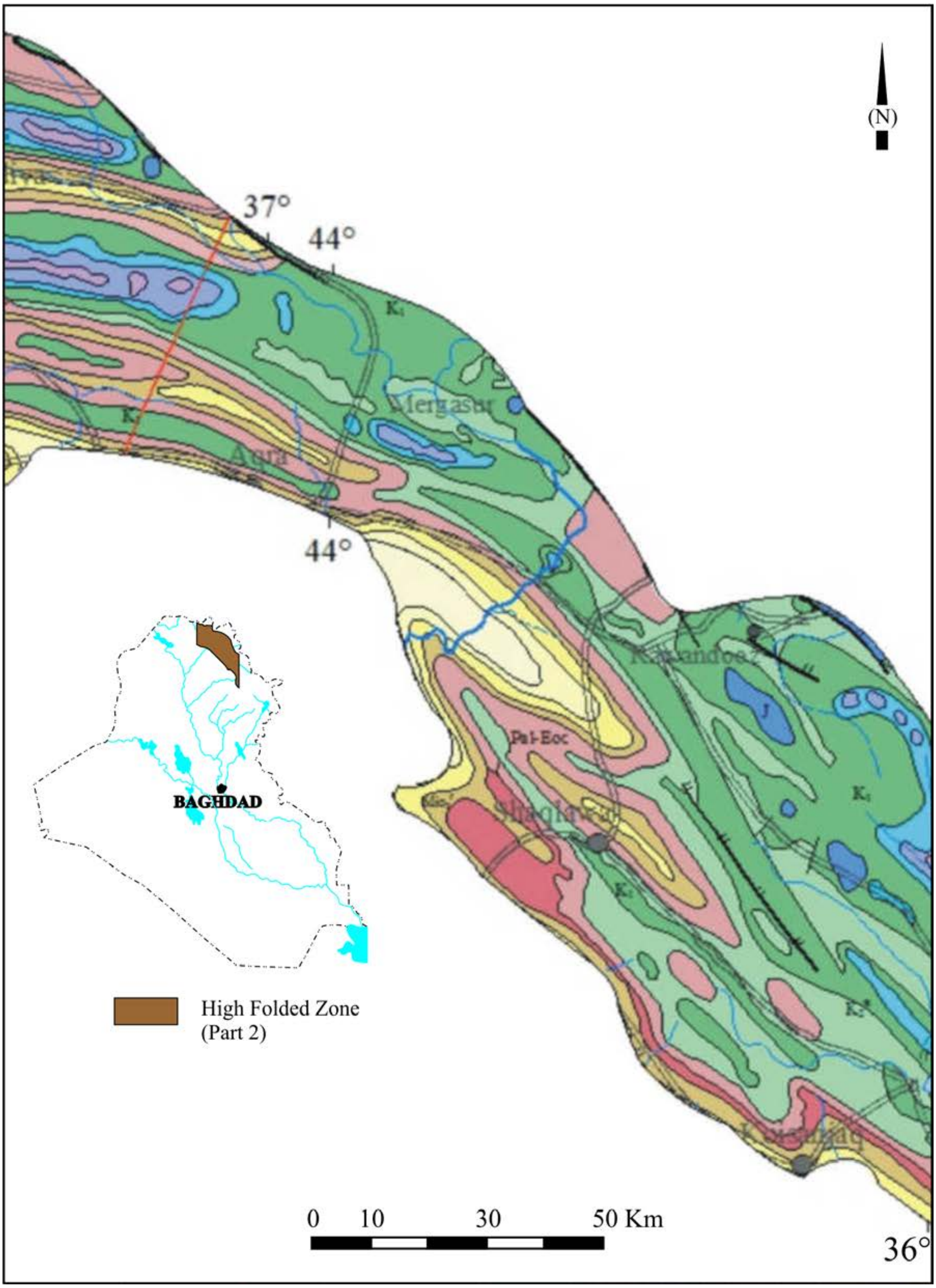
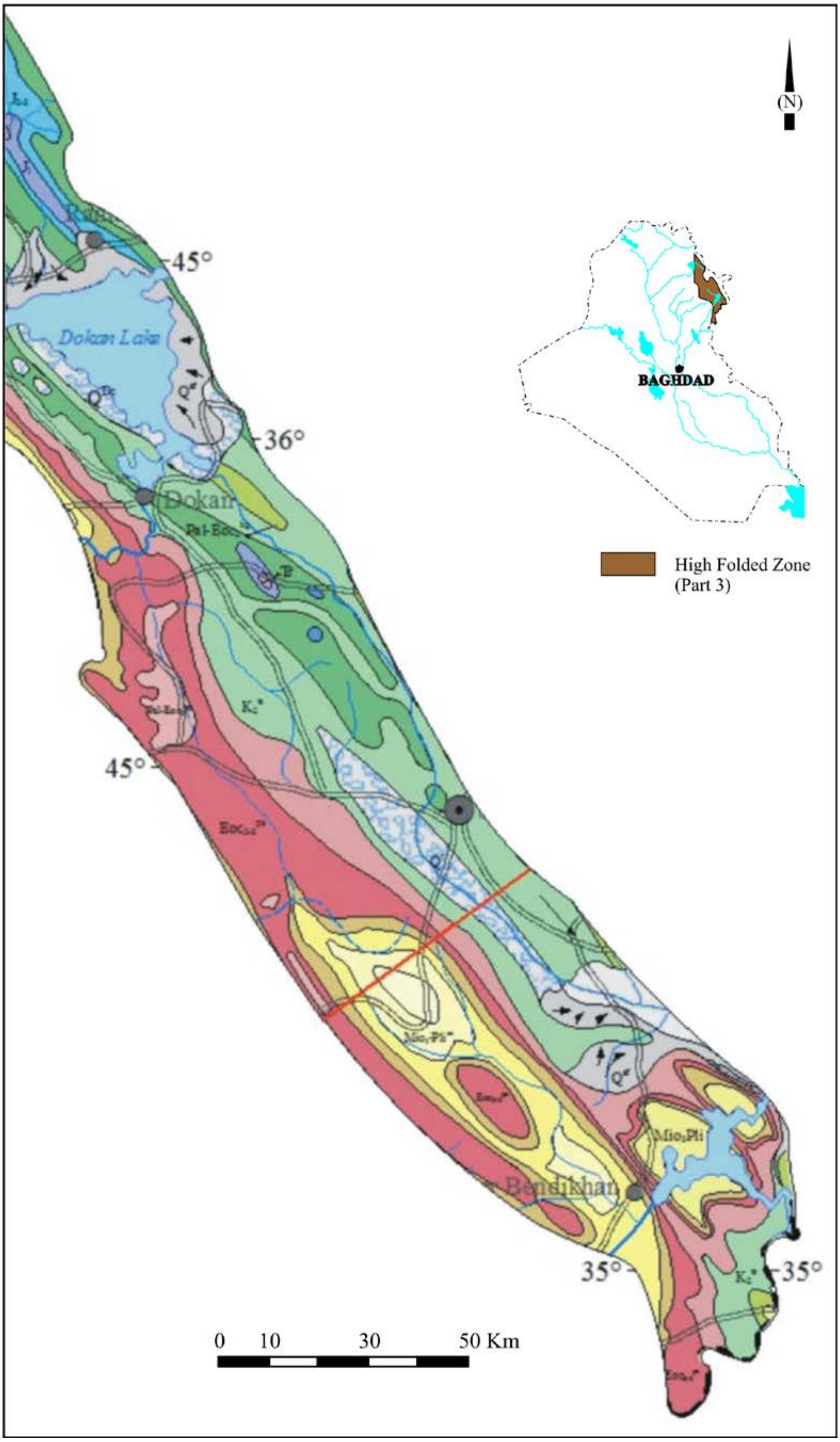


Fig.2: Geological map of the High Folded Zone, scale 1: 1000 000 (Part 1)
(After Sissakian and Fouad, 2012)



Cont. Fig.2: Part 2



Cont. Fig.2: Part 3

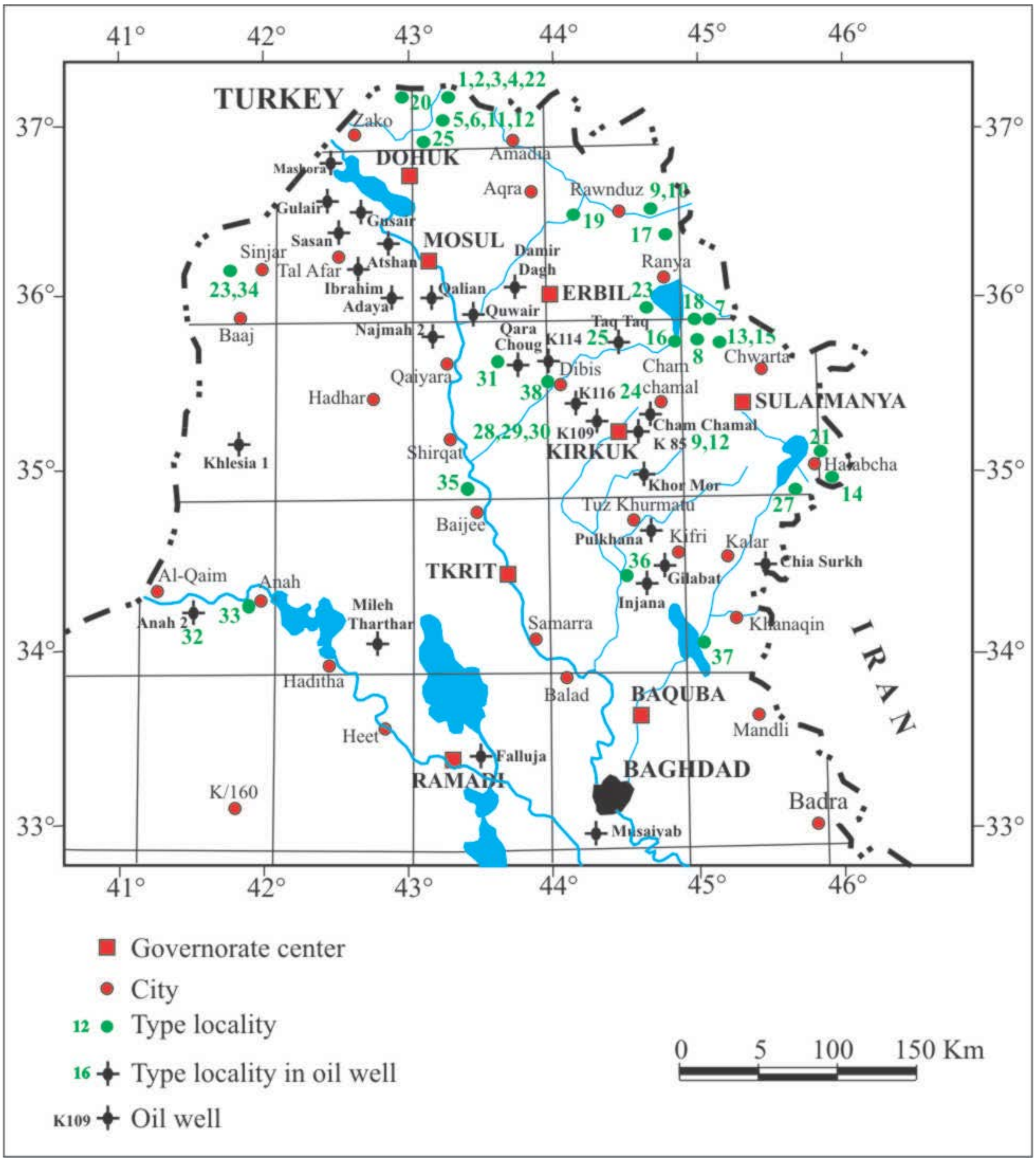


Fig.3: Location of the type localities of the exposed geological formations in the High Folded Zone
(Numbers in green represent the reference numbers of the exposed formations, refer to Table 1 to indicate the name of the formation)

Table 1: Reference number of the type locality or type section of
Each exposed formation, as indicated in Fig. (3)

Serial No.	Formation	Serial No.	Formation	Serial No.	Formation	Serial No.	Formation
1	Geli Khana	10	Garagu	19	Tanjero	28	Bajwan
2	Kurra China	11	Sarmord	20	Kolosh	29	Tarjil
3	Baluti	12	Balambo	21	Sinjar	30	Anah
4	Sarki	13	Qamchuqa	22	Khurmala	31	Euphrates
5	Sehkaniyan	14	Dokan	23	Gercus	32	Jeribe
6	Sargelu	15	Kometan	24	Avanah	33	Fatha
7	Naokelekan	16	Gulneri	25	Pila Spi	34	Injana
8	Barsarin	17	Aqra – Bekhme	26	Shurau	35	Mukdadiya
9	Chia Gara	18	Shiranish	27	Baba	36	Bai Hassan

1. MESOZOIC

Within the Mesozoic Era, 19 formations are exposed in the High Folded Zone, representing Triassic, Jurassic and Cretaceous Periods. The formations are described hereinafter, continuously and systematically.

1.1. Triassic

During the Early Triassic the Neo-Tethys, which was opened since Late Permian, was progressively widening, forming an unconformity in the northern and eastern margins of the Arabian Plate, consequently a passive margin was developed. During Middle – Late Triassic the Neo-Tethys was further widening along the northern and eastern margins of the Arabian Plate. A rifting occurred within the passive margins; creating a broad and highly restricted intra-shelf basin in the Mesopotamia, which was separated from the open ocean by a narrow rift with alkali basalts and an outer ridge of thinned continental crust on which an open marine carbonate platform developed (Jassim and Goff, 2006).

The Triassic Period, in the High Folded Zone is represented by three formations. They form part of the Late Permian – Liassic Megasequence (AP6) established by Sharland *et al*. (2001) and are described hereinafter.

1.1.1. Geli Khana Formation (Early Triassic)

Type Locality: The Geli Khana Formation is defined by Wetzel in 1950, the type section is along Geli Khana, north flank of Ora anticline. The top of the formation occurs in the stream, about 1 Km south of the Turkish frontier; it is defined by the following coordinates (Bellen *et al*., 1959) (Fig.3):

Longitude 43° 21' 30" E
Latitude 37° 19' 06" N

Exposure Areas: The Geli Khana Formation is exposed in Amadiya only, within the High Folded Zone, but it is exposed in the Imbricate Zone (Sissakian and Fouad, 2012). Its subsurface extensions south of the High Folded Zone and farther southwards are obscure, because majority of the deep test oil wells were not reached the Early Triassic. However, the formation was encountered in Atshan 1, Ibrahim 1 and Milih Tharthar 1 oil wells, southwest of the zone, but not in Khlesia oil well (Fig.3), which hit the Paleozoic Khabour formation (I.P.C., 1963).

Lithology: In the type locality, the Geli Khana Formation consists of laminated ferruginous dolomites, 3.5 m thick. Dark foetid dolomites, with bands of grey dolomitic limestones; contain abundant recrystallized gastropods, 58 m thick. Hard fine grained, dark grey, limestone, with intercalations of olive green shales and yellow brown marls, 138 m thick. Bluish shales, with intercalations of yellow limestones and occasional sandy bands, 154 m thick. Greyish and yellowish, thin bedded limestones and shales with bands of recrystallized breccias, 65 m thick. Greyish thin bedded limestones and hard, limy shales, with streaks and ribs of ripple-marked sandstone, 156 m thick (Bellen *et al*., 1959). Near Halabja (Fig.4), it consists of rubby, thinly bedded limestone and bands of shale, occasionally sandstone beds occur too, overlain by blue limestone with dolomitic limestone (Bolton, 1954c).

Fig.4: The Geli Khana Formation (**G**) overlain by the Kurra China (**K**) and Baluti formations (**B**), near Halabja

Thickness: In the type locality, the thickness of the Geli Khana Formation is 575 m, near Halabja in Sirwan valley 435 m, near Amadiya 550 m, near Ranya not mentioned.

Fossils: In the type locality, the following fossils were recorded from the Geli Khana Formation: *Myophoria* spp., *Lingula tenuissama* Bronn, *Spirorbis valvata* Goldfuss, *Glomospira* sp., *Trocholina* sp., *Problematina* sp. and ostracods (Bellen *et al*., 1959).

Age: Bellen *et al*. (1959) claimed Middle Triassic age (Anisian – Ladinic) for the Geli Khana Formation; from correlation with the better-dated Sirwan gorge succession. According to Dunnington *et al*. (1959), the age of the formation is Landinian based on *Daonella indica, D.* cf. *indica, D. lomelli* and *D. lomelli-taramelli*.

Depositional Environment: According to Pesl (1976), the lower part of the Geli Khana Formation represents lagoonal evaporitic sedimentation. This is supported by the presence of lenticels of gypsum in the whole section in boreholes and in Sirwan section. In the type section, the abundant breccia in the formation, may represent recrystallization breccia; after solution of gypsum or anhydrite. The top of the formation represents the Tr50 MFS of Sharland *et al*. (2001) (Aqrawi *et al*., 2010).

Lower contact: The Geli Khana Formation is underlain by the Bedu Formation; the contact is conformable and gradational, taken at the colour change from grey above to purple below, which corresponds to a lithological change from dominant limestone above to dominant shale below. However, in Sirwan gorge, gypsum lenticles occur too in the lower contact (Bellen *et al*., 1959).

1.1.2. Kurra China Formation (Late Triassic)

The Kurra China Formation is one of the most widely spread formations of Late Triassic age in northern Iraq, forming conspicuous ridges.

Type Locality: The Kurra China Formation is defined by Wetzel in 1950, the type section is in Geli Khana and Kurra China ridge, northern limb of Ora anticline, the base of the section occurs in the stream, about 1 Km south of the Turkish frontier, it is defined by the following coordinates (Bellen *et al*., 1959) (Fig.3):

Longitude 43° 21' 30" E
Latitude 37° 19' 06" N

Exposure Areas: The Kurra China Formation is exposed in Sarki only, within the High Folded Zone, but it is exposed in the Imbricate Zone (Sissakian and Fouad, 2012). Its subsurface extensions south of the High Folded Zone and farther southwards are obscure, because the majority of the deep test oil wells did not reach the Triassic. However, the formation was encountered in Alan 1, Butmah 2, Atshan 1, Qalian 1, Ibrahim 1, Milih Tharthar 1 and Khlesia oil wells (Fig.3) (I.P.C., 1963).

Lithology: In the type locality, the Kurra Chine Formation consists of "dark brown and black limestones, alternately thin bedded and thick bedded, with occasional intercalations of thick bedded, foited dolomites showing slump structures and of papery shales" (Bellen *et al*., 1959). Near Halabja, it consists of thinly bedded limestone, overlain by thickly bedded grey limestone; followed by massive blue limestone and black dolostone (Fig.4) (Bolton, 1954).

Thickness: In the type locality, the thickness of the Kurra China Formation is 834 m, near Halabja it is about 400 m.

Fossils: Bellen *et al*. (1959) recorded the following fauna in Kurra China Formation from the type locality: *Posidonia wengensis* Wissaman, *P. mut.altior* Frech, *P. idriana* Mojs, *Estheria minuta* (Goldfuss), *Estheria* sp., *Glomospira* spp., *Archaediscus* sp., *Problematina* sp., spicules and ostracods. The same author listed the following fossils from the Sirwan area:

Spongiostroma sp., and poorly preserved micro fauna including: *Archaediscus* sp., *Problematina* sp., *Glomospira* spp., *Coskinolinopsis primaefus* Henson, *Favreina* sp., and *Corprolithus* sp.

Age: The age of the Kurra China Formation is Upper Triassic, possibly Rhaetic at the top (Bellen *et al*., 1959). Moreover, Jassim *et al*. (1984) claimed a Late Triassic age, according to the presence of the *Posidonia* fauna, from the type Kurra China Formation and *Estheria* sp., from the upper part of the formation; suggest Late Triassic or even Rhaetic age.

Depositional Environment: The abundance of anhydrite and the abundant dissolution breccia in the Kurra China Formation, indicate lagoonal condition (Jassim *et al*., 1984). The carbonates represent the Tr60 and Tr70 MSF of Sharland *et al*. (2001), whereas the anhydrites represent lowstand sediments at the base of sequences Tr70 and Tr80 (Aqrawi *et al*., 2010).

Lower Contact: The Kurra China Formation is underlain by the Geli Khana Formation; the contact is sharp and erosional marked by ferruginous horizon up to 3 m thick (Bellen *et al*., 1959).

1.1.3. Baluti Formation (Late Triassic)

Type Locality: The Baluti Formation is defined by Wetzel in 1950 and amended by Morton in 1951, the type section of the formation is south of Amadiya, 800 m southeast of Zeiwa village and 2 Km west – northwest of Baluti village in the core of the Chia Gara anticline. A subsidiary type section, in which the full formation is exposed, was discovered later near Sarki village, 9 Km east of Baluti village, it is defined by the following coordinates (Bellen *et al*., 1959) (Fig.3):

Longitude 43° 27' 12" E
Latitude 36° 59' 56" N

Exposure Areas: The Baluti Formation is exposed in Chia Gara, Sarki and Ranya only, within the High Folded Zone, but it is exposed northwards in the Imbricate Zone (Sissakian and Fouad, 2012). Its subsurface extensions south of the High Folded Zone and farther southwards are obscure, because the majority of the deep test oil wells did not reach the Triassic. However, the formation was encountered in Butmah 2, Qalian 1, Atshan 1, Khlesia and Milih Tharthar 1 oil wells (Fig.3), southwest of the zone (I.P.C., 1963).

Lithology: In the type locality, the Baluti Formation consists of grey and green shales, calcareous, dolomitic with intercalations of thinly bedded dolomitized limestones, silicified limestones, and solution recrystallization breccias (? Following solution of anhydrites), pseudo-oolitic limestones" (Bellen *et al*., 1959). Near Halabja, it consists of green and grey shale, thinly bedded dolomitic limestone, and green and grey shale (Fig.4) (Bolton, 1954c). In Gara anticline, it consists of gray, marly dolomitic limestone (Abdullaziz, 1978).

Thickness: In the type locality, the thickness of the Baluti Formation is 36.2 m, in Sarki (the supplementary type section) 43.5 m, in Sirwan valley 42 m, in Ranya not mentioned.

Fossils: Very few fossils are known from Baluti Formation; such as *Glomospira* sp., ostracods, *Problematina* sp., *Archaediscus* sp. and indeterminate mollusks (Bellen *et al*., 1959 and Jassim *et al*., 1984).

Age: The Baluti Formation is Rhaetic age, based on *Glomospira* sp. (Danington *et al*., 1959).

Depositional Environment: The Baluti Formation is deposited under lagoonal condition; this is supported by abundant solution breccias in the outcrops (Jassim *et al*., 1984). According to Aqrawi *et al*. (2010), the formation is deposited in a continental setting and may include Aeolian (loess) sediments. The formation probably represents the latter part of a lowstand to early transgressive sequence of Tr80 MFS (Aqrawi *et al*., 2010).

Lower contact: The Baluti Formation is underlain by the Kurra China Formation; the contact is gradational and conformable taken at the first appearance of thick green shales above the bedded silicified dolomite (Bellen *et al*., 1959).

1.2. Jurassic

During Early Jurassic, the rate of subsidence on the northern margins of the Arabian Plate slowed and relatively uniform marginal marine clastics, evaporites and shallow water lagoonal carbonates were deposited. During Middle – Late Jurassic, the deposition occurred during isolation of the main intra-shelf basin from the Neo-Tethyan Ocean, probably due to renewed rifting along the northeastern margin of the Arabian Plate. Deposition in the basin occurred in a restricted, relatively deep water, environment during Middle Jurassic. The basin became evaporitic during Late Jurassic (Jassim and Buday, 2006 in Jassim and Goff, 2006).

The Jurassic Period, in the High Folded Zone is represented by six formations. They represent the uppermost part of the Late Permian – Liassic Megasequence (AP6) and the whole Late Toarcian – Early Tithonian (Middle – early Late Jurassic) Megasequence (AP7), and the Late Tithonian representing the lowermost part of Megasequence (AP8), established by Sharland *et al*. (2001). The exposed formations are described hereinafter.

1.2.1. Sarki Formation (Early Jurassic)

Type Locality: The Sarki Formation is defined by Wetzel in 1952, the type section of the formation is in the Chia Gara range, south of Amadiya. A section runs 170° E, from 200 m west of Baluti village; up a stream course, which drains the southern (strike) slope of Chia Gara, it is defined by the following coordinates (Bellen *et al*., 1959) (Fig.3):

Longitude 43° 59' 37" E
Latitude 36° 59' 37" N

Exposure Areas: The Sarki Formation is exposed in Surdash, Sehkaniyan, Ranya, and Chia Gara only, within the High Folded Zone, but it is exposed in the Imbricate Zone (Sissakian and Fouad, 2012). Its subsurface extensions south of the High Folded Zone and farther southwards are not so clear; it passes to Butmah Formation (Jassim and Goff, 2006).

Lithology: In the type locality, the Sarki Formation consists of "upper division of 181 m of soft grey dolomites, highly cavernous, and weathering into massive beds of "cargneule" type, alternating with soft, featureless, friable, cherty dolomites and with grey and yellowish shales and blocky marls with melikaria (box-work structure). Lower division of 122 m of thin bedded, cherty and dolomitic limestones, fine grained to porcellaneous, pale grey, weathering whitish, alternating with friable, cherty shales, and occasional dark, sugary dolomites. Also commonly, thin beds of shell-breccias, oolitic limestones, micro-conglomerates, and recrystallization breccias occur, with dark brown, massive bedded dolomites at base" (Bellen *et al*., 1959). Near Amadiya, it consists of purple grey cherty dolomite, overlain by well bedded, brown and fine grained dolomitic limestone (Hall, 1954), near Ranya, it consists of thinly bedded, light grey dolomitized limestone, with splintery fractures, generally bituminous and fossiliferous (Bolton, 1954a). In Gara anticline, it consists of white and grey, massive dolomitic limestone (Abdullaziz, 1978).

Thickness: In the type locality, the thickness of the Sarki Formation is 303 m, near Amadiya it is 300 m, near Ranya it exceeds 230 m, and in Gara anticline it is about 400 m.

Fossils: In the type locality, the upper part of Sarki Formation contains only rare *Archaediscus* sp., *Problematina* sp., *Glomospira* spp., minute gastropods, fish debris and algae. The lower part of the formation has similar fauna with addition of *Trochalina* sp., *Glomospira* spp .and rich *Cyrenids eomiddon* Cox (Bellen *et al*., 1959).

Age: The age of the Sarki Formation is Liassic, possibly including part-Rhaetic, but regarded as Liassic only, by convention (Bellen *et al*., 1959). However, Early Liassic age has been inferred based on the stratigraphic position of the formation between the well defined underlying Upper Triassic Kurra China Formation and the well defined overlying Middle Jurassic beds of the Sargelu Formation (Jassim and Goff, 2006). Moreover, Aqrawi *et al*. (2010) claimed that the age of the formation may start from Late Triassic.

Depositional Environment: Buday and Suk (1978) concluded that the Sarki Formation is transgressive as indicated by the prevailing subtidal conditions. Oscillation in water level is assumed for the upper argillaceous part of the formation. Supratidal conditions are assumed for the deposition of the lower part of the formation. The Sarki Formation represents the MFS J05, however, Tr80 also may be included in the lower part of the formation (Aqrawi *et al*., 2010).

Lower Contact: In the type locality, the Sarki Formation is underlain by Baluti Formation, the contact is conformable and gradational taken at the top of interbedded green and grey shales and dolomitic limestone, and at the base of dark brown massive dolomites, which constitute the lowest feature-forming unit in Sarki (Bellen *et al*., 1959). Abdullaziz (1978) and Jassim *et al*. (1984) also recorded conformable contact between the two formations. However, according to Dannington *et al*. (1959) the contact appears to be sharp although conformable.

1.2.2. Sehkaniyan Formation (Early Jurassic)

Type Locality: The Sehkaniyan Formation is defined by Wetzel and Morton in 1950, the type section of the formation is at Surdash anticline, Sulaimaniyah district in a stream lying 1 Km southwest of Sehkaniyan village, it is defined by the following coordinates (Bellen *et al*., 1959) (Fig.3):

Longitude 45° 08' 00" E
Latitude 35° 52' 55" N

Exposure Areas: The Sehkaniyan Formation is exposed in Surdash, Ranya, Chia Gara, and Ser Amadiya only, within the High Folded Zone, but it is exposed in the Imbricate Zone (Sissakian and Fouad, 2012). Its subsurface extensions south of the High Folded Zone and farther southwards are not so clear, because it passes to Mus Formation (Bellen *et al*., 1959).

Lithology: In the type locality, the Sehkaniyan Formation consists of "Upper division of 51 m dark, foited, sacharoidal dolomites and dolomitic limestones, locally with chert. Middle division of 44 m, organic and pellety limestones, locally dolomitized, with silicified fossils and some chert, in beds of thickness of 1 m (towards top) to 20 cm (towards base), dark blue to dark brown at top, greenish grey at base. Lower division of 85 m, consists of dark, saccharoidal dolomites and subordinate dolomitized limestones, with pseudo-breccias (probably replacing solution-brecciated gypsious marls) at top" (Bellen *et al*., 1959). Near Amadiya, it consists of massive to bedded, black and brown saccharoidal dolomite (Hall, 1954), near Ranya it consists of massive dark dolomite (Fig.5) with a sugary texture, generally bituminous (Bolton, 1954b). In Surdash, it consists of three units, these are: **Lower Unit** (85 m) consists of brownish grey massive dolomite and dolomitic limestone. **Middle Unit** (44 m) consists of dark grey, thickly bedded limestone and dolomitic limestone. **Upper Unit** (55 m) consists of brownish and dark grey dolomitic limestone (Al-Shwaily *et al*., 2012).

Thickness: In the type locality, the thickness of the Sehkaniyan Formation is 180 m, near Aamdiya 200 m, near Ranya ranges from (200 – 250) m, in Surdash 184 m.

Fossils: From the type section of The Sehkaniyan Formation, the following fossils were recorded: *Lithiotis* sp., *Spiriferina* sp., *S. ampla* Bittner, *Spiniferina* spp., *Zelleria* sp., *Hauranya* sp., *Lituola* sp., *Glomospira* spp., ostracods, algae and gastropods and pelecypods debris (Bellen *et al*., 1959).

Fig.5: The Sehkaniyan Formation in Surdash anticline

Age: The age of the Sehkaniyan Formation is Liassic, probably Upper Liassic, by regional correlation (Bellen *et al*., 1959). Based on the fossils and by correlation with Early Jurassic Lithiolitis bearing units in Iran (Kent *et al*., 1951) and the Middle Liassic occurrence of the *Boueina hochstetteri* in Morocco, a Liassic, probably Upper Liassic age has been assigned to the formation (Bellen *et al*., 1959), and Early Jurassic age claimed by Al-Shwaily, *et al*. (2012).

Depositional Environment: Buday and Suk (1978) considered the Sehkaniyan Formation as starting of regressive condition leading to the deposition of supratidal and intertidal sediments at the expense of subtidal environment. The cyclicity was attributed to the sea level changes; brought by tectonic pulses. However, Aqrawi *et al*. (2010) considered the depositional environment as dominantly subaqueous evaporites in a shallow, arid intrashelf basin and it is a part of transgressive system tract, as compared to Alan Formation. Moreover, the lower and upper contacts of the Sehkaniyan Formation represent J10 and J20 of the MFS, respectively.

Lower Contact: The Sehkaniyan Formation is underlain by Sarki Formation; the contact is gradational and conformable taken at the base of dark brown massive dolomite unit, 60 m thick, and at the top of splintery, yellow-green shales with limestone (Bellen *et al*., 1959). Jassim *et al*. (1984) also reported about conformable contact between the two formations.

1.2.3. Sargelu Formation (Middle Jurassic, Bajocian – Bathonian)

Type Locality: The Sargelu Formation is defined by Wetzel in 1948, the type section of the formation is at Surdash anticline, in the northern part of Iraq, in the course of the stream, which flows northwards through Sargelu village, the base lies 280 m north of the stream confluence at Sargelu village, it is defined by the following coordinates (Bellen *et al*., 1959) (Fig.3):

Longitude 45° 09' 25" E
Latitude 35° 52' 44" N

Exposure Areas: The Sargelu Formation is exposed in Sehkaniyan, Surdash, Pera Magroon, Ranya, Kurrek, north of Rawandooz, Chia Gara, and Ser Amadiya only, within the High Folded Zone, but it is widely exposed in the Imbricate Zone (Sissakian and Fouad, 2012). Its subsurface extensions south of the High Folded Zone and farther southwards are clear, it exists almost in the whole Low Folded Zone and farther south and southwest wards. The formation was encountered in Butmah 2, Ibrahim 1, Adayah 1, Atshan 1, Gullar 1, Ain Zala 16, Faluja 1, Qara Chauq 1, Damir Dagh 1, Sasan 1, Milih Tharthar 1, Makhul 1, Qalian 1, Najmah 29, Samarra 1, Kifl 1, and Samawa 1 oil wells, south and southwest of the zone. However, not in Khlesia oil well (Fig.3), which hit Paleozoic Khabour Formation (I.P.C., 1963).

Lithology: In the type locality, the Sargelu Formation consists of thin bedded, black, bituminous limestones, dolomitic limestones and black, papery shales, with streaks of thin black chert in the upper parts" (Bellen *et al*., 1959). Near Amadiya, it consists of black radiolarian shales, papery bitumious shales, yellow marly limestone, with abundant ammonites (Hall, 1954). Near Ranya, it consists of thinly bedded shaley black limestone and shale with black chert and brown dolomitic marl, highly fossiliferous (Bolton, 1954b), in Pera Magroon and Surdash, it consists of dark grey, thickly bedded limestone and dolomitic limestone, with thin horizon of black papery shale (Al-Shwaily *et al*., 2012).

Thickness: In the type locality, the thickness of the Sargelu Formation is 115 m, near Amadiya ranges from (150 – 300) m, in Chia Gara 65 m, near Ranya 70 m, in Pera Magroon and Surdash 120 m.

Fossils: In the type locality, the following fossils were recorded from the Sargelu Formation: In the uppermost 12 m: *Posidonia ornate* Quenstedt, *Posidonia somaliensis Cox, Parkinsonia* sp., *Stephanoceras* sp., occasional plant remains. In the next 21 m, the following fossils were identified: Poor impressions of ammonites. In the lowermost 82 m, the following fossils were identified: *Rhynchonella curviceps* Dal Piaz, *Rhynchonella de lottoi* Dal Piaz, *Posidonia opalina* (Quenstedt) and *Graphaea balli* (Stefanini) (Bellen *et al*., 1959).

Age: The age of the Sargelu Formation is Bathonian at the top, uppermost Liassic at the base (Bellen *et al*., 1959). Al-Shwaily *et al*. (2012) claimed a Middle Jurassic age (Bajocian – Bathonian) for the formation.

Depositional Environment: According to Buday and Suk (1978), the Sargelu Formation was deposited in basinal marine environment, possibly of euxinic conditions but the lower part shows sedimentation under intertidal – supratidal marine conditions. Sharland *et al*. (2001) placed the J30 (Middle Callovian) MFS within the Sargelu Formation (Aqrawi *et al*., 2010).

Lower contact: The Sargelu Formation is underlain by Sehkaniyan Formation; the contact is gradational and conformable taken at the top of massive bedded dolomitic limestone and below thin-bedded blue cherty brittle and laminated limestone. This contact is persistent throughout exposure areas (Bellen *et al*., 1959).

1.2.4. Naokelekan Formation (Late Jurassic)

Type Locality: The Naokelekan Formation is defined by Wetzel and Morton in 1950, the type section of the formation is at a road side and in stream bed, 500 m northwest of Naokelekan village, east of Rawandooz town, it is defined by the following coordinates (Bellen *et al*., 1959) (Fig.3):

Longitude 44° 44' 10" E
Latitude 36° 36' 00" N

Exposure Areas: The Naokelekan Formation is exposed in Surdash, Ranya, Chia Gara, Ser Amadiya, Sargelu, Pera Magroon, Ranya, Kurek, north of Rawandooz, Bazanja and near Halabja; within the High Folded Zone, but it is widely exposed in the Imbricate Zone (Sissakian and Fouad, 2012). Its subsurface extensions south of the High Folded Zone and farther southwards are obscure. "It did not exists in deep wells west of the Tigris River, since all Upper Jurassic sediments are absent in the Cretaceous/ Jurassic unconformity, which places Aptian or Albian Sarmord Formation directly above eroded Middle Jurassic" (Bellen *et al*., 1959). Moreover, the formation passes to Najmah Formation, in the aforementioned areas. However, the formation was encountered in K 109 and Qara Chauq 1 (Fig.3) (I.P.C., 1963).

Lithology: In the type locality, the Naokelekan Formation consists of shaley limestone, 4 m hard, dark grey or bluish, mottled limestone with ammonite traces, 7 m of thin bedded, extremely bituminous limestones and dolomites, with intercalated, black, bituminous, calcareous shales" (Bellen *et al*., 1959). Near Ranya, it consists of laminated shaley limestone with mottled grey and brown limestone followed by black carbonaceous shales (Fig.6) (Bolton, 1954b), in Pera Magroon and Surdash; it consists of black and thinly bedded shaley limestone and bituminous limestone and dolomitic limestone (Al-Shwaily *et al*., 2012).

Thickness: In the type locality, the thickness of the Naokelekan Formation is 14 m. In Surdash and Pera Magroon the thickness is 16 m (Al-Shwaily *et al*. 2012), in Ranya not mentioned.

Fossils: From the type area of the Naokelekan Formation, no fossils were recorded from the upper part. In the "Mottled bed", the following fossils were recorded: *Vinalephinctes* sp., *Ataxioceras* sp., in the "Coal bed" the following fossils were recorded: *Prosospinites* sp., *Epipeltocerictes* sp., *Klimatosphinctes mirus* (Bukowski), *Glochicerictes* sp., *Trimarginites arolicus* (Oppel) and *Peltoceras indicus* Spath (Bellen *et al*., 1959). Buday and Suk (1978) gave the following list of fossils: *Kurnubia palestnensis* Henson, *Protoglobigerina* sp., *Trocholina* sp., *Ammobaculites* sp., *Nautiloculina oolithica* Mohler, *Pfenderina* sp., miliolids and algae (*Cladocoropsis* sp., *Thaumatoporella* sp., *Dasycladaceas* and *Shurquaria heybrochi* Henson).

Fig.6: The Naokelekan Formation, east of Sulaimaniyah city

Age: The age of the Naokelekan Formation is Upper Oxfordian at the top of a coal horizon, and possibly Callovian at base. The age at the top is possibly Lower Kimeridgian; from correlation with other sections (Bellen *et al*., 1959). Buday and Suk (1978) claimed a Callovian – Kimmeridgian age for the formation. Al-Shwaily *et al*. (2012) claimed a Late Jurassic age for the formation.

Depositional Environment: Pesl (1976) considered the depositional environment of the Naokelekan Formation as euxinic of subsiding basin. Neocomites indicated that the formation gradually passing from the underling Sargelu Formation and represented an example of dense sedimentation, locally in a starved basin, with frequent periods of hiatus and platform wedged sedimentation. The Naokelekan Formation corresponds in age and sometimes in facies the Sargelu and Najmah formations; between J30 and J50 MFS (Goff, 2005 in Aqrawi *et al*., 2010).

Lower contact: The Naokelekan Formation in the type locality, is underlain by Sargelu Formation; the contact is apparently conformable taken at the top of thinly bedded cherty limestones with *Posidonia ornate* Quenstedt, and below soft, brown, papery shales with thin, dark grey dolomites (Bellen *et al*., 1959). Al-Shwaily *et al*. (2012) recorded the same contact between the two formations in Pera Magroon and Surdash vicinities.

1.2.5. Barsarin Formation (Late Jurassic)

Type Locality: The Barsarin Formation is defined by Wetzel in 1950, the type section of the formation is in a road cut, opposite to Barsarin village, east of Rawandooz town, it is defined by the following coordinates (Bellen *et al*., 1959) (Fig.3):

Longitude 44° 39' 18" E
Latitude 36° 37' 13" N

Exposure Areas: The Barsarin Formation is exposed in Surdash, Ranya, Chia Gara, Ser Amadiya, Korek, Sargelu, Pera Magroon, Barzanja and near Halanja; within the High Folded Zone, but it is widely exposed in the Imbricate Zone (Sissakian and Fouad, 2012). Its subsurface extensions south of the High Folded Zone and farther southwards are obscure. "There is no age equivalent to the Barsarin Formation north of Makhul and west of the Tigris River". However, it is well correlatable with the upper part of the Gotnia Formation (Bellen *et al*., 1959). Nevertheless, the formation is encountered in K109 and K117 (in Avanah and Khurmala Domes, respectively), but not in Khlesia oil well (Fig.3), which hit Paleozoic Khabour Formation (I.P.C., 1963).

Lithology: In the type locality, the Barsarin Formation consists of "Laminated limestones and dolomitic limestones, some fluffy-textured, locally cherty, alternately in normal beds and in brecciated, crumbled and contorted beds. The autoclastically brecciated beds show admixed shaley and marly material with "melikaria" structures" (Bellen *et al*., 1959). Near Ranya, it consists of black and brown bituminous dolomitic shales and thin dolomitic limestone (Bolton, 1954b). In Korek and Sar Amadiya, gypsum beds occur within the formation (Dunnington *et al*., 1959). In Pera Magroon and Surdash, it consists of dark grey thickly bedded limestone and dolomitic limestone with stromatolitic limestone (Al-Shwaily *et al*., 2012) (Fig.7).

Fig.7: Barsarine Formation capped by terrace of Rawandooz River,
in the type locality, near Barsarine village
(Note the stromatolite (in the inset) as characteristic feature of the formation)

Thickness: In the type locality, the thickness of the Barsarin Formation is 17 m, near Ranya 10 m (Bellen *et al*., 1959), in Pera Magroon and Surdash 17 m (Al-Shwaily *et al*., 2012).

Fossils: No fossils were recorded within the Barsarin Formation (Bellen *et al*., 1959). However, Kaddouri (1986) in Aqrawi *et al*. (2010) recorded *Clypeina jurassica* and *Nautiloculina oolithica* in Banavi area.

Age: The age of the Barsarin Formation is not demonstrated. Upper Jurassic,? Kimeridgian, possibly Lower to Middle Kimeridgian, i.e. Lower Tithonian (Bellen *et al*., 1959). Jassim *et al*. (1984) claimed undifferentiated Upper Jurassic age (Pre-Tithonian). Kaddouri (1986) in Aqrawi *et al*. (2010) claimed Kimmeridgian – Tithonian age for the formation. Al-Shwaily *et al*. (2012) claimed Late Jurassic age for the formation.

Depositional Environment: According to Pesl (1976), the Barsarin Formation is of lagoonal evaporitic origin. Buday and Suk (1978) performed petrographic study and concluded that the environment is of intertidal to supratidal flats under evaporitic sabkha conditions, with intense aridity associated with sporadic marine flooding. Aqrawi *et al*. (2010) claimed the formation was deposited in a separate and perhaps structurally elevated sub-basin that was partially isolated from Gotnia basin, which was starved of calstics. The formation represents MFS bounded between J70 to J110 (Aqrawi *et al*., 2010).

Lower Contact: The Barsarin Formation, in the type locality is underlain by Naokelekan Formation. The contact is apparently gradational and conformable taken at the top of laminated dolomitized, normally bedded, slightly fragmented limestone, with thin whitish layers, and at base of an intraformational breccia, (1.3 – 1.8) m thick with angular blocks of dolomitized limestones, of different weathered appearances, but probably monogenetic (Bellen *et al*., 1959). In Pera Magroon and Surdash anticlines, the contact is also gradational and conformable, between the two formations (Al-Shwaily *et al*., 2012).

1.2.6. Chia Gara Formation (Late Jurassic – Early Cretaceous, Late Tithonian – Berriasian)
Type Locality: The Chia Gara Formation is defined by Wetzel in 1950, the type section is at Chia Gara anticline, south of Amadiya in the northern part of Iraq. The upper 197 m is located along Geli Garagu; about 600 m south of Garagu village, whereas the lower 35 m is located about 1.5 Km west – southwest of Gara village. The top and the bottom are defined by the following coordinates, respectively (Bellen *et al*., 1959) (Fig.3):

Longitude 43° 23' 38" E
Latitude 37° 00' 50" N
Longitude 43° 24' 44" E
Latitude 36° 59' 55" N

Remark: Although the Chia Gara Formation is of Late Jurassic – Early Cretaceous age, but it is included within the Jurassic sequence, because it is exposed almost in sections including Jurassic rocks.

Exposure Areas: The Chia Gara Formation is exposed in Surdash, Ranya, Chia Gara, Ser Amadiya, Sargelu, Bekhme, Korek, Pera Magroon, and most probably in Shakrook anticline; northeast of Spindara village? (Sissakian and Youkhanna, 1979). It is exposed northwards in the Imbricate Zone (Sissakian and Fouad, 2012). Its subsurface extensions south of the High Folded Zone and farther southwards are not so clear; it passes to Mkhul and Karimia formations, in Kifl 1 it passes to Gotnia Formation. However, it is hit in Faluja 1, Samarra 1, Qara Chauq 1, and Musaiyib 1, but not in Khlesia oil well (Fig.3), which hit Paleozoic Khabour Formation (I.P.C., 1963).

Lithology: In the type locality, the Chia Gara Formation consists of "unbroken succession of thin bedded limestones and shales, containing rich ammonite faunas, and grading upwards to yellowish marly limestones and shales" (Bellen *et al*., 1959). Near Ranya, it consists of thinly bedded platy limestone, dark brown shales and dolomitic marl (Bolton, 1954b). In Gara anticline, it consists of thinly bedded shale and bituminous limestone, upwards become yellow in color (Abdullaziz, 1978).

Thickness: In the type locality, the thickness of the Chia Gara Formation is 232 m, near Ranya ranges from (25 – 30) m, in Sirwan valley 30 m (Bellen *et al*., 1959), in Pera Magroon 120 m and Surdash 120 m (Al-Shwaily *et al*., 2012).

Fossils: Bellen *et al*. (1959) identified the following fauna in Chia Gara Formation, from the type section: *Tylostoma depresso* Picket, *Cyclammia* sp., *Pseudocyclammina kelleri* Henson, *Trocholina* sp., *Cristellarias*, *Groeberceras* sp., *Protacanthodiscus* sp., *Natica pidanceti* Coquand, *Exogyra latissima* Lamarck, *Terebratula carteronian* D'Orbigny, *Zeilleria* sp., *Neocomites praeneocomiensis* (Burckhardt), *Ancyloceras* sp., *Paradontoceras calistoides* (Behrendsen), *Haploceras* sp., *Spiticeras* sp., *Oxylenticeras lepidum* Spath, *Pseudolissoceras zeitteli* (Burckhardt), *Phanerostephanus subsenex* Spath, *P. hudsoni* Spath, *P. dalmasiformis* Spath, *Cochliocerioceras turriculatum* Spath, *Nanostephanus subcornutus* Spath, *Proniceras garaense* Spath, *P. simile* Spath, *Nothostephanus kurdistanensis* Spath, radiolaria and ostracods.

Age: The age of the Chia Gara Formation is Upper Jurassic – Lower Cretaceous, Tithonian – Berriasian (Bellen *et al*., 1959). According to Karim and Al-Kubaysi (2011) and Al-Shwaily *et al*. (2012) the age is Late Tithonian – Berriasian.

Depositional Environment: The Chia Gara Formation is deposited in basinal condition, with bathyal depth showing shelf influence. The abundant radiolarian and chert horizons in the formation indicate connection with the Qulqula Radiolarian Series. According to Aqrawi *et al*. (2010) the formation represents MFS sequence bounded between J110 to K30.

Lower Contact: In Gara anticline, the Chia Gara Formation is underlain by Barsarin Formation, the contact is conformable marked by sharp lithological contact between fine grained, laminated, dark blue, thinly bedded, shaley, papery limestones, weathering pale grey (above) and cherty, dolomitic, brecciated, grey limestones, weathering grey to yellow (below) (Bellen *et al*., 1959). However, Aqrawi *et al*. (2010) claimed unconformable contact between Chia Gara and Barsarin formations.

1.3. Cretaceous

During Early Cretaceous, the deposition occurred in a large intra-shelf basin contemporaneous with the new phase of ocean floor spreading in the Neo-Tethys. The opening of the Neo-Tethys led to the drifting away of a narrow microcontinent; a new passive margin formed along the northeastern margin of the Arabian Plate. This margin was formed by a carbonate ridge along the north facing passive margin of the Neo-Tethys (Jassim and Buday, 2006 in Jassim and Goff, 2006). During the Late Cretaceous, a foreland basin formed around the northern margin of the Arabian Plate (Al-Qaim *et al*., 2012), which represents, partly the nowadays area of the High Folded Zone.

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 whole of the Iraqi territory. The same stress regime in the northeast of the Arabian Plate led to the formation of intraplate extensional and transextensional basins of NW – SE and E – W trend, respectively (Jassim and Buday in Jassim and Goff, 2006). These basins were in form of grabbens and were receiving synrift sediments of Late Cretaceous age (Fouad and Nasir, 2009), especially in the extreme western part of the High Folded Zone. According to Al-Qayim and Saadallah (1994), isolated reef buildup, which grew over a tectonic swell, was developed on the Arabian Plate's active margin during the Late Cretaceous. The unstable tectonic conditions of this period were responsible for variability and complex facies distribution of the buildup.

The Cretaceous Period, in the High Folded Zone is represented by 10 formations. They represent the Late Tithonian – Early Turonian Megasequence AP8 and majority of the Late Turonian – Danian Megasequence AP9, established by Sharland *et al*. (2001). The exposed formations are described hereinafter

1.3.1. Garagu Formation (Early Cretaceous) (Valanganian – Hauterivian)

Type Locality: The Garagu Formation is defined by Wetzel in 1950, the type section is in the core of Chia Gara anticline, along Geli Garagu, the top being situated at the base of the massive cliff, the base lies about 600 m north of Garagu village, it is defined by the following coordinates (Bellen *et al*., 1959) (Fig.3):

Longitude 43° 23' 38" E
Latitude 37° 00' 50" N

Exposure Areas: The Garagu Formation is exposed only in the type locality, in Chia Gara anticline and in Amadiya within the High Folded Zone (Bellen *et al*., 1959). However, Dunnington *et al*. (1959) in Aqrawi *et al*. (2010) reported about the exposures of the formation in Banik, within the Imbricate Zone. Moreover, Aqrawi *et al*. (2010) reported about the subsurface extension of the formation into Kirkuk and Bai Hassan oil fields within the Low Folded Zone. It may pass to Ratawi Formation in the southern and middle parts of Iraq (I.P.C., 1963). Moreover, the formation is encountered in Jambur 13 deep test well, Qara Chouq 1, Najmah 1, Makhul 2 and Milih Tharthar 1 oil wells. Moreover, its equivalent Yamama Formation is hit in Awasil 5, Fallujah 1, and Samara 1 (Fig.3) (I.P.C., 1963).

Lithology: In the type locality, the Garagu Formation consists of "Upper oolitic division, 24 m thick, consists of ferruginous oolitic marls and sandstone. Middle division of organic detrital limestone, 22 m thick, weathering into a brown cliff. Lower oolitic division with coarse sandstone and sandy, oolitic limestone, 46 m thick, with rich fauna "(Bellen *et al*., 1959).

Thickness: In the type locality, the thickness of the Garagu Formation is 92 m. No data are available from surface sections about the thickness of the formation, elsewhere.

Fossils: The following fossils were recorded in Garagu Formation by Bellen *et al*. (1959): *Stylina subtabulata* Gregory, *Calamophyllia* sp., *Pseudocyclammina litus* (Yokoyama), *Terebratula* cf. *waldensis* de Loriol, *Cuneolina* sp., *Trichites suprajurensis* Krumbech, *Subthurmanina occitanica* (Pictet), *Neocomites* sp., Hexacoralla including Axosmilia neocomiensis Gregory, Lochameosmilia sp., *Corbulomina* cf. *aligera* (Hamlin), *Terebratula* cf. *whitfieldi* Vokes, *Thracia neocomiensis* De Orbigny, *Ampullina* cf. *syriaca* Conrad, *Trocholina* cf. *elongate* (Leupoldi), *Nautiloculina oolithica* Mohler. Karim and Salman (1992) recorded the following fossils from Bekhme section: *Pseudocyclammina jaccardi* (Schrodj), *Epistomina caracolla* (Roemer) Franke, *Textularia* sp., *Rotalia* sp., *Cuneolina* sp.

Age: Bellen *et al* (1959) recorded the age of the Gragau Formation as Valanganian and ? Hauterivian (Lower), Karim and Salman (1992) assigned the age as Lower Cretaceous (Berriasian – Hauterivian).

Depositional Environment: The Garagu Formation was deposited in very shallow marine environment (Tidal flat) (Murry, 1973; Jassim *et al*., 1984, and Karim and Salman, 1992). The formation represents the K10 to K40 sequence of MFS (Aqrawi *et al*., 2010).

Lower Contact: In the type locality, in Gara anticline, the Garagu Formation is underlain by Chia Gara Formation, the contact is gradational and conformable, taken at the base of oolitic sandy beds, and above dark, brownish, silty limestone and marls (Bellen *et al*., 1959).

Remark: This formation is one of the most problematic exposed formations in Iraq. It is not recorded elsewhere than the type locality in Gara anticline, near Garagu village and very near surroundings, within the High Folded Zone, and in small areas in the Imbricate Zone. According to the authors' opinion, either the formation is a special facies of one of the exposed Cretaceous formations, or it is extensions off the type locality are missed with other lithologically similar Cretaceous formations. However, the second possibility is more likely, because the formation was encountered in some oil wells within Kirkuk, Bai Hassan and Jambur oil fields (Aqrawi *et al*., 2010). Moreover, the formation may be the equivalent of the basinal part of the Sarmord Formation (Dunnington *et al*., 1959). This means, the formation is missed with the Sarmord Formation and mapped as the latter, elsewhere in the High Folded Zone. Moreover, Bellen *et al*. (1959) noted a gradational and conformable upward transition between Gragu and Sarmord formations in Amadiya vicinity, and the formation passes into neritic massive limestones of Qamchuqa Formation; therefore, the formation was most possibly missed with other Cretaceous formations.

1.3.2. Balambo Formation (Early Cretaceous, Valanganian – Turonian)

Type Locality: The Balambo Formation is defined by Wetzel in 1947, the type section is at Sirwan valley, near Halabja, North Iraq, Southern scarp-face of Jebel Balambo, about 3 Km due east of Kawata village, which lies on the north bank of the Sirwan river at the confluence of Sirwan and Zimkan rivers, it is defined by the following coordinates (Bellen *et al*., 1959) (Fig.3):

Longitude 45° 57' 12" E
Latitude 35° 07' 7.8" N

Exposure Areas: The Balambo Formation is exposed in hills flanking the Shahri Zour Plain, between Sulaimaniyah and Zimkan valley (Fig.8), Dokan, Endezah area, Kurek, north of Rawandooz, Ranya, Pira Magroun, Sarchinar, Sarmord, Surdash, and Azmir. The formation passes westwards from Sulaimaniyah to the Sarmord Formation, therefore, the latter is not recognized east of Sulaimaniyah. The transition between the two formations is in forms of tongues, and then totally merges to each other. The formation is not encountered in the oil wells of the Low Folded Zone and southwards, except in Injana 5 and Pulkhana 5 (Fig.3). Further, southwards, the formation passes to Ratawi, Zubair and Shu'aiba formations (I.P.C., 1963).

Fig.8: The Balambo Formation showing well bedded and highly deformed nature (Along Sulaimaniya – Said Sadaq road)

Lithology: In the type locality, the Balambo Formation consists of "Upper division of 503 m, thin bedded globigerinal, passing downwards to radiolarian limestones, grey, weathering white, and forming smooth weathered slopes without marked features. Lower division of 259 m, thin bedded, blue ammonitiferous limestone with intercalations of olive green marls and dark blue shales" (Bellen *et al*., 1959). Near Ranya, it consists of thinly bedded, fine grained limestone with globigirinal marly shale, and hardly distinguishable from Qamchuqa and Sarmord formations (Bolton, 1954b). In Balambo Mountain, it consists of thinly bedded, fine grained grey globigerinal limestone (Fig.8), with interbedding of marly shales and chert layers, the lower part includes dark grey shales (Bolton, 1954c). In Pera Magroon and Surdash anticlines, the formation consists of two units: Lower Unit consists of 140 m grey, tough, fine crystalline, thickly bedded amoniteferous limestone and dark blue papery shale. Upper Unit consists of 180 m of alternation of limestone and marl (Al-Shwiali *et al*., 2012).

Thickness: In the type locality, the thickness of the formation is 762 m, near Ranya about 500 m, in Balambo Mountain 760 m (Bellen *et al*., 1959), in Pera Magroon anticline 330 m, in Surdash anticline 320 m (Al-Shwaily *et al*., 2012).

Fossils: Bellen *et al.* (1959) listed the following fauna from the Balambo Formation: **Turonian:** Upper part: *Globigerina cretacea* D'Orbigny, *Globotrancana lapparenti* Brotzen, *Glt lapparenti cornata* Bolli. Middle part: *Gumbelina* spp., *Gyroidina* sp., *Pseudotextularia elegans* (Rzehak), *Inoceramus debries*, ostracods and oligostegina. Basal part: *Globotrancana lapparenti* subspp. *Glt asgali* Richel, *Glt. Renzi* Candolf, *Rotalipora appenninca* (Renzi), *Gumbelina* spp., *Shackonia cenomana* Shacko, and oligostegina. **Cenomanian:** *Rotalipora appenninca* (Renzi), R. typical (Ganolfi), R. alpha (Ganolfi), *Globigerina* spp., *Hasergerinalla simplex* Morrow, *Hasergerinalla* sp. *Globotrancana alpine* Bolli, *Thalmanniella ticinensis* (Ganolfi), *Mantelliceras* sp., radiolarian and oligostegina. **Albian:** (Near top): *Oxytropidoceras* sp., *Prohystoceras* sp., (near base): *Hilobits* sp., Idiohanites sp., *Hileolites subsiformis* Auchtt, *Pachydesmoceras denisonianus* Auchtt, *Ticinella roberti* (Gandolfi), *Planulina pustulosa* Umiker, *Valvulineria* sp., and radiolarian. **Aptian – Barremian:** Belemnite (indef.), radiolarian and *Pseudohoploceras* sp. **Hauterivian – Valanganian:** Upper part: *Hilobits* sp., Phylloceras Tethys D'Orbigny and radiolarian. Middle part: *Hilobits* sp., *Crioceras plicatilis* (Philips), *Crioceras* sp., *Neocomites* sp., *Acanthodiscus* sp., *Thurmannites* sp., *Holcodiscus* sp. Lower part: *Crioceras plicatilis* (Philips), *Crioceras raricostatum* (Philips), Neocomites *houdardo* Roman and *Olostephanus* sp.

Age: Bellen *et al*. (1959) claimed Valanganian – Berriasian age to the Balambo Formation. In Pera Magroon and Surdash viciniteis, Al-Shwaily *et al*. (2012) claimed Valanganian – Turonian age for the formation.

Depositional Environment: The Balambo Formation represents open marine environment of normal salinity (Jassim *et al*., 1984). The formation is bounded between K40 and K50 MFS (Aqrawi *et al*., 2010).

Lower Contact: The Balambo Formation is underlain by the Chia Gara Formation; the contact is non sequential with missing basal part of Valanganian and parts of Berriasian (Bellen *et al*., 1959). The contact with the underlying Chia Gara Formation, in Pera Magroon and Surdash vicinities is based at the bottom of a thick succession of fine grained, thinly bedded limestone of dark blue colour (Al-Shwaily *et al*., 2012).

1.3.3. Sarmord Formation (Hauterivian – Barremian)

Type Locality: The Sarmord Formation is defined by Wetzel in 1950, the type section is at Surdash anticline, in the northern part of Iraq. It consists of two areas: The upper 182 m is exposed in the Qamchuqa gorge; within the vicinity of Sarmord village, whereas the lower 273 m is exposed along the stream, which flows northwards through Sargelu village. The two parts are defined by the following coordinates, respectively (Bellen *et al*., 1959) (Fig.3):

Longitude 43° 02' 07" E
Latitude 35° 54' 18" N
Longitude 45° 09' 28" E
Latitude 35° 52' 45" N

Exposure Areas: The Sarmord Formation is exposed in Chia Gara, Ser Amadiya, Galley Ali Beg gorge, Bekhme gorge, Kurek, north of Rawandooz, Ranya, Pira Magroon, Surdash, Bradost. It is not exposed east of Sulaimaniyah, but towards north; it is exposed in northeast of Dokan Lake, also northeast and northwest of Dohuk. The formation passes eastwards from Sulaimaniyah to the Balambo Formation; therefore, the latter is not recognized west of Sulaimaniyah. The transition between the two formations is in forms of tongues, and then the latter merges totally into the former formation. Moreover, the Sarmord Formation passes upward to the Qamchuqa Formation, in form of tongues, which are well expressed in Pera Magroon anticline. However, its subsurface extensions are behind the southern limits of the Low Folded Zone, it is encountered in Damir Dagh 1, K116, K109, Cham Chamal 2, Najmah 29, Qara Chouq1, Hamrin 1, Jambur 13 deep test, Bai Hassan 13, Gullar 1, Ain Zala 16, Butmah 2, Alan 1, Ibrahim 1, Adayah 1, Atshan 1, Makhul 2, and Sasan 1. Moreover, the formation is encountered in Musaiyib 1, but not in Khlesiaya 1 (Fig.3), which hit Paleozoic Khabour Formation (I.P.C., 1963). The formation passes west and southwards into the Garagu, Zangura, Zubair, Sulaiy, and Ratawi formations (I.P.C., 1963 and Jassim *et al*., 1984).

Lithology: In the type locality, the Sarmord Formation consists of brown and bluish marls, buff weathering, with alternation of marly neritic limestone (Bellen *et al*., 1959). Near Ranya, it consist of thinly bedded marly limestone and marl with shaley partings (Bolton, 1954b) (Fig.9), in Pera Magroon and Surdash vicinity, it consists of alternation of light grey thickly bedded marly limestone and bluish grey marl (Al-Shwaily *et al*., 2012).

Thickness: In the type locality, the thickness of the Sarmord Formation is 455 m, near Ranya about 400 m (Bellen *et al*., 1959), in Surdash 450 m and in Pera Magroon 450 m (Al-Shwaily *et al*., 2012).

Fossils: According to Bellen *et al*. (1959) the fauna is concentrated in the upper 80 m of the Sarmord Formation, the following fossils were identified: *Astroconia* sp., *Heteraster oblongus* Brongniart, *H. couhoni* Agassiz, *Pholedomya esmarki* Nils, *Potamides philipi* Leymerie, *Trochus* sp., *Premocalculus inopinatus* Elliott, *Salpingoporella* cf. *mohalbergi* Lorenz and echinoid.

Age: According to the aforementioned fossils, the age of the Sarmord Formation is Hauterivian at base, Barremian at top (Bellen *et al*., 1959 and Jassim *et al*., 1984). Al-Shwaily *et al*. (2012) claimed Early Cretaceous age for the formation.

Depositional Environment: The Sarmord Formation with its marl component, echinoid and algae represent quiet marine sedimentation of inner shelf facies (inner neritic – neritic) (Jassim *et al*., 1948). The Sarmord Formation is bounded between K60 and K70 sequence of MFS (Aqrawi *et al*., 2010).

Lower Contact: In the type locality, the Sarmord Formation is underlain by Balambo Formation, the contact is conformable and gradational, taken at the base of buff-weathering, unfossiliferous marls and at the top of grey weathering ammonitiferous limestones with shales (Bellen *et al*., 1959). In Pera Magroon anticline, the formation is underlain by the Balambo Formation, the contact is gradational based on series of alternation of brownish grey limestone and marl (Al-Shwaily *et al*., 2012).

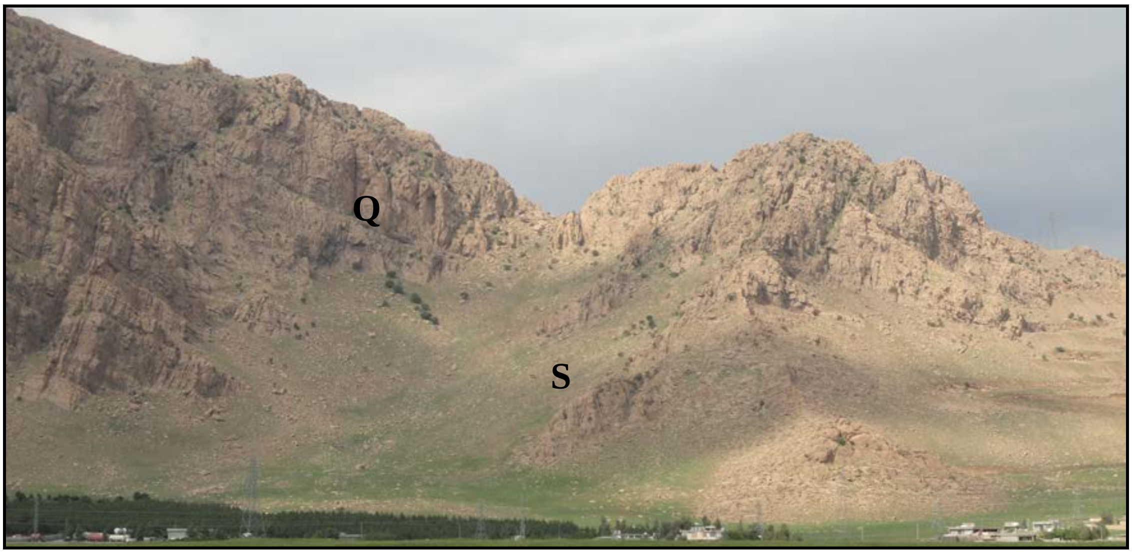


Fig.9: The Sarmord Formation (S) overlain by the Qamchuqa Formation (Q) east of Ranya, alog the eastern bank of Dokan Lake

1.3.4. Qamchuqa Formation (Early Aptian – Early Cenomanian)

The Qamchuqa Formation is one of the most wide spread formations in Iraq, it forms the carapace of the main mountains; in the High Folded Zone.

Type Locality: The Qamchuqa Formation is defined by Wetzel in 1950, the type section is at Qamchuqa gorge, NE Iraq, it runs along the gorge to Sarmord, it is defined by the following coordinates (Bellen *et al*., 1959) (Fig.3):

Longitude 45° 03' 05" E
Latitude 35° 54' 03" N

Exposure Areas: The Qamchuqa Formation is exposed widely in the Iraqi Kurdistan Region, at Pira Magroon, Dokan, Khalikan, Ranya, Koi Sanjaq, Shaqlawa, Bekhme, Gelly Ali Beg, Alana Su, Balikan, Kurek, Zozek, Handreen, Bradost, Peris, Chia Gara, Ser Amadiya, north of Rawandooz, Ranya, north and northeast of Dokan Lake, north east and north of Dohuk, and east of Zakho. Moreover, its subsurface extensions are behind the southern limits of the High Folded Zone and even behind the Low Folded Zone (I.P.C., 1963). The Qamchuqa Formation passes laterally, westwards, between Kirkuk and Tigris River into the Jawan Formation, which is underlain by Sarmord Formation. The same lateral passage occurs southwestwards from Ain Zala area and southwards from Mosul. The formation is encountered in Qalian 1, Damer Dagh 1, K116, K109, K130, Cham Chamal 2, Qra Chouq 1, Bai Hassan 13, Hamrin 1, Jambur 13 deep test well, Gullar 1, Gusair 1, Ain Zala 6 and 22, Butmah 2, Alan 1, Sasan 1, Ibrahim 1, Adayah 1, Atshan 1, and Najmah 29 oil wells, but not in Khlesia 1, Anah 2 and Milih Tharthar1 oil wells (Fig.3). Moreover, the formation passes farther south and westwards to Mauddud Formation, which is encountered almost in all southern oil wells (I.P.C., 1963), and it is exposed in the Iraqi Western Desert (Sissakian and Fouad, 2012).

Remark: Many workers considered the Qamchuqa Formation forms the carapace of Safeen and Hareer mountains. The authors denied this assumption, due to the presence of exposures that include index fossils, which indicate the presence of Aqra – Bekhme Formation forming the carapace of the mentioned mountains, whereas the Qamchuqa Formation is exposed as windows in deeply cut valleys only.

Lithology: In the type locality, the Qamchuqa Formation consists of "Upper limestone unit, 28 m thick, of detrital limestone, locally argillaceous and dolomitized, Middle dolomite unit, 316 m thick, of coarsely crystalline mosaic or saccharoidal dolomite with some interstitial calcite. Middle limestone unit, 147 m thick, of massive rather argillaceous limestones, partly dolomitized, rare disseminated quartz silt occurs in association with a glauconitic horizon in the middle of this unit. Lower dolomite unit, 55 m thick, of very coarsely crystalline dolomite. Lower limestone unit, 61 m thick, of massive limestone, with rather argillaceous matrix, abundant macrofossil detritus" (Bellen *et al*., 1959). Near Rawandooz, it consists of massive to thickly bedded limestone (Figs.9 and 10), with large shell fragments and foraminiferal deposits (Bolton, 1954a). In Chia Gara and Matin anticlines, it consists of thickly bedded to massive limestone and dolomitic limestone (Abdullaziz, 1978). In Safin, Shakrook and Harir anticlines, it consists of limestones and dolostones, forming massive escarpments. The limestones are grey and brown, hard, bedded to massive, occasionally fossiliferous, recrystallized, bituminous, detrital and organic. Whereas, the dolostones are brown and greyish brown, saccharoidal, coarse crystalline, hard to very hard (Sissakian and Youkhanna, 1979). In Surdash and Pera Magroon, the formation consists of three units. Lower Unit (162 m) consists of dark grey, massive limestone. Middle Unit (139 m) consists of alternation of grey very coarse crystalline dolomitic limestone and yellowish green marl. Upper Unit (384 m) consists of grey massive limestone and dolomitic limestone (Al-Shwaily *et al*., 2012).

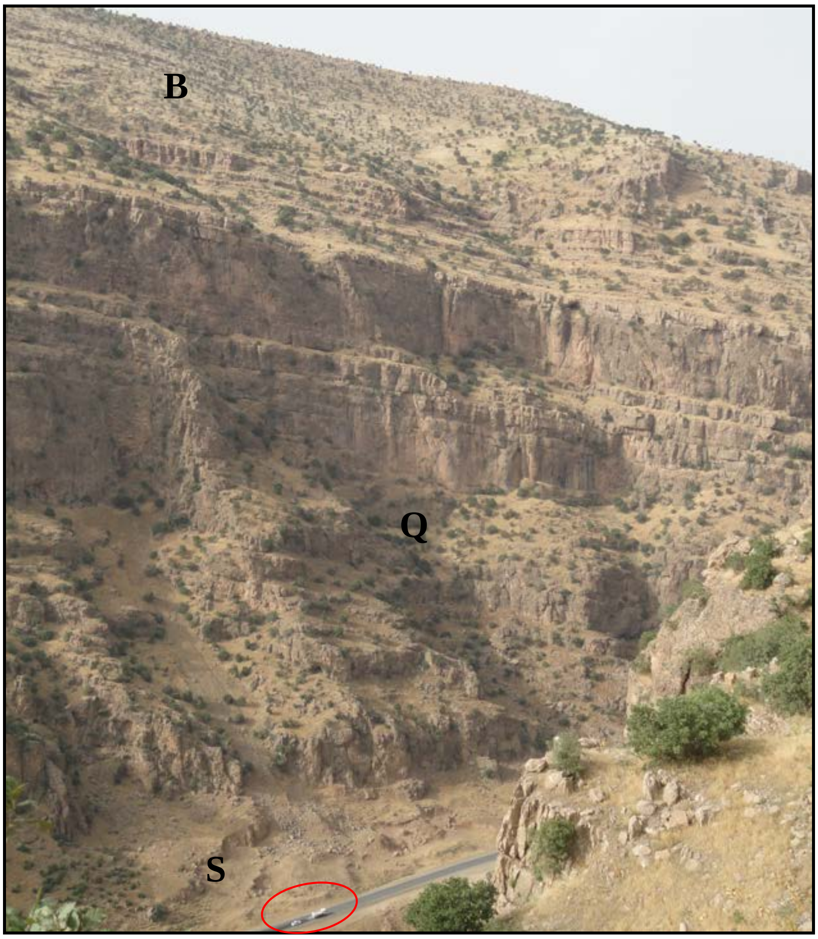


Fig.10: Massive limestone and dolostone beds in the Qamchuqa Formation (Q) underlain by thinly bedded soft Sarmord Formation (S), and overlain by well thinly bedded Bekhme Formation (B) in Gulley Ali Beg gorge. (Compare the thickness with the size of the two cars)

Remark: The uppermost part (30 – 50 m) of Qamchuqa Formation in Safin and Shakrook anticlines consists of a lithological development, which is not described elsewhere. This part consists of soft rocks with slope morphology, which differs from the morphology of the Qamchuqa and Bekhme formations (massive cliffs). The lower 10 m consists of light grey bedded, very fine crystalline, hard with iron oxide concretions (2 cm in diameter) on the top of the last bed. The middle part (30 – 40 m) consists of interbedding of limestone, light grey, fossiliferous, bedded and hard, with black shales, thinly bedded to papery. Horizons of dolomitic bituminous limestone with chert nodules of 0.5 m thick and a horizon (0.5 – 1.0 m) of yellowish green marl occur too. The upper part (15 m) consists of light grey limestone, fine crystalline, bedded, hard and slightly bituminous. A highly shelly limestone horizon exists in the bottom of this part. Such succession is abnormal in Qamchuqa Formation, which consists mainly of massive carbonates. However, this unit may be the equivalent of the Middle Unit recorded by Al-Shwaily *et al*. (2012).

Thickness: In the type locality, the thickness of the formation is 792 m, near Rawandooz 1000 m (Bellen *et al*., 1959). In Harir (105 – 115) m, in Shakrook (50 – 75) m, in Safin (77 – 105) m, near Spindara village 150 m, all thicknesses are of the exposed parts (Sissakian and Youkhanna, 1979). In Surdash 647 m, in Pera Magroon 650 m, few meters in Azmir, as tongues within Balambo Formation (Al-Shwaily *et al*., 2012).

Fossils: Bellen *et al*. (1959) recorded the following fossils from the Qamchuqa Formation: *Guneolina* sp., *Pseudochrysalidina conica* (Henson), *Pseudochrysalidina* sp., *Salpingoporella muhlbergii* (Lerenz), *Permocalculus inopinatus Elliott*, *Orbitolina* spp., *O. discodea* Gras, *Trocholina* cf. *lenticularis* Henson, *Choffatella decipens* Schlumberger, miliolids, *Munieria baconica* Deecke and abundant sponge spicules. Muniem and Yacoub (1979) determined the following fossils for Qamchuqa Formation from Shaqlawa- Harer area: *Pseudocyclammina litus* Yokoyama, *Nautiloculina* sp., *Pseudochrysalidina conica* (Henson), *Pseudolituonella* sp., *Guneolina* sp., algae (Dasycladaceas), miliolids (*Quiqueloculina* sp.), *Orbitolina concave* Lamarck, *O. discodea* Gras, echinoids spines and shell fragments. From Gara anticline, *Orbitolina lenticularis* Henson, *O. discodea* Gras, *Orbitolina concave* Lamarck, *Pfenderina* sp., *Quiqueloculina* sp., *Triloculina* sp., *Spirolculina* sp., *Pseudolituonella* sp., *Hensonella* sp., coral fragments, echinoid spines, Textularia sp. and few planktonic.

Age: Bellen *et al*. (1959) claimed an Albian intra – Barremian age for the Qamchuqa Formation, Jassim *et al*. (1984) estimated the age according to the rich *Orbitolina* assemblages as Albian – Cenomanian; in the upper part, and Intra Barremian in the lower part. Al-Shwaily *et al*. (2012) claimed an Early Cretaceous age (Early Aptian – Early Cenomanian) for the formation.

Depositional Environment: The fossils' assemblages within the Qamchuqa Formation indicate warm tropical shelf to inner shelf marine conditions of normal salinity, with neritic environment indicating local changes to basinal; in its uppermost part (Jassim *et al*., 1984). The Qamchuqa Formation includes K70 to K110 MFS (Aqrawi *et al*., 2010).

Lower Contact: In the type locality, the Qamchuqa Formation is underlain by Sarmord Formation; the contact is conformable and gradational taken at the base of massive, cliff forming limestone and above the marls and marly limestone of the Sarmord Formation. In Chia Gara anticline, it is underlain by Garagu Formation, in Matin anticline most probably by Sarmord Formation (Abdullaziz, 1978). In Safin, Shakrook and Harir anticlines, the base of the formation is not exposed. However, in Shakrook anticline, near Spindara village, very thick succession of limestones and dolostones are exposed, there the base of the formation may be is exposed and the underlying formation is either a Jurassic formation ? or Chia Gara Formation? (Sissakian and Youkhanna, 1979). In Pera Magroon and Surdash anticlines, the formation is underlain by Sarmord Formation, the contact is based on the base of the first massive limestone (Al-Shwaily *et al*., 2012).

1.3.5. Dokan Formation (Late Campanian – Late Maastrichtian)

Type Locality: The Dokan Formation is defined by Lancaster Jones (year; not recorded), the type section is at Dokan Dam in Sulaimaniyah District. It is observed in the excavation of the Bellmouth Spillway shaft. This exposure, together with others examined during excavation, is now concealed behind concrete, but the formation can still be seen immediately below the Gulneri Shale in the Right Bank tunnel and on the sides of the gorge downstream of the dam. It is defined by the following local coordinates (Bellen *et al*., 1959) (Fig.3):

660 670 E
768 510 N

Exposure Areas: The Dokan Formation has restricted exposures, in Dokan and along the southwestern flank of Surdash and Pera Magroon anticlines. However, the subsurface extensions of the formation in the High Folded and Low Folded Zones are obscure, it is encountered in many oil wells, such as Demir Dagh 1, K116 and 130, Cham Chamal 2, Qara Chouq 1, and Bai Hassan 13 (Fig.3), and it is not encountered in the oil wells of the western, middle and southern parts of Iraq. Its age equivalents are Wara, Ahmadi, Rumaila, Mishrif, Mahliban and Rutbah formations (I.P.C., 1963).

Lithology: In the type locality, the Dokan Formation consists of "light grey or white-weathering oligostiginal limestones. Locally ruby, with glauconitic coatings of constituent pebble-like masses, locally worm-riddled" (Bellen *et al*., 1959).

Thickness: In the type locality, the thickness of the Dokan Formation is 3.65 m.

Fossils: The following fossils were recorded in Dokan Formation by Amer (1993): *Rotalipora greenhorensis* (MORROW), *R. cushmani* (MORROW), *R. appenninca* (RENZ), *Praeglobotruncana gibba* KLAUS, *P. stephani* (PLUMER), *Globigerinelloides maltispina* (LALICK), *G. aspera aspera* (EHRENBERG), *G. escheri* (KAUFMAN), *G. bentonensis* (MORROW), *Hedbergella planispira* LOEBLICH and TAPPAN, *H. delrioensis* (CARSEY), *H. amablis* LOEBLICH and TAPPAN, *Clavihedbergella simplex* (MORROW), *Heterohelix moremani* (CUSHMAN), *H. reussi* (CUSHMAN), *Helvetoglobotruncana helvetica* BOLLI, *Whiteinella baltica* DOUGLAS and RANKIN, *Lenticulina* cf. *gryei* TAPPAN, *Stomiosphaera spherica* (KAUFMAN), *S. ovalis* (KAUFMAN), *Bonetocardielle conoidea* (BONET) and rare miliolids, bryozoa and gastropods.

Age: The age of the Dokan Formation in the type locality is Cenomanian, possibly Upper, but not uppermost, or Middle (Bellen *et al*., 1959). Amer (1993) claimed Cenomanian – Early Turonian age.

Depositional Environment: The Dokan Formation represents intra-Cenomanian transgressional, basinal sediments (Bellen *et al*., 1959). The faunal assemblages are mainly pelagic fauna of the genera *Globigerinelloides, Hedbergella, Heterohelix, Praeglobotruncaua, Rotalipora, Dicarinella* with abundant Calcisphers and rare miliolids, bryozoa and gastropods, therefore, the formation represents a typical basinal (pelagic) facies in an open sea environment (bathyal zone), with shallowing effects indicted by the presence of gastropods, algae, miliolids (Jassim *et al*., 1984). The Dokan Formation includes K120 to K140 MFS (Aqrawi *et al*., 2010).

Lower Contact: In the type locality, the Dokan Formation is underlain by Qamchuqa Formation; the contact is an erosional unconformity (Bellen *et al*., 1959).

1.3.6. Gulneri Formation (Late Campanian – Late Maastrichtian)
Type Locality: The Gulneri Formation is defined by Lancaster Jones, in 1957, the type section is at Dokan Dam in Sulaimaniyah District, it is in the southern branch of the right bank grouting tunnel, it is defined by the local following coordinates (Bellen *et al*., 1959) (Fig.3):

659 860 E
768 400 N

Exposure Areas: The Gulneri Formation has very restricted exposures, in Dokan area only and most probably in Safeen anticline, in a deep cut canyon like valley, which dissects Safeen anticline, near Sama Quli Galley village. According to Taha and Karim (2009), the Gulneri Formation of the type locality passes to the overlying Kometan Formation. However, its subsurface extensions in the High and Low Folded Zones are obscure. The formation is not encountered in oil wells; however, unnamed shales are encountered in Qara Chouq 1, K116, Bai Hassan 13, and Pulkhana 5 oil wells, which are in the same stratigraphic level of the Gulneri Formation, moreover, it has no age equivalent in the southern parts of Iraq (I.P.C., 1963).

Lithology: In the type locality, the Gulneri Formation consists of "Black, bituminous, finely laminated calcareous shale, with some glauconite and cellophane in the lower part" (Bellen *et al*., 1959). According to Taha and Karim (2009) the Gulneri Formation consists of marl and marly limestone, which are changed to ball and pillow-like structure by lithostatic pressure during burial, with minor shale beds, which originally were marl and are changed to shale-like rocks by pressure and solution, and impregnated by bitumen.

Thickness: In the type locality, the thickness of the Gulneri Formation is (1.1 – 1.2) m.

Fossils: The following fossils were recorded in the Gulneri Formation from the type locality by Bellen *et al*. (1959): *Rotalipora appenninca* (RENZ), *Globotruncana helvetica* BOLLI, minute globigerinds, gumbelinids, fish detritus and small bicarinata *Globotruncana spp*. Amer (1993) recorded the following fossils: *Helvetoglobotruncana helvetica* (BOLLI), *Praeglobotruncana stephani* (GRANOLFI), *Hedbergella planispira* LOEBLICH and TAPPAN, *H. delrioensis* (CARSEY), *Heterohelix moremani* (CUSHMAN), *H. reussi* (CUSHMAN), and *Clavihedbergella subdigitata subdigitata* (CUSHMAN).

Age: The age of the Gulneri Formation is Early Turonian (Bellen *et al*., 1959 and Amer, 1993).

Depositional Environment: The Gulneri Formation was deposited in a deep marine water of normal salinity (Amer 1993). The formation is located between K140 and K150 MFS (Aqrawi *et al*., 2010).

Lower Contact: In the type locality, the Gulneri Formation is underlain by the Dokan Formation; the contact is an erosional unconformity (Bellen *et al*., 1959).

Remark: Taha and Karim (2009) suggested to abondon the Gulneri Formation and merge it with the overlying Kometan Formation, due to its thickness and absence in surface sections. Although the authors confirm this suggestion, because the thickness and surface exposures of the formation contradicts with the ISC instructions for the definition of a formation, but the presence of the formation between two unconformities rejects this suggestion. However, in many locations; off the type locality, the unconformities are not recorded, and the formation passes into the underlying Dokan Formation, then they should be conjoined and referred to as the Dokan/ Gulneri formations. Similarly, if the formation passes to the Kometan Formation, then they should be joined and referred to as the Kometan/ Gulneri formations. However, if the equivalent of the formation overlies the Balambo Formation conformably, it will form a part of the Balambo Formation and should not be included within the Gulneri Formation. Moreover, eastwards from the type area, the Gulneri Formation must have equivalents in the continuous basinal sediments of the Balambo Formation, which were deposited in possibly unbroken succession from the Early Cretaceous to the Late Turonian times (Bellen *et al*., 1959).

1.3.7. Kometan Formation (Turonian – Early Campanian)

Type Locality: The Kometan Formation is defined by Dunnigton in 1953; the type section is at Kometan, near Andezah, northeast of Ranya, N Iraq; it runs N 234 E° from Kometan village, and the base of the formation lies about 400 m from the center of the village, near the top of the northeastern slope of the gorge cut by the stream, which runs east through Duwaila. The top of the formation is exposed about 220 m from the village, where it forms a small scarp, dipping northeast; it is defined by the following coordinates (Bellen *et al*., 1959) (Fig.3):

Longitude 44° 48' 18" E
Latitude 36° 24' 28" N

Exposure Areas: The Kometan Formation is exposed widely in the eastern part of the Iraqi Kurdistan Region, especially east of the Greater Zab River. In hills flanking the Shahri Zour Plain, between Sulaimaniyah and Halabja, Zar Gelli, Shaikhan, Endezah, Surdash, Koi Sanjaq, Ranya, Dokan, Sarchinar, Pera Magroon, Azmir, north of Sulaimaniyah, and Bana Bawi. Moreover, its subsurface extensions are behind the High Folded Zone and even behind the southern limits of the Low Folded Zone, since it is encountered in many oil wells such as Demir Dagh 1, K109 and 116, Cham Chamal 2, Najmah 29, Qara Chouq 1, Bai Hassan 13, Injana 5, Hamrin 1, Mkhul 2, Hibbarah 1, and Jambur 13 deep test well (Fig.11) (I.P.C., 1963). The age equivalents of the Kometan Formation in the oil wells of the western parts of Iraq are Fahad and Maotsi formations, whereas in the oil wells of the southern parts of Iraq, there is no age equivalent, because the Santonian and Campanian are missing (I.P.C., 1963).

Lithology: In the type locality, the Kometan Formation consists of "White-weathering, light grey, thin-bedded, globigerinal – oligostiginal limestones, locally silicified, with flat-tended ramulose chert concretions in occasional beds. Glauconitic, especially at the base" (Bellen *et al*., 1959). Near Ranya, it consists of grey; when fresh and white when weathered, thinly well bedded, chalky globigerinal limestone (Bolton, 1954b). In Bana Bawi anticline, near Koi Sanjaq, the formation is exposed in three small outcrops, near Kom Isban and (two outcrops) near Wanka village. It consists of light grey, splintery, silicified limestone, thinly well bedded with fossil fragments (Sissakian and Youkhanna, 1979). In Pera Magroon and Surdash anticlines, it consists of well bedded, white, hard globigerinal – oligostiginal limestone (Fig.10). Near Said Sadaq, east of Sulaimaniyah city, a crenulated limestone occur within the Kometan Formation, indicating intense folding of he rocks (Ghafor *et al*., 2012).

Fig.11: Thinly well bedded limestone of the Kometan Formation
(Along Sulaimaniyah – Sadi Sadaq road)

Thickness: In the type locality, the thickness of the Kometan Formation is 36 m, near Ranya 500 m (Bolton, 1954b), in Bana Bawi anticline; the exposed part is (6 – 8) m (Sissakian and Youkhanna, 1979), in Azmir 217 m, in Pera Magrooon and Surdash ranges from (150 – 175) m (Al-Shwaily *et al*., 2012).

Fossils: Bellen *et al*. (1959) recorded the following fossils from the Kometan Formation: *Oligostegina, Gumbelina* spp., *Globigerina cretacea* D'Orbigny; *G. infracretacea* Glaessner; *G.* cf. *alpine* Bolli, *G renzi* Gandolfi, *G. sigali* Reichel; *G. lapparenti lapparenti* Brotzen; *G. lapparenti coronata* Bolli, *Globigerina* spp., *Planoglobulina* sp., *Bulimia* sp., radiolaria, sponge spicules and *Inoceramus* sp. Jawi (1978) studied the section of Demir Dagh and recorded the following fauna from the Kometan Formation: *Globotruncana concavata* (Brotzen), *Glt. helvetica* Bolli, *Glt. marginata* (Reuse), *Hedbergella crassa,? Hedbergella* spp. and sponge spicules.

Age: The age of the Kometan Formation, according to planktonic fauna and nano-fossils is Coniacian – Santonian. The Lower Turonian age is restricted to the High Folded Zone. In Shaqlawa – Kio Sanjaq vicinity, Sissakian and Youkhanna (1979) claimed Coniacian – Santonian. Aqrawi *et al*. (2010) claimed Upper Turonian – Lower Campanian age for the formation, whereas Karim *et al*. (2012) claimed Turonian to Late Campanian for the Kometan Formation. Moreover, Al-Shwaily *et al*. (2012) claimed a Late Cretaceous age for it.

Depositional Environment: The Kometan Formation represnts a typical basinal marine environment of bathyal depth. It could be termed as planktonic ooze (Jassim *et al*., 1984). The Kometan Formation includes K150, K160 and K165 MFS (Aqrawi *et al*., 2010).

Lower Contact: In the type locality the Kometan Formation is underlain by the Balambo Formation, the contact is unconformable, faunal break and intense glauconitization at the base of the formation indicate depositional hiatus, with probable erosion (Bellen *et al*., 1959). The Kometan Formation passes laterally into the uppermost part of Balambo Formation (Bolton, 1954b). In Bana Bawi anticline, the base is not exposed (Sissakian and Youkhanna, 1979). In Pera Magroon and Surdash, it is underlain by Qamchuqa Formation, the contact is based on the first white, well bedded limestone overlying the massive beds of the Qamchuqa Formation (Al-Shiwaili *et al*., 2012). Between Sulaimaniyah and Halabja, Balambo Formation underlies the Kometan Formation; the contact seems to be gradational, marked by the absence of thin marl interbeds, which are frequent in Balambo Formation.

1.3.8. Aqra – Bekhme Formation (Late Campanian – Late Maastrichtian)

The Aqra – Bekhme Formation is one of the most widely spread formations in the Iraqi Kurdistan Region, especially in the middle and western parts of the High Folded Zone and forms the carapace of the main mountains.

Type Locality: The Aqra – Bekhme Formation, previously was two formations: Aqra and Bekhme, they are merged together by Jassim *et al*. (1984). The Aqra Formation is defined by Bennett in 1945, the type section is in Aqra, North Iraq, it runs along the Geli Sheikh Andul Aziz, with base in the lowest exposed beds about 1 Km northwest of Aqra, and top at about 300 m northwest of Aqra Police Post. Bekhme Formation is also defined by Wetzel in 1950, the type section is in Bekhme gorge, Greater Zab River, Northeast Iraq, it lies on the eastern bank, at the northern end of the gorge along the mule path to Dar-e-Tesu, both type sections are defined by the following coordinates, respectively (Bellen *et al*., 1959) (Fig.3):

Longitude 43° 55' 26" E
Latitude 36° 46' 43" N
Longitude 44° 16' 30" E
Latitude 36° 41' 45" N

Exposure Areas: The Aqra – Bekhme Formation has very wide exposures, in the western half part of the High Folded Zone area; it almost disappears east of the Greater Zab River, where it is replaced by Shiranish and Tanjero formations. In many localities of the eastern part of the zone, lenses of Aqra Formation are present in the Tanjero Formation. The formation is exposed at Amadiya, Rawandooz (Alana Su), Chia Gara, Diana, Kurek, Handireen, Zozik, Peris, Aqra, Zanta and Bekhme gorges, Safeen, Hareer, Shakrook, Bana Bawi, Zawita, east of Zakho, and east and north of Duhok. However, its subsurface extensions are obscure, since it is not encountered in any oil well. It is replaced either by Shiranish Formation or Pilsner Limestone. (I.P.C., 1963). Towards the west, the formation passes into Shiranish Formation, which intern passes into Jibab Marls and Pilsner Limestone. Whereas, towards south, its age equivalents are Khasib, Tanuma, Sa'di, Hartha, Qurna and Tayarat formations (I.P.C, 1963).

Remark: Many workers denied the presence of the Aqra – Bekhme Formation in Safeen and Hareer Mountais. The authors disagree with this assumption, due to the presence of exposures, which include index fossils of the Aqra – Bekhme Formation forming the carapace of the mentioned mountains (Sissakian and Youkhanna, 1979).

Lithology: In the type section, the Aqra Formation consists of "Reef-limestone complex, with massive rudist-shoal reefs, detrital fore-reef limestone; locally dolomitized and siliceous, locally impregnated with bitumen". The Bekhme Formation in the type section consists of "Upper division of 211 m of bituminous secondary dolomites with dispersed glauconite, replacing glauconitic, organic, detrital limestones, some globigerinal limestone intercalations with macrofossils detritus. Middle division, recognized informally as the "*Cosinella zone*", 94 m thick, comprising reef-detrital limestones with rudist debris, alternating with fore-reef shoal limestones with rich foraminiferal faunas. Basal conglomeratic division, 10 m thick, comprising globigerinal and foraminiferal limestones and polygenetic breccias- conglomerate, with ferruginous globigerinal marls locally" (Bellen *et al*., 1959). Near Rawandooz (Fig.10), it consists of thickly bedded to massive limestone (Bolton, 1954a). Near Sar Sang and Zawita, it consists of grey limestone interbedded with dolostone and yellow marl (Abdullaziz, 1978). In Harir, Safin, Shakrook and Ban Bawi anticlines, the formation consists mainly of limestones and dolostones. The limestones are light grey, brown, hard to very hard, well bedded to massive, locally dolomitic, bituminous, fossiliferous, reefal, recrystallized, detrital, and organic. Some chert and iron concretions of 5 cm in size occur too, whereas, the dolostones are brown, very fine crystalline with silty texture (Sissakian and Youkhanna, 1979).

Thickness: In the type locality, the thickness of the Aqra Formation is 739.5 m, whereas that of Bekhme Formation is 315 m (Bellen *et al*., 1959). Near Rawandooz, the thickness is 75 m, in Harir 110 m, in Shakrook 180 m, in Safin (120 – 150 m), in Bana Bawi (50 – 100) m (the base is not exposed), in Bistana anticline 20 m (the base is not exposed) (Sissakian and Youkhanna, 1979).

Fossils: The following fossils were recorded from the Aqra – Bekhme Formation: *Abathomphalus mayaroensis* (Bolli), *Gansserina gansseri* (Bolli), *Globotruncana aegyptica* Nakkady, *Glt*. *arca* (Cushman), *Glt*. *elevata* Brotzen, *Glt*. *falsocalcarata* Kerdany and Andel-Salam, *Glt*. *lapparenti* Brotzen, *Glt*. sp., *Globotruncanita conica* (White), *Gla*. *stuartiformis* (Dalbiez), *Globigerinelloides* sp., *Hedbergella planispira* (Tappan), *Heterohelix globulosa* (Ehrenberg), *H. striata* (Ehrenberg), *Kuglerina rotundata* Bronnimann, *Pseudotextularia elegans* (Rzehak), *P*. sp., *Rugoglobigerina rugosa* (Plummer) and *Rugoglobigerina* sp. *Dictyoconella* sp., *Lepidorbitpides socialis* (Leymerie), *Loftusia coxi* Henson, *L*. *elongate* Cox, *L*. *harrisoni* Cox, *L*. *morgani* Douville, *Nummofallotia* sp., *Omphalocyclus macroporus* (Lamarck), *Om*. (*Torreina*) *torrei* Palmer, *Orbitoides apiculatus* Schlumberger, *O*. *medius* D’Archiac, *O*. *tissoti* Schlumberger, *Pseudorbitoides* sp., *Rhapydionina* sp., *Siderolites calcitrapoides* Lamarck, *Si*. sp., *Sulcoperculina* globos De Cizancourt, *Bolivina incrassate* Reuss, *Cibicides* sp., *Eggerellina* sp., *Elphidium* sp., *Fissoelphidium* sp., *Lagena* sp., *Lenticulina* sp., *Marginulinopsis anstinana* (Cushman), *Nodosaria* sp., *Pseudochrysalidina* sp., *Pyrgo* sp., *Quiqueloculina* sp., *Rotalia skourensis* Pfender, *Siproloculina* sp. and *Textularia* sp.

Age: The age of the Aqra Formation in the type locality is probably Maastrichtian, whereas that of Bekhme Formation is Upper Santonian (Bellen *et al*., 1959). Kassab (1972) claimed Upper Campanian – Lower Maastrichtian age, and Upper Campanian – Upper Maastrichtian age by Amer (1993).

Depositional Environment: The Aqra – Bekhme Formation was deposited in a reef, shoal and fore reef facies. The algae, corals and miliolids were deposited under organic reefal facies or restricted environment with high salinity (Buday, 1980; Amer, 1993, and Al-Kubaysi, 2006). The formation includes K170, K175, K180 and K185 MFS (Aqrawi *et al*., 2010). According to Al-Qayim and Saadallah (1994), the Aqra – Bekhme Formation is developed as an isolated reef buildup, which grew over a tectonic swell. This and other similar structures were developed on the Arabian Plate's active margin during the Late Cretaceous of collisional phase between Arabian and Iranian Plates. The unstable tectonic conditions of this period were responsible for variability and complex facies distribution of the buildup.

Lower Contact: In the type locality, the base of the Aqra Formation is not seen and possibly the lowermost massive limestones belong to Bekhme Formation. The Bekhme Formation, in the type locality is underlain by Qamchuqa Formation, the contact is an erosional unconformity, without appreciable angular discordance, but with polygenetic conglomerate at the base of the Bekhme Formation and extensive dolomitization below. The contact is placed at the base of the conglomerate and is clear-cut (Bellen *et al*., 1959). In Rawandooz, the Bekhme Formation lies directly above the Qamchuqa Formation, without angular unconformity, but with a wide stratigraphic gap, the Kometan Formation being missing (Bolton, 1954a). In Harir, Shakrook, Safin anticlines, the formation is underlain by Qamchuqa

Formation unconformably, except in Bana Bawi anticline, where it is underlain by Kometan Formation, also unconformably. In the former case, the contact is based on the bottom of the first thick limestone or dolostone bed, which overlain a soft succession (Youkhanna and Sissakian, 1986), whereas in the latter case the contact is based on the bottom of the first limestone or dolostone bed, which overlies the thinly bedded silicified limestone of the Kometan Formation. Locally, a basal conglomerate (1.5 – 2 m) was observed between Qamchuqa and Aqra – Bekhme formations, this horizon may pass into limestones of the latter formation (Sissakian and Youkhanna, 1979).

Remarks:
1) In all exposed areas of Qamchuqa and Aqra – Bekhme formations, when the aforementioned soft rocks sequence is not developed (Sissakian and Youkhanna, 1979), then the contact between the two formations, in the field is obscured and it is almost impossible to differentiate between the two formations, except in the bedding nature.
2) Amin and Karim (2008) studied the contact between Qamchuqa and Aqra – Bekhme formations in north of Erbil and concluded that the contact seems to be gradational, because no conglomerate or any indication for break in sedimentation and erosion was found. They considered the formerly described conglomerate (Bellen *et al*., 1959) as "secondary ball and pillow-like structures"; secondary (diagenetic) in origin, as they formed during burial by stress of the overburden and their ball shape is enhanced by weathering. Moreover, they claimed that the boundary zone, across the contact had suffered from deepening (deposited during highstand systems tract) in contrast to previous studies that claimed shallowing, which was assumed to be represented by conglomerate.
3) The direct contact Between Qamchuqa and Aqra – Bekhme formations can not be conformable, due to the lack of the Kometan Formation (Coniacian – Santonain), with time span of more than 5.8 Ma, because the Early Campanian is also missing. Therefore, no gradational contact can be accepted between the two formations. However, locally the described soft rocks between the formations (Sissakian and Youkhanna, 1979 and Youkhanna and Sissakian, 1986) may represent an equivalent succession for the Kometan Formation, agewise.

1.3.9. Shiranish Formation (Late Campanian – Late Maastrichtian)

The Shiranish Formation is one of the most widely spread formations in Iraq; it fills the trough of the main synclines between the anticlines in the High Folded Zone.

Type Locality: The Shiranish Formation is defined by Henson in 1940, the type section is at Shiranish Islam village, near Zakho, it occurs in outcrops immediately above and below the village; it is defined by the following coordinates (Bellen *et al*., 1959) (Fig.3):

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

Exposure Areas: The Shiranish Formation is exposed widely in the High Folded Zone, extending from extreme southeastern part to the northwestern part of Iraq, almost without any interruption. Moreover, its subsurface extensions are behind the southern limits of the High Folded Zone and even the southern limits of the Low Folded Zone, Jazira Plain, Mesopotamia Plain, and partly in the northern parts of the Western Desert. The formation is encountered in Qalian 1, Damir Dagh 1, K109, 116, and 130, Cham Chamal 2, Najmah 29, Qara Chouq 1, Bai Hassan 13 deep test, Taq Taq 1, Pulkhana 5, Injana 5, Hamrin 1, Makhul 2, Jambur 13 deep test, Mashorah 1, Gullar 1, Gusair 1, Ain Zala 16 and 22, Butmah 2, Alan 1, Sasan 1, Ibrahim 1, Qalian 1, Khlesia 1, Fallujah 1, Samarra 1, and Musaiyib 1 oil wells (Fig.3).

However, in some wells of the western part of Iraq, Pilsner Limestone and Jibab Marl replace the Shiranish Formation. Moreover, towards the southern parts of Iraq, Khasib, Tanuma, Sa'di, Hartha, Qurna, Tayarat and Digma formations are the age equivalents of the Shiranish Formation (I.P.C., 1963).

Lithology: In the type locality, the Shiranish Formation consists of "Upper division of 99 m of blue marls, overlying lower division of 128.8 m of thin bedded marly limestones. The beds weather in a typical pale blue colour but are dark blue (or black where bituminous) on fresh surface. Globigerinal sediments throughout" (Bellen *et al*., 1959). Near Amadiya, it consists of bluish black, thinly bedded marl, occasionally bituminous (Hall, 1954). Near Ranya, it consists of shaley marl and marl, with characteristic blue colour; it passes gradationally to Kometan Formation (Bolton, 1954a). In Dohuk vicinity, it consists of blue, thinly bedded marl and marly limestone (Taufiq and Domas, 1977). In Azmir vicinity, it consists mainly of marly shales and becomes silty and pebbly towards its eastern margin (Bolton, 1954b). In Safeen, Hareer, Shakrook anticlines, the formation consists of two parts: The lower part consists of white and grey well bedded limestone, occasionally include iron and chert concretions. The upper part consists of blue and greyish blue marls and shales, almost papery (Sissakian and Youkhanna, 1979). In Pera Magroon, Khalikan (Fig.12) and Surdash anticlines, the formation consists of two members: **Lower Member** (55 m) composed of alternation of marly limestone and marl. The **Upper Member** (150 m) composed of bluish grey, thinly to thickly bedded, fine crystalline, conchoidally fractured marl (Al-Shwaily *et al*., 2012).

Fig.12: The Siranish Formation, with the background, of the massive beds of the Qamchuqa Formation (Along Sulaimaniya – Dokan road)

Thickness: The thicknesses of the Shiranish Formation in the type section it is 227.5 m, near Ranya about 300 m, near Amadiya 300 m, near Zakho 230 m, east of Azmir 130 m, west of Azmir 260 m. In Shaqlawa 150 m, in Kom Isban 230 m, in NE Koisanjaq 300 m (Sissakian and Youkanna, 1979), in Surdash and Pera Magroon is 250 m (Al-Shwaily *et al*., 2012).

Fossils: The following fauna were recorded from the Shiranish Formation in the type section by Bellen *et al*. (1959): *Globigerina cretacea* D'Orbigny, *G. aspera* (Ehrenberg), *Rugoglobigerina* spp., *Gumbelina striata* (Ehrenberg), *G. globulosa* (Ehrenberg), *Pseudotextularia elegans* (Rzehak) *P. varians* Rzehak, *Globotrancana arca* Cushman, *Glt. fornicate* Plummer, *Glt. gagnebini* Tilev, *Glt. gansseri* Bolli, *Glt. leupoldi* Bolli, *Glt. ros*etta (Carsey), *Glt. stuarrti* (De Lapparent), *Bolivina incrassate* Reuss, *Inoceramus regularis* D'Orbigny and macrofossils detritus. The same fauna were recognized by Kassab (1972; 1975 and 1976) and Yacoub (1978).

Age: The accepted age of the Shiranish Formation is Upper Campanian – early Upper Maastrichtian (Bellen *et al*., 1959; Amer, 1977, and Jawi and Said, 1978). However, Sissakian and Youkhanna (1979) claimed a Lower Maastrichtian age in Shaqlawa – Koi Sanjaq area, and Early Campanian as claimed by Al-Badrani *et al*. (2012). Al-Shwaily *et al*. (2010), claimed a Late Cretaceous age (Late Campanian – Late Maastrichtian) for the formation.

Depositional Environment: Kassab (1972 and 1975) considered the Shiranish Formation was deposited in deep marine water in subsiding basin. Buday and Suk (1978), Issa (1978) indicated that the environment was of quiet deep marine water, far from current action as it is predominated by pelagic facies of foraminiferal ooze. According to Al-Qayim *et al*. (1986), the deposition of the Shiranish Formation took place within the anoxic zone, i.e. in water depth exceeds 150 m, for the lower part and much exceeds 150 m, for the upper part. This assumption is based on the lack of bioturbation and actual benthonic fauna. Aqrawi *et al*. (2010) considered the formation to be bounded between K175 and K185 of MFS.

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). South of Chia Gara anticline, the formation passes into Aqra – Bekhme Formation, (Abdullaziz, 1978). In Shaqlawa – Koi Sanjaq vicinity, the contact between Shiranish and the underlying Bekhme Formation is conformable, and locally they interfingers with each other in Bana Bawi mountain between Wanka and Alyawa villages, and in the southeastern plunge of Safeen anticline (Sissakian and Youkanna, 1979). Moreover, in the northwestern plunge of Hareer anticline and near Khlaifan. In Pera Mgroon and Surdash anticlines and eastwards, Kometan Formation always underlies the Shiranish Formation, although the contact is unconformable, due to lack of part of Santonian and Lower Campanian, which attains about 10 Ma, but no any indication can be observed in the contact to prove the lack of this time span. However, in the Bustana area, between Koi Sanjaq and Khalikan, the lowermost part of the Shiranish Formation seems to pass in the uppermost part of the Kometan Formation, it is almost impossible to differentiate the two formations, due to large lithological similarity (from field observations of the Senior author with Prof. Kamal H. Karim; Suliamani University, 2006).

Remarks:

1) Karim *et al*. (2008) studied the contact between Kometan and Shiranish formations (Cretaceous) in the field and laboratory. They elucidated the nature of the contact and discussed the previous ideas of unconformable contact. On lithological basis, the contact is grouped into three types: Obviously gradational, Burrowed-glauconitic and Sharp contacts. Following recent studies, the basin in which the sediments of these types are deposited is considered as foreland basin. The contact is interpreted to represent the beginning of clastic influx into the basin at threshold time and space between pure carbonate sedimentation and mixed sedimentation of clastic and carbonate, during and after drowning of the previous platform. All found evidence suggest that the contact is most probably conformable and shows no signs of sub aerial erosion or long non-deposition, but does not exclude short submarine erosions and slow rate of sedimentation across the contact. Moreover, the obvious gradational contact is more common. However, locally sharp contact and burrowing and glauconitization occur too. The former case contains rip-up clasts and pebble-like bodies, which have intraformational and diagenetic (nodules) origin, respectively. Depending on the recent studies, in term of depositional basin, the contact represents a foreland basin that existed in front of southwest advancing front of the Iranian Plate. The authors; agree with this assumption, based on field observations.

2) Al-Badrani *et al*. (2012) claimed conformable contact between Kometan and Tanjero formations based on nanofosslis zonation, *Aspidolithus parcus – Calculites ovalis* Interval Biozone (CC 18 – CC 19) and *Ceratolithoides aculeus* Interval Biozone (CC 20).
3) The lowermost part of the Shiranish Formation interfingers with the uppermost part of the Tanjero Formation. Locally, it is almost impossible to differentiate between them; lithologically (From field observations of the Senior author). The interfingering increases eastwards of Pera Magroon, indicating continuous obduction and subduction of the ophiolite.
4) The Shiranish Formation, east of Koi Sanjaq consists mainly of shales, sandstones and siltstones with conglomerates. The limestone part, which is developed west of Koi Sanjaq is not developed. This is attributed to the closeness of the depositional basin from the source rocks, which were ophiolites, more coarse size sediments and conglomerates can be seen in the formation in near by areas (From field observations of the Senior author).

1.3.10. Tanjero Formation (Late Campanian – Late Maastrichtian)

The Tanjero Formation is one of the wide spread formations in Iraq; it fills the trough of the main synclines between the anticlines.

Type Locality: The Tanjero Formation is defined by Dunnington in 1952, the type section is in Sirwan valley, near Halabja, north Iraq, between Kani Karweshkhan and the scarp of Nador, the type section is at 1 Km south of Kani Karweshkhan, directly across the dip and tangential to the large curve of the river, it is defined by the following coordinates (Bellen *et al*., 1959) (Fig.3):

Longitude	45°	54'	14"	E
Latitude	35°	07'	42"	N

Exposure Areas: The Tanjero Formation is widely exposed in the Iraqi Kurdistan Region, almost without interruption, except in Aqra – Duhok area. It is exposed in the slopes facing Shahri Zoor Plian between Halabja and Sulaimaniyah, Pira Magroon, Surdash, Dokan, Ranya, Shaqlawa, Safeen, Bana Bawi, Rawandooz, Gara, Matin, Barzan, east of Zakho. However, its subsurface extensions are obscure, since it is not encountered in any oil well. It is always replaced with its age equivalent the Shiranish Formation (I.P.C., 1963). The authors believe that the formation has no subsurface extensions off the High Folded Zone. This is attributed to the distance from the source area and the flysch nature of the formation, caused by obduction.

Remark: Many workers; like Al-Mutwali (1983) denied the presence of the Tanjero Formation near Shaqlawa, within the limbs of Safeen anticline. However, the recognized fossils by Kassab (1975) and the described lithology and the mapped unit by Sissakian and Youkhanna (1979) prove the presence of the formation in the area involved.

Lithology: In the type section, the Tanjero Formation consists of "Upper part, of 1532 m of silty marls, siltstones, sandstones, conglomerates, and sandy or silty organic detrital limestones, with intercalations of organic reef and shoal type limestones. Lowe part, of 484 m of Globigerinal marls and rare marly limestones with silt; silt content diminishing downwards. The non-calcareous clastics throughout are dominated by chert and green rock detritus; the conglomerates in the upper part includes pebbles of Mesozoic limestones of various ages, of dolomites and recrystallized limestones, and radiolarian cherts. The upper part of the formation is rapidly variable, both vertically and laterally, in the immediate vicinity of the measured section" (Bellen *et al*., 1959). Near Amadiya, it consists of olive green and greenish black globigerinal marl, silty marl, siltstone, sandstone and mudstone, occasionally conglomerate and limestone lenses (Hall, 1954). Near Ranya, it consists of grey marly and silty shales, with marl and greywackes and occasional beds of conglomerate

(Bolton, 1954b). In Shaqlawa – Koi Sanjaq vicinity, the formation consists of sandstone, claystone, shale and conglomerate, with characterized dark olive green colour and concretions of different sizes, which attain up to 1 m in diameter (Sissakian and Youkhanna, 1979. In Pera Magroon and Surdash anticlines, the formation is divided into two members: **Lower Member** (300 m) consists of alternation of sandstone, mudstone, shale, conglomerate, claystone and sandy limestone. **Upper Member** (659 m) consists of alternation of sandstone, mudstone and silty claystone, dominated with mudstone and silty claystone (Al-Shwaily *et al*., 2012). In Sulaimaniyah and eastwards, the formation includes very thin beds of marly silicified limestone (Fig.13), near Darbandi Khan lake, hard conglomerate beds occur within the formation, pebbles are mainly limestone and very rare chert, rounded to well rounded, not more than 1 cm in size (From the field observations of the Senior author, 2012).

Thickness: The thicknesses of the Tanjero Formation in the type section is 2018 m, near Ranya about 1000 m, near Amadiya it ranges from (700 – 1000) m, east of Azmir 600 m, in Tanjero valley 1300 m. In Safeen anticline; west of Hijran village 120 m, in Mirawa anticline 140 m, in Bana Bawi anticline; near Susa village 320 m, in Bistana anticline 350 m (Sisskain and Youkhanna, 1979). In Pera Magroon, Surdash and Azmir anticlines, it is about 1000 m (959 m, near Hanaran Suru village) (Al-Shwaily *et al*., 2012). In Suliamaniyah vicinity, the thickness is about 1000 m and may be more, measuring of the true thickness is difficult, due to folding of the rocks and being covered by the Sulaimaniyah city and Quaternary sediments (From field observations of the Senior author).

Fig.13: Thin limestone horizons within the Tanjero Formation in Surdash anticline

Fossils: The following fossils were found in the Lower part of the Tanjero Formation: *Loftusia elongate* Cox, *Siderolites calcitrapoides* Lamarck, *Globigerina cretacea* D'Orbigny, *Globigerina* spp., *Globotrancana calcarata* D'Orbigny, *Glt. leupoldi* Bolli, *Glt. fornicate* Plummer, *Pseudotextularia elegans* (Rzehak). Whereas in the upper part the following fossils were found: *Gryphaea vesicularis* (Lamarck), *Hippurites cf. morgani* Douville, *Hippurites* spp., *Praeradiolites cylindraceus* (Desmoulins), *Turbo clathratus* Binkhorst, *Vaccinites galloprovincialis* Douville, *Loftusia morgani* Douville, *Loftusia elongate* Cox, *L. persica*

Brady, *Omphalocyclus macropora* (Lamarck), *Siderolites calcitrapoides* Lamarck, *Globotrancana stuarrti* (De Lapparent), *Glt. leupoldi* Bolli, *Glt. arca* Cushman, *Glt. fornicate* Plummer, *Gumbelina* spp., *Pseudolithothamnium album* Pfender, *Trinocladus* sp., and *Ovulites* sp. Kassab (1975) established two zones and five planktonic subzones within Tanjero Formation in surface and subsurface sections in northern Iraq, these are: **1)** *Globotrancana fornicate-stuartiformis-elevata-ros*etta-*ventricosa* Zone (Upper Campanian – Lower Maastrichtian). *Glt. aegyptica Nakkady subzone (*Upper Campanian), and *Glt. Arca-tricarnata-subciroumnodifer* subzone (Lower Maastrichtian). **2)** *Glt. Contuse-esnhensis-duwi* Zone (Middle – Upper Maastrichtian). *Glt. Gansseri-bahijae* subzone (basal Maastrichtian), *Abathamphalusma yaroensis* subzone (Middle Maastrichtian), and *Glt. falsocalcarata* subzone (Upper Maastrichtian).

Age: According to Bellen *et al*. (1959) the age of the Tanjero Formation is Upper Campanian – Maastrichtian. Kassab (1975), claimed an Upper Campanian – Uppermost Maastrichtian age for the formation. Al-Shwaily *et al*. (2010), claimed a Late Campanian – Late Maastrichtian age for the formation.

Depositional Environment: According to Bellen *et al*. (1959) the Tanjero Formation was deposited in a deep trough-like depression. The formation is a proper turbidities sequence; the source of the clastics or turbidities fans related to the already developed Upper Cretaceous Orogeny in the northeast. The formation passes laterally into the basinal sequence of Shiranish Formation. Occasional shallowing; especially in the later times of deposition resulted in deposition of shoal or reef of Aqra limestone (Jassim *et al*., 1984). The formation includes K170, K175 and K180 MFS (Aqrawi *et al*., 2010).

Remark: Bellen *et al*. (1959) referred to the developed foreland basin in its depositional area as "a deep trough-like depression", and for the obducted ophiolites as "uplifted orogen of some nature, which lay immediately to the northeast of Iraq's northeastern borders".

Lower contact: In the type locality, the Tanjero Formation is underlain by the Shiranish Formation; the contact is gradational and conformable placed at the lowest occurrence of silt grade clastics, which corresponds approximately to change of weathering colour from blue (Shiranish Formation) below to olive green (Tanjero Formation) above (Bellen *et al*., 1959). In Shaqlawa – Kio Sanjaq vicinity, the Tanjero Formation is underlain by Shiranish Formation, the contact is conformable and based on the top of the last thin limestone followed by olive green clastics, in Bustana anticline there is interfingering between the two formations (Sisskain and Youkhanna, 1979). In Pera Magroon, Surdash and Sulaimaniyah vicinities, the Tanjero Formation is underlain by the Shiranish Formation, the contact is conformable, it is based on the top of the last thinly bedded white limestone (Al-Shwaily *et al*., 2012).

Remrks:

1) Many workers denied the presence of the Tanjero Formation in Shaqlawa vicinity. However, the aforementioned recorded fossil assemblages and the presence of the ball and pillow structure within the beds are good indications for the presence of the Tanjero Formation in Shaqlawa vicinity. The same sedimentary structure was found by Al-Shaibani *et al*. (1986) in Dokan Area to be good indication for identifying of the formation.

2) Amin and Karim (2008), and Taha and Karim (2009) used the term of "pillow and ball-like structure" for the concretions, which are developed in the Tanjero Formation and considered them as characteristic features.

3) Sharbezheri (2010) recognized a special unit between Tanjero and Shiranish formations, near Samaquli village west of Koi Sanjaq. He estimated the time span of this unit, which is about 70 m thick to be about 2.150 Ma, and recommended to announce a new formation; called Samaquli Formation, with age of Late Campanian – middle Late Maastrichtian. The authors are not in accordance with the suggestion of Sharbezheri (2010), because the announcement of a new formation needs more requirements (Instructions of ISC), not only those mentioned in his article.

4) The lowermost part of the Tanjero Formation interfingers with the uppermost part of the Shiranish Formation. Locally, it is almost impossible to differentiate between them; lithologically (From the observations of the Senior author). The interfingering increases eastwards of Pera Magroon, indicating continuous obduction and subduction of the ophiolite.

2. CENOZOIC

The Cenozoic formations are widely exposed in the Iraqi High Folded Zone. The Cenozoic Era is divided into five main sequences, including: **1)** Paleocene – Early Eocene, **2)** Middle – Late Eocene, **3)** Oligocene, **4)** Early – Middle Miocene, and **5)** Late Miocene – Pleistocene. The five sequences are described hereinafter.

2.1. Paleocene – Early Eocene

During the Middle Paleocene, towards southwest of the longitudinal developed basin, a foredeep (within the foreland) was developed within the present area of the High Folded Zone, which was progressively migrating towards southwest including the area of the Low Folded Zone (Jassim and Buday in Jassim and Goff, 2006). Mainly flysch sediments of the Kolosh Formation filled the basin, with reef bodies, which were deposited in shallow areas, representing Sinjar and Khurmala formations.

The Paleocene – Eocene Sequence, within the Cenozoic Era 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 the formation of ridges and basins, generally of NW – SE trend in the northern and central parts of Iraq (Jassim and Buday in Jassim and Goff, 2006).

The Paleocene – Early Eocene Sequence is represented by three formations. They represent the lower half part of the Megasequence AP10 (Sharland *et al*., 2001), the three formations are described hereinafter.

2.1.1. Kolosh Formation (Late Paleocene – Early Eocene)

Type Locality: The Kolosh Formation is defined by Dunnington in 1952; the type section is at Kolosh, it is defined by the following coordinates (Bellen *et al*., 1959) (Fig.3):

Longitude 44 ° 33' 45" E
Latitude 36 ° 09' 50" N

Exposure Areas: The Kolosh Formation is widely exposed in the Iraqi Kurdistan Region, almost everywhere in the High Folded Zone, like in Zar Geli, Shaikhan, Endezah, Balki, Pera Magroon, Tasloojah, Qara Dagh, Darbandi Khan, Sartaq Bammu, Shaqlawa, Koi Sanjaq, Dokan, Sarchinar, Chia Gara, Dohuk. Its subsurface extensions are clear, it extends south and southwest off the High Folded Zone, since it is encountered in many drilled oil wells in the Low Folded Zone, like Demir Dagh 1, K117, 116, and 130, Cham Chamal 2, Taq Taq 1, Pulkhana 1, Butmah 2, Alan 1, and Sasan 1 oil wells (Fig.3). Moreover, its equivalent, Aaliji Formations is encountered in the oil wells of the western part of the Low Folded Zone. In the southern part of Iraq, the Umm Er Radhuma and Akashat formation, which are exposed in Iraqi Southern and Western Deserts, respectively are its age equivalent (I.P.C., 1963).

Lithology: In the type locality, the Kolosh Formation is composed of "Shale and fine sandstone, composed of fragments of various grain size of green-rock, chert, and radiolarite. Interfingering occurs with Sinjar limestone, especially in the higher parts" (Bellen *et al*., 1959). In Dohuk vicinity, it consists of greenish gray, thinly bedded clastics (Abdullaziz, 1978). In Shaqlawa – Koi Sanjaq vicinity it consists of shales, claystones, sandstones, and siltstone with rare conglomerate and very rarely very thin marly limestone beds, the black colour is a characteristic feature (Sissakian and Youkhanna, 1979). In Pera Magroon, near Derbendi Khan Lake (Fig.14), and Qara Dagh, the formation consists of black and very dark green shales, sandstones, claystones and very thin silicified marly limestone, with yellowish white color (Al-Shwaily *et al*., 2012).

Thickness: The thicknesses of the Kolosh Formation in the type section it is 777 m. In Shaqlawa and Harir it ranges from (150 – 180) m, in Koi Sanjaq 230 m (Sissakian and Youkhanna, 1979). In Pera Magroon and Qara Dagh it is about 70 m (Al-Shwaily *et al*., 2012).

Remark: The authors are not in accordance with the measured thicknes of the Kolosh Formation by Al-Shwaily *et al*. (2012), because the thickness is certainly more than 100 m and increases eastwards of Sulaimaniyah.

Fossils: The following fauna were recorded from the Kolosh Formation in the type section by Bellen *et al*. (1959): *Miscellanea miscella* (D'Archiac and Haime), *Dictyokathina simplex* Smout, *Lockhartia* sp., *Saudia labyrinthica* Henson, *Ammodiscus incertus* D'Orbigny, *Anomalinoides granosa* (Hantken), *Bulimia quadrata* Plummer, *Globigerina bulloides* D'Orbigny, *Globorotalia angulata* (White), *Gyroidina soldanii* D'Orbigny, *Loxostoma applinae* Plummer, *Nodosaria zippei* Reuss, *Nattallides trumpyi* (Nuttall), *Pseudovalvulineria* spp., ostracods, miliolids and valvulinids.

Fig.14: The Kolosh Formation near Debendi Khan Lake
(The inset is a close up view for the fine conglomerate)

Kassab (1976) reviewed the type section and was able to divide the formation into three planktonic zones and one benthonic zone: **1)** *Globorotalia uncinata* zone (Lowermost Middle Paleocene), **2)** *Globorotalia angulata* zone (Middle Paleocene), **3)** *Globorotalia pusilla puslla* zone (High Middle Paleocene) and **4)** *Lockhartia coniti zone* (uppermost Middle Paleocene).

The same zones were established by Muniem (1976) from two sections north of Dohuk. Al-Barram (1980) established similar faunal zonation and age as that of Kassab (1976) from Shaqlawa area. However, from Shaqlawa area also Al-Mutwali (1983) stated that the lower part of the section belongs to *Globorotalia trinidadensis* zone of Lower Paleocene and divided it to three subzones: **1)** *Globorotalia psuedobulloides* subzone, **2)** *Gr. compressa* subzone and **3)** *Gr. incostans* subzone. In the upper part of the sequence on the other hand, the sediments belongs to *Globorotalia subbotina* zone of Lower Eocene age.

Age: The age of the Kolosh Formation is Paleocene – Lower Eocene (Bellen *et al*., 1959). According to Kassab (1976), Muniem (1976) and Al-Barram (1980) the Kolosh Formation is of early Middle Paleocene – Upper Paleocene age. Jassim *et al*. (1984) accepted the findings of Al-Mutwali (1983), as they believed that the *Globorotalia uncinata* zone is of uppermost Danian (Lower Paleocene). Karim and Al-Jibouri (1992) also claimed Lower Plaeocene (Danian) age. According to Al-Shwaily *et al*. (2012), the age of the Kolosh Formation is Paleocene – Early Eocene.

Depositional Environment: The rhythmic sandstone and shale in major parts of the Kolosh Formation with graded bedding is accepted to be of turbidite origin. The upper part with interfingering limestone sandstone and shale represents the terminal uplift of the basin in the Upper Paleocene and hence of shallow water shelf, or inner type with abundant terrigenous influx (Jassim *et al*., 1984). According to Al-Qayim *et al*. (2008) the sediments represent distal turbidite facies of an unattached submarine fan complex that is developed far from feeding channel systems. The Lower contact of the formation is slightly higher than the Pg10, whereas the top of the formation represents Pg20 MFS (Aqrawi *et al*., 2010).

Lower Contact: In the type locality, the Kolosh Formation is underlain by the Tanjero Formation; the contact is unconformable marked by a total faunal change without transitional elements (Bellen *et al*., 1959). In Shaqlawa – Koi Sanjaq vicinity, it is underlain unconformably by the Tanjero Formation; the contact is not sharp and not distinct, due to large lithological similarity. The contact was based on a bottom conglomerate bed (3 – 8) m thick, the pebbles are small (1 – 3 cm) composed of carbonates and silica (Sissakian and Youkhanna, 1979). The same contact is developed around the Darbandi Khan Lake (Fig.14) (From the field observations of the Senior author). Al-Shaibani *et al*. (1986) described the Cretaceous/ Tertiary contact in detail from Dokan Area. They found deeply weathered conglomerate layer with thickness of one meter (underlain by 8 m thick pebbly sandstone) indicating the contact. According to biostratigraphic study, the contact represents a gap between Middle Maastrichtian and Middle Thanetian. The pebbly sandstone layer represents Tanjero sediments deposited in a deep to shallow marine condition, followed by a subareal condition during the aforementioned hiatus.

2.1.2. Sinjar Formation (Late Paleocene – Early Eocene)

Type Locality: The Sinjar Formation is defined by Keller in 1941; the type section is near Mamisa village on Jebel Sinjar, it is defined by the following coordinates (Bellen *et al*., 1959) (Fig.3):

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

Exposure Areas: The Sinjar Formation is exposed as a continuous ridge in the eastern parts of the High Folded Zone, such as Darbandi Bazian, Qara Dagh, Tasloojah, Darbandi Khan, and Bammu. Its subsurface extensions south and southwest of the High Folded Zone are clear, since the formation is encountered in Qalian 1, Demir Dagh 1, K116, Cham Chamal 2, Taq Taq 1, Mushorah 1, and Sasan 1 oil wells (Fig.3). Moreover, it is age equivalent;

Umm Er Radhuma Formations is encountered in the oil wells of the southern parts of Iraq, whereas towards west, it passes to Khurmala and/ or Aaliji formations, which are encountered in many oil wells (I.P.C., 1963).

Lithology: In the type section, the Sinjar Formation consists of "Limestone showing elements of algal reef facies, lagoonal miliolid facies, and shoal nummulitic facies, usually recrystallized and yellowish of colour" (Bellen *et al*., 1959). In Taslooja and Qara Dagh (Fig.15) vicinity, the formation consists of pale grey massive and fine crystalline limestone (Al-Shwaily *et al*., 2012).

Fig.15: The Sinjar Formation underlain by the Kolosh Formation in Qara Dagh anticline
(The inset shows the details of the limestone)

Remark: In Darbandi Khan vicinity, some of the limestone beds include fine pebbles (0.5 – 1 cm), the pebbles increase in the upper part of the single bed, and in the uppermost part of the formation, the majority of the limestone beds changes to fine conglomeratic limestone (From the field observations of the Senior author).

Thickness: The thickness of the Sinjar Formation in the type section is 176 m (Bellen *et al*., 1959). In Darbandi Bazian – Qara Dagh – Darbandi Khan vicinities the thickness ranges from (15 – 65) m, decreasing eastwards, in Taslooja 90 m, but increases westwards to more than 100 m, southwest of Pera Magroon.

Fossils: The following fossils were recorded from the Sinjar Formation by Bellen *et al*. (1959): *Alveolina globosa* Leymerie, *Alveolina primaeva* Reichel, *Dictyoconus arabicus* Henson, *Dictyokathina simplex* Smout, *Idalina sinjarica* Grimsdale, *Miscellana miscella* (d'Archiac and Haime), *Nummulites atacicus* Leymerie, *Opertorbitolites* sp., *Saudi labyrinthica (*Grimsdale), *Taberina daviesi* Henson, *Parachaetetes asvapatii* Pia. Amer (1977) recorded the following fossils in the Sinjar Formation: *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) and Late Paleocene – Early Eocene (Amer, 1977 and Buday, 1980 and Salih and Abdullah, 2009), Selandian – Lutetian (Salih, 2012). Al-Shwaily *et al*. (2012) claimed Paleocene – Early Eocene age for the Sinjar Formation.

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 miliolids facies and 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. According to Salih and Abdullah (2009) the formation was deposited in a warm, shallow and illuminated water. The formation is bounded between Pg10 and Pg20 MFS (Aqrawi *et al*., 2010).

Lower Contact: In the type section, the lower contact of Sinjar Formation, with the underlying Shiranish Formation is unconformable (Bellen *et al*., 1959), the unconformity being marked by a complete faunal and facies change. In Koi Sanjaq vicinity, it is underlain conformably by Kolosh formation, the contact is sharp and clear, based on the bottom of the first limestone bed, locally interfingers with the Khurmala Formation (Sissakian and Youkahanna, 1979). The same contact details were recorded in Pera Magroon, Qara Dagh, Tasloojah anticlines (Al-Shwaily *et al*., 2012). In Darbandi Bazian, Darbandi Khan, Bammu, the Sijnar Formation is underlain by Kolosh Formation conformably, locally they interfinger to each other, especially its lower part. The contact is sharp and very clear, due to the lithological change from black clastics of the Kolosh Formation to limestones of the Sinjar Formation.

2.1.3. Khurmala Formation (Late Paleocene – Early Eocene)
Type Locality: The Khurmala Formation is defined by Bellen in 1953, the type section is at I.P.C oil well K114; between drilling depths 3225 and 3869 ft (about 1000 – 1200 m), it is defined by the following coordinates (Bellen *et al*., 1959) (Fig.3):

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

Exposure Area: The Khurmala Formation is exposed in Safeen, Bana Bawi, Koi Sanjaq, Dohuk, Amadiya, Gara anticline, Khlaifan. Its subsurface extensions south and southwest of the High Folded Zone are clear, since the formation is encountered in K40, K81, K114, K116, K117, Cham Chamal 2, Quwair 1, Taq Taq 1, Atshan 1, and Sasan 1 oil wells (Fig.3). Moreover, it is age equivalent; Umm Er Radhuma Formations is encountered in the oil wells of the southern parts of Iraq, whereas towards west, it passes to Aaliji formations, which is encountered in many oil wells (I.P.C., 1963).

Lithology: In the type section, the Khurmala Formation consists of "Dolomite, suboolitic in parts, and finely recrystallized limestone. Probably Chamical 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 Dohuk vicinity, it consists of hard, pale yellow, dolostone and thinly bedded sandy limestone (Fig.16) (Abdullaziz, 1978). In Shaqlawa – Koi sanjaq vicinity, the formation consists of limestone, recrystallized, dolomitic and coralline, very rarely bituminous and sandy, even fine conglomeratic; pebbles are mainly of carbonate and chert, up to 3 cm in size (Sissakian and Youkhanna, 1979).

Fig.16: Limestone of the Khurmala Formation overlying Kolosh and Tanjero formations

Thickness: The thickness of the Khurmala Formation in the type section is 185 m (Bellen *et al*., 1959). In Shaqlqawa and Salahiddeen, it ranges from (3 – 12) m, in Kom Isban about 20 m, in Degala 100 m, in Koi Sanjaq 75 m, in Haibat Sultan mountain 20 m (Sissakian and Youkhanna, 1979).

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, 1980). 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) and Barwary (1983) suggested Late Paleocene – Early 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), Al-Qayim (1995), and Jassim and Buday in Jassim and Goff (2006) claimed restricted lagoonal environment for the formation. The formation is bounded between Pg10 and Pg20 MFS (Aqrawi *et al*., 2010).

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. In Dohuk vicinity, it is underlain by Kolosh Formation with gradational contact (Abdullaziz, 1978). In Shaqlawa – Koi Sanjaq vicinity, the formation is underlain conformably by the Kolosh Formation, the contact is sharp and clear, due to large lithological difference, locally they interfinger to each other, and with Sinjar Formation too. The contact is based at the bottom of the first limestone bed (Sissakian and Youkhanna, 1979).

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 in the present area of the High Folded Zone; this foredeep was separated from the basin to the southwest by a belt of nummulitic limestone shoals of Avanah Formation, which separated between the High Folded and Low Folded Zones (Jassim and Buday in Jassim and Goff, 2006).

The Middle – Late Eocene Sequence represents the upper half part of the Middle Paleocene – Eocene Megasequence AP10, established by Sharland *et al*. (2001), it includes three formations, and they are described hereinafter.

2.2.1. Gercus Formation (Early – Middle Eocene)

Type Locality: The Gercus Formation is defined 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, and is defined between the following coordinates (Bellen *et al*., 1959) (Fig.3):

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

Exposure Areas: The Gercus Formation is one of the most widely exposed formations in the High Folded Zone, almost continuously without interruption from the southeastern side towards northwestern side. It is exposed in Zakho, Dohuk, Swaratooqa, Amadiya, Zawita, Shaqlawa, Hareer, Salah Al-Deen, Koi Sanjaq, Darbandi Bazian, Tasloojah, Qara Dagh, Darbandi Khan, and Bammu. The subsurface extensions of the formation off the High Folded Zone are not clear, since it is not encountered in any drilled oil well. The authors believe that the formation does not extend off the High Folded Zone, but its age equivalents, Avanah and Jaddala formations are encountered in many oil wells, except Damir Dagh 1 and Taq Taq 1, in the Low Folded Zone, south and west of the High Folded Zone.

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. Lenticles 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). Near Amadiya it consists of brick red shales and sandstones, occasional conglomerate and lenticular limestone (Fig.17) (Hall, 1954). In Dohuk vicinity, it consists of reddish brown, thinly bedded sandstone, siltstone, conglomerate interbedded with claystone, rarely gypsum may occur too (Abdullaziz, 1978). In Shaqlawa – Koi Sanjaq vicinity, the formation consists of claystone, sandstone, siltstone all red in color, and very rare conglomerate lenses (Sissakian and Youkanna, 1979).

Remarks:

1) In Dohuk vicinity, gypsum beds occur in the Gercus Formation too (from the field observations of the Senior author).

2) In Salah Al-Deen – Shaqlawa vicinity, limestone beds occur within the Gercus Formation, with thickness range from (1 – 20) m (Sissakian and Youkhanna, 1979).

3) In Sartaq Bammu, south of Darbandi Khan, the Gercus Formation consists almost of conglomerates, forming steep cliffs (from the field observations of the Senior author).

4) In Darbandi Bazian vicinity and eastwards, Lawa (2012) renamed the Gercus Formation as Sagirma Formation, according to the existence of numerous limestone beds in the formation.

The authors are not in accordance with this assumption, because the announcement of a new formation needs requirements, which are not available in Lawa (2012).

Fig.17: Red clastics of the Gercus Formation overlain by limestone of the Pila Spi Formation, along the road between Amadiya and Duhok

Thickness: The thickness of the Gercus Formation in the supplementary type section is 838 m (Bellen *et al*., 1959), near Amadiya it is about 200 m. In Shaqlawa – Koi Sanjaq vicinity it ranges from (110 – 150) m, but in Mirawa anticline it is 220 m (Sissakian and Youkhanna, 1979), in Darbandi Bazian – Qara Dagh vicinity, it ranges from (35 – 120) m.

Fossils: The following fossils were recorded within the Gercus Formation by different authors from different localities. From the type area, Bellen *et al*. (1959) recorded only radiolaria and ostracods. Similarly, most outcrop areas are devoid of fossils. However, Muniem and Yacoub (1979) found fossiliferous layer within the formation in Shaqlawa area that *Miscellanea miscella* (D'Archiac and Haime), revealed the following fauna: textularids, miliolids, *Dorthia* sp., *Rotalia* sp. and *Miscellanea miscella* (D'Archiac and Haime), Jassim *et al*. (1984) believed that this layer belongs to Khurmala Formation exactly at the base of Gercus Formation.

Age: The age of the Gercus Formation is probably Middle Eocene (Bellen *et al*., 1959). The fauna quoted from Jassim *et al*. (1974) for the Sinjar limestone at the base of Gercus Formation in Derbendi Khan area indicate Lower Eocene (Lower Ypresian) age. They (op.cit) indicate that the contact between the two formations is seemingly gradational. This would strongly suggest Lower Eocene age for the base of the Gercus Formation in the area. From Dohuk area, Al-Omari and Sadik (1975) studied Alveolina bearing beds at base of Pila Spi Formation and top of Gercus Formation; they assigned Middle Eocene age to these beds. Therefore, the top of Gercus Formation in Dohuk area would be Middle Eocene age as maximum. In conclusion, the Gercus Formation is Lower – Middle Eocene.

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). The Gercus Formation is bounded between Pg20 and Pg30 MFS (Aqrawi *et al*., 2010).

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). In Dohuk and Amadiya vicinity, the formation locally is underlain unconformably by Qamchuqa and/ or Aqra – Bekhme Formation, in other areas, it is underlain by Kolosh and Khurmala formations (Abdullaziz, 1978). In Shaqlawa – Koi Sanjaq vicinity, the formation is underlain unconformably by Kolosh Formation and/ or Khurmala Formation; in both cases the contact is clear and sharp. In the former case, the contact is based on the clear colour difference; between black and red, whereas in the latter case the contact is based on the top of the last limestone bed (Sissakian and Youkhanna, 1979). In Darbandi Bazian, Pera Magroon, Qara Dagh, Darbandi Khan, Bammu, the Gercus Formation is underlain by the Kolosh Formation, the contact is based on the top of the last black clastics and the bottom of the first red clastic bed.

Remark: The authors believe that the described unconformable contact of the Gercus Formation with the underlying Qamchuqa and/ or Aqra – Bekhme Formation by Abdullaziz (1978) most probably be a tectonic contact, because no such contact is described elsewhere.

2.2.2. Avanah Formation (Early – Late Eocene)
Type Locality: The Avanah Formation is defined by McGinty in 1953, the type section is in the oil well K 116 in Kirkuk structure, it is defined by the following coordinates (Bellen *et al*., 1959) (Fig.3):

Longitude 43° 59' 06.34" E
Latitude 35° 47' 28.99" N

Exposure Areas: The Avanah Formation is exposed only in Bammu anticline (Fig.18) (Youkhanna and Hradecky, 1978), within the High Folded Zone. However, its subsurface extension extends to the Low Folded Zone (Bellen *et al*., 1959). The formation is encountered south and southwest of the High Folded Zone in many oil wells within the Low Folded Zone, like K109, 116, and 117, Alan1, Mushorah 1, Gusair 1, Ain Zala 16 and 22, and Butmah 2 (Fig.3). Moreover, its age equivalent, the Jaddala Formation is encountered in many oil wells in the Low Folded Zone (I.P.C., 1963).

Remark: The authors believe that the Avanah Formation is exposed in different parts of the High Folded Zone underlying the Pila Spi Formation (Fig.18). They are not differentiated due to lithological similarity, and because the geological maps, which are compiled from interpretation of aerial photographs, cover large parts of the High Folded Zone, therefore, it is almost impossible to differentiate the two formations. However, the formation is exposed in Dohuk vicinity below the Pila Spi Formation, but it is not differentiated and mapped separately, it is also exposed in Sartaq Bammu anticline, at the tourist entrance, with a thickness of not more than 3 m (From the field observations of the Senior author).

Lithology: The Avanah Formation, in the type sections consists of "Limestones, generally dolomitized and recrystallized, of shoal facies, with occasional intercalations of lagoonal limestones, which are treated as Pila Spi limestone tongues. The top part is less recrystallized and dolomitized than the part below 2394 feet (about 710 m)" (Bellen *et al*., 1959). In Bammu anticline, it consists of light grey, well bedded recrystallized and dolomitized limestone, with some chert nodules (Youkhanna and Hradecky, 1978).

Fig.18: The Avanah Formation (**A**) underlying the Pila Spi Formation (**P**)
in Sartaq Bammu area, South of Darbendi Khan

Thickness: The thickness of the Avanah Formation, in the type section is 212 m (Bellen *et al*., 1959, in Bammu anticline, unfortunately it is not measured (Youkhanna and Hyradecky, 1978). In other exposed localities it is not more than (3 – 5) m.

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 globulus*, *Discocyclina dispance*, *Sphaerogypsina* sp. and *Nummulites atacicus* (Karim, 1977). Youkhanna and Hyradecky (1978) recognized the following fossils: *Duscocyclins* sp., *Nummunlites* sp., *N. perforates* var *bayharicusis*, *N. golbulus*, with planktonic fauna: *Globigerina* sp., *Globorotalia aragonesis*.

Age: The age of the Avanah Formation is Middle – Upper Eocene (Bellen *et al*., 1959; Amer, 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 Avanah Formation represents the shoal facies as demonstrated by the dominant occurrence of *Nummulites* and *Discocyclina* species (Middle Eocene). 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 highstand of sea level. According to Youkhanna and Hradecky (1978) the formation is of shallow marine shoal facies. The Avanah Formation is bounded between Pg 20 and Pg30 MFS (Aqrawi *et al*., 2010).

Lower Contact: In the type locality, the Avanah Formation is underlain by Khurmala Formation; the contact is probably unconformable (Bellen *et al*., 1959). In Bammu anticline, the bottom of the formation is not exposed (Youkhanna and Hradecky, 1978).

2.2.3. Pila Spi Formation (Middle – Late Eocene)

Type Locality: The Pila Spi Formation is defined by Lees (1930) from Pila Spi area; near Darbandi Khan Dam, it was redefined by Wetzel (1947) and amended and augmented by Bellen (1957) (Bellen *et al*., 1959), the type section is defined by the following coordinates (Fig.3):

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: The Pila Spi Formation is very well exposed in the High Folded Zone; in form of outstanding scarps, which represent the contact between the High Folded and Low Folded Zones. It is exposed in Zakho, Dohuk, Zawita, Amadiya, Gara, Alqosh, Ain Sifni, Aqra, Peris, Shaqlawa, Salah Al-deen, Koi Sanjaq, Haibat Sultan, Qara Dagh, Darbandi Khan, Zimnako, Sharwaldir, and Bammu. The subsurface extensions of the formation south and southwest of the High Folded Zone is obscure, since it is encountered in few oil wells, which are drilled in the Low Folded Zone, south and southwest of the High Folded Zone, like Cham Chamal 2, Taq Taq 1, Dmir Dagh 1 (Fig.3). However, it passes to Avanah Formation, which is encountered in many oil wells, also its age equivalent Jaddala Formation (I.P.C., 1963).

Lithology: The Pila Spi Formation, in the type section consists of two parts: "The higher part shows well bedded bituminous limestone, weathering white, chalky and crystalline, with bands of pale green marl or chalky marl with buckled bedding planes; bands of buff chert nodules towards the top, traces of fossils; 57 m thick. The lower part shows well bedded limestones, hard though of chalky appearance, porous or vitreous, bituminous or white, poorly fossiliferous, algal and shell sections in calcite, 28 m thick" (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). Near Amadiya, it consists of well bedded, white dolomitic limestone (Hall, 1954). In the Dohuk vicinity (Fig.17), it consists of dolomitic and chalky limestones, overlain by well bedded, crystalline dolomitic limestone with chert nodules, locally bituminous and marly (Abdullaziz, 1978). In Dohuk and Be Khair anticlines, it consists of white to yellowish grey, massive to thickly bedded, cavernous, splintery, partly fossiliferous dolostone with chert nodules; locally in the lowermost part Alveolina was recognized (Taufiq and Domas, 1977). In Shaqlawa – Koi Sanjaq vicinity, it consists of white and yellowish grey dolomitic, chalky, well bedded limestone, occasionally bituminous, fossiliferous and marly (Sissakian and Youkhanna, 1979). In Derbendi Khan and Sartaq Bammu vivinities it consists of well bedded dolostone and limestone (Fig.18).

Remark: The authors believe that the recognized Alveolina by Taufiq and Domas (1977) in Dohuk vicinity, most probably indicates the Avanah Formation?.

Thickness: The thickness of the Pila Spi Formation in the type section is 85 m and in the supplementary type section is 189 m (Bellen *et al*., 1959), near Amadiya it ranges from (80 – 180) m, in Dohuk and Be Khiar anticline 143 m (Taufiq and Domas, 1977). In Salah Al-Deen 120 m, in Kom Isban 89 m, in Koi Sanjaq 56 m, and in Shaqlawa 70 m (Sissakian and Youkhanna, 1979).

Fossils: The following fossils were recorded, by different authors in the 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). From the Baranan Dagh area near Pila Spi, better fauna was recorded: miliolids (*Pyrgo* sp.), chilostromellids, *Praerhpydionina huber* Henson, *Rhapydionina urensis* Henson, *R. williamsoni* Henson, *R. macfadyeni* Henson. Behnam (1977) in Dohuk area reported miliolids, peneroplids, ostracods and textularids. Al-Hashimi and Amer (1985); recorded *Rhapydionina urensis* Henson, *Spirolina* sp., *Peneroplis* sp., *Bigenerina* sp., *Somalina* sp., *Alveolina* sp., rotalids, miliolids and algae.

Age: The age of the Pila Spi Formation is probably Middle and/ or Upper Eocene (Bellen *et al*., 1959). The age is considered as Middle – Upper Eocene (Amer, 1977; Buday, 1980 and Al-Hashimi and Amer, 1985), whereas Sissakian and Youkhanna (1979), and Jassim and Buday in Jassim and Goff (2006) claimed a 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). Khanaqa (2011) found a new facies in the Pia Spi Formation and claimed that the depositional environment is a carbonate ramp with low topographic patchy reef, back reef and lagoon. The evidence for ramp are gradual changes of the facies and absence of high energy facies. The ramp is bordered from the south and southwest by open marine basin where Jaddala Formation was deposited, while it is limited from the north by paleohigh, which separates the ramp from Walash – Naopurdan Group. The Pila Spi Formation is bounded between Pg20 and Pg30 MFS (Aqrawi *et al*., 2010).

Lower Contact: In the type locality, the Pila Spi Formation is underlain by the Gercus Formation, the contact is sometimes gradational through interfingering, sometimes appear to be marked by a conglomerate. In the supplementary type section, it is underlain unconformably by the Gercus Formation, the contact is marked by a conglomerate (Bellen *et al*., 1959). In Shaqlawa – Koi Sanjaq vicinity, the lower contact is unconformable with the underlying Gercus Formation. The contact is sharp, based on a conglomerate horizon, which ranges in thickness from (1 – 5) m. Near Shaqlawa, the conglomerate is 12 m thick, whereas in areas where the conglomerate is not developed, the contact is based on the bottom of the first limestone bed (Sissakian and Youkhanna, 1979). In Bammu, north of Khanaqeen, the Pila Spi Formation is underlain by Avanah Formation (Youkhanna and Hradecky, 1978). In Darbandi Bazian, Qara Dagh, Darbandi Kkan, the Pila Spi Formation is underlain by the Gercus Formation, the contact is sharp and based on the top of the last red clastic bed.

Remark: In different parts of the High Folded Zone, Avanah Formation underlies the Pila Spi Formation, without any significant break and seems to be conformable. This case is not recognized and mapped, therefore, the lower contact of the Pila Spi Formation is considered with the Gercus Formation, as the underlying formation. However, in Sartaq Bammu, the

Pila Spi Formation is underlain by Avanah Formation; the contact is not clear and seems to be conformable (from the field observations of the Senior author).

2.3. Oligocene

At the end of the Eocene, and during the Oligocene, the main intraplate basin became narrower due to the tilting of west Arabia, and uplift of the High Folded Zone, except the southern marginal parts. The eastern shore line receded and reached 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 (Jassim and Buday in Jassim and Goff, 2006). A clear unconformable contact occurs between the Oligocene formations and the underlying Eocene Pila Spi Formation, although locally the Early Miocene Euphrates Formation or the Middle Miocene Fatha Formation overlies the Pila Spi Formation. Amin (2009) proved the unconformable contact between Oligocene and Eocene, and considered it as type one sequence boundary without deposits of distal lowstand system tract, which is attributed to weathering resistance of the Pila Spi Formation during Oligocene time.

The exposures of the Oligocene Epoch in the Iraqi High Folded Zone have extremely limited extensions, only along the contact area between the High and Low Folded Zones. This is attributed to the nature of the Neo-Tethys, which was a narrow seaway forming reef back reef and fore reef basins. However, Oligocene rocks are most probably present overlying the Pila Spi Formation wherever Miocene rocks are present too, in the High Folded Zone.

It is worth mentioning that Khanqa *et al*. (2009) and Sissakian and Fouad (2012) found some Oligocene formations overlying the Pila Spi Formation south of Qara Dagh, in Qara Wais and Aj Dagh anticlines (The last two anticlines are off the High Folded Zone), and they may be present more to the southeast and northwest along the cliffs of the Pila Spi Formation. The same case was observed in Haibat Sultan, Darbandi Bazian, Ain Sifni and Dohuk vicinities.

The Oligocene Epoch, in the High Folded Zone is represented by five formations, these are described, hereinafter. They represent the lowermost part of the Late Eocene – Recent Megasequence (AP11), established by Sharland *et al*. (2001).

2.3.1. Shurau Formation (Early Oligocene)

Type Locality: The Shurau Formation is defined by Bellen (1956); the type section is in Kirkuk structure, oil well K109, it is defined by the following coordinates (Bellen *et al*., 1959) (Fig.3):

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

Exposure Areas: The Shurau Formation is exposed only in Bammu anticline, and possibly in Qara Dagh anticline. However, it may be exposed above Pila Spi Formation, in the extreme south and southwestern parts of the High Folded Zone (From the field observations of the Senior author). Its subsurface extensions south and southwest of the High Folded Zone are obscure, since it is encountered in few oil wells, such as K109, Bai Hassan 3, Gusair 1, Ain Zala 22, and Musaiyab 1 (Fig.3). However, in many other oil wells it is not differentiated, but recorded as "Kirkuk Group" (I.P.C., 1963).

Lithology: The Shurau Formation, in the type section consists of "About 5.5 m of grey dense limestone and about 13 m of porous coralline limestone" (Bellen *et al*., 1959). In Bammu antilcline, it consists of white to pink, well bedded, splintary, fossiliferous limestone and brecciated limestone (Youkhanna and Hradecky, 1978).

Thickness: The thickness of the Shurau Formation in the type section is 18 m (Bellen *et al*., 1959), in Bammu anticline is 9 m (Youkhanna and Hradecky, 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).

Age: The age of the Shurau Formation is most probably Lower Oligocene (Bellen *et al*., 1959). Moreover, 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, 1974; Jassim *et al*., 1984; Al-Hashimi and Amer, 1985 and Jassim and Buday in Jassim and Goff, 2006). The formation is bounded between Pg30 and Pg40 MFS (Aqrawi *et al*., 2010).

Lower Contact: The lower contact of the Shurau Formation, in the type locality is conformable with the underlying Sheikh Alas Formation (Bellen *et al*., 1959), whereas, in Bammu anticline, the lower contact with the underlying Avanah Formation is covered by thick scree, therefore, its nature cannot be deduced (Youkhanna and Hradecky, 1978).

2.3.2. Baba Formation (Middle Oligocene)

Type Locality: The Baba Formation is defined by Bellen (1956), the type section is in Kirkuk structure at oil well K109 as the type locality, it is defined by the following coordinates (Bellen *et al*., 1959) (Fig.3):

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

Exposure Area: The Baba Formation is exposed only in Shalwerdir and Bawgaru anticlines, north of Khanaqeen. However, it may be exposed above Pila Spi Formation, in the extreme south and southwestern parts of the High Folded Zone (From the field observations of the Senior author). The subsurface extensions of the formation south and southwest of the High Folded Zone are not so clear, since it is encountered in some of the drilled oil wells, like Qalian 1, K5, 16, 20, 30, 37, 50, 60, 74, 87, 97, 109, 115, 127, 136, 147, 160, and K170, Qara Chauq 1, Bai Hassan 3, 12, 13, and 23, Gullar 1, Gusair 1, Ain Zala 22, Dujaila 1, and Musaiyib 1 (Fig.3). However, in the southwestern parts of the Low Folded Zone and the northern parts of the Western Desert, the Baba Formation is not differentiated in some oil wells, but the Oligocene rocks are recorded as Kirkuk Group (I.P.C., 1963).

Lithology: The Baba Formation in the type section consists of "Porous dolomitized limestone" (Bellen *et al*., 1959). In Bawgaru anticline, it consists of greyish white, fine crystalline, dolomitic limestone (Youkhanna and Hradecky, 1978).

Thickness: The thickness of the Baba Formation in the type section is 20 m (Bellen *et al*., 1959), in Bawgaru anticline ranges from (57 – 78) m (Youkhanna and Hradecky, 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. Youkhanna and Hradecky (1978) recognized the following fossils: *Rotalia* sp., *R. voiennoti, Amphistegina* sp., *Lepidocyclina* sp., *Nummulites* sp., *Textularia* sp., *Operculina* sp., *O. companata*, *Heterostegina* sp., and corraline 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; Youkhanna and Hradecky, 1978; Al-Hashimi and Amer, 1985; Jassim and Buday in Jassim and Goff, 2006, and Karim *et al*., 2012).

Depositional Environment: The Baba Formation represents reef – fore-reef facies (Bellen, 1956 and 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. The formation is bounded between Pg40 and Pg50 MFS (Aqrawi *et al*., 2010).

Lower Contact: The Baba Formation, in the type locality is underlain, unconformably by the Shurau Formation (Bellen *et al*., 1959), in Bawgaru anticline, it is underlain conformably by Tarjil Formation, whereas, in Sharweldir anticline; the base is not exposed (Youkhanna and Hradecky, 1978).

2.3.3. Bajawan Formation (Late Oligocene)
Type Locality: The Bajawan Formation is defined by Bellen (1956), the type section is at Kirkuk, in oil well K109 as the type locality, it is defined by the following coordinates (Bellen *et al*., 1959) (Fig.3):

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

Exposure Areas: The Bajawan Formation is exposed in Baski Zanur Dagh, Darbandi Sagirma, Bammu, Sharweldir and Bawgaru anticlines (north of Khanaqeen vicinity). Moreover, may be it is exposed overlying the Pila Spi Formation along the extreme southern margins of the High Folded Zone. The subsurface extensions of the formation in the High Folded Zone are obscure. The authors believe that the formation has no subsurface extensions within the zone. However, the subsurface extensions of the Bajwan Formation south and southwest of the High Folded Zone is not clear, since it is encountered in few oil wells, like Dujaila 1, Musaiyib 1, Qalian 1, Ain Zala 16 and 22, Gusair 1, Gullar 1, Bai Hassan 3, 13, and 23, K1, 8, 20, 30, 37, 50, 60, 70, 78, 88, 100, 109, 120, 130, 140, 150, 160, and 176 (and many others). However, in the southwestern parts of the Low Folded Zone and the northern parts of the Western Desert, the Bajwan Formation is not differentiated in some oil wells, but the Oligocene rocks are recorded as Kirkuk Group (I.P.C., 1963).

Lithology: The Bajawan Formation, in the type section consists of "Tight, cream-colourd, back-reef miliolid limestones, alternating with more porous, partly dolomitized, rotalid – algal reef limestones, with fairly abundant coral fragments. The reef beds become thicker and more abundant towards the base of the formation. Thin wisps of non-fossiliferous green marl occur too" (Bellen *et al*., 1959). In north of Khanaqeen vicinity, it consists of light grey, fossiliferous, hard, thickly bedded to massive limestone (Youkhanna and Hradecky, 1978).

Thickness: The thickness of the Bajawan Formation in the type section is 39 m (Bellen *et al*., 1959), in Bammu 27 m, in Slarweldir 26 m, and in Bawgaru 46 m (Youkhanna and Hradecky, 1978).

Fossils: The following fossils were recognized in Bajwan Formation: *Praerhapydionina delicata* 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). Youkhanna and Hradecky (1978) recognized the following fosslis: *Borelis pygmaes*, *Borelis* sp., *Peneroplis thomasi*, *Lepidocyclina* sp., *Austrotrillina howchinin*, *A.* sp., *Rotalia viennoti*, *Valvulina* sp., *Archais kirkukensis*, and *Praerhapydiomia delicate*.

Age: The age of the Bajwan Formation is Middle Oligocene (Bellen *et al*., 1959; Karim, 1977; Youkhanna and Hradecky, 1978; Al-Hashimi and Amer, 1985), whereas Jassim and Buday in Jassim and Goff (2006) claimed a 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. The formation is bounded between Pg40 and Pg50 MFS (Aqrawi *et al*., 2010).

Lower Contact: The lower contact of the Bajawan Formation, in the type locality is conformable with the underlying Baba Formation (Bellen *et al*., 1959). In Bammu anticline, it is underlain unconformably by Shurau Formation, in Sharweldir and Bawgaru anticlines, by Baba Formation unconformably (Youkhanna and Hradecky, 1978).

2.3.4. Tarjil Formation (Late Oligocene)

Type Locality: The Tarjil Formation was first described by Bellen in 1956 from Kirkuk structure in oil well K85 as the type locality, which is defined by the following coordinates (Bellen *et al*., 1959) (Fig.3):

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

Exposure Areas: The Tarjil Formation is exposed in Bezniyan and Bawgaru anticlines in north of Khanaqeen area only. Moreover, it may be exposed overlying the Pila Spi Formation along the extreme southern margins of the High Folded Zone. The subsurface extensions of the formation in the High Folded Zone are obscured. The authors believe that the formation has no subsurface extensions within the zone. However, the subsurface extensions of the Bajwan Formation south and southwest of the High Folded Zone is not clear, since it is encountered in few oil wells, like Dujaila 1, Najmah 29, Ibrahim 1, Makhul 2, Gusair 1, Gullar 1, Bai Hassan 4, 13, and 23, K27, 46, 61, 74, 85, 100, 115, 136, and 152 (and many others), QaraChouq 1, Hamrin 1, However, in the southwestern parts of the Low Folded Zone and the northern parts of the Western Desert, the Tarjil, Formation is not differentiated in some oil wells, but the Oligocene rocks are recorded as Kirkuk Group (I.P.C., 1963).

Lithology: The Tarjil Formation, in the type locality consists of slightly dolomitized, marly limestone (Bellen *et al*., 1959). In north of Khanaqeen, it consists of well bedded, clayey and silty fossiliferous limestone, slightly dolomitized (Youkhanna and Hradecky, 1978).

Thickness: The thickness of the Tarjil Formation in the type section is 100 m, in north of Khanaqeen it is 126 m (Youkhanna and Hradecky, 1978).

Fossils: The following fossils were recognized in the Tarjil Formation: *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 (Andul-Munium and Jawi, 1978 and Al-Hashimi and Amer, 1985). Youkhanna and Hradecky (1978) recorded the following fossils: *Globigerina* sp., *Globorotalia* spp., *Bolivina* sp., *Textularia* sp., *Anomalina* spp., *Lepidocyclina* sp., *Rotalia* sp., *Ditrupa conea*, *Operculina* sp., *Dyopondicularia* sp. and *Turrilinidae orcioinds*.

Age: Middle Oligocene age was claimed to the Tarjil Formation by the following authors: Bellen *et al*. (1959); Munim and Jawi (1978); Youkhanna and Hradecky (1978), and Al-Hashimi and Amer (1985), whereas Jassim and Buday in Jassim and Goff (2006) claimed an Early Oligocene age; 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, 1974; Andul-Munim and Jawi, 1978; Youkhanna and Hradecky, 1978, and Al-Hashimi and Amer, 1985). Whereas Jassim and Buday in Jassim and Goff (2006) claimed that, the formation was deposited in outer shelf environment, as stated by Bellen *et al*. (1959). The formation lies between Pg40 and Pg50 MFS (Aqrawi *et al*., 2010).

Lower Contact: The lower contact of the Tarjil Formation, in the type locality is unconformable with the underlying Palani Formation (Ditmar *et al*., 1971), the unconformity is being marked by a concentration of glauconite (Bellen *et al*., 1959), whereas in north of Khanaqeen, the base is not exposed (Youkhanna and Hradecky, 1978).

2.3.5. Anah Formation (Late Oligocene)

Type Locality: The Anah Formation is introduced by Bellen in 1956, the type section is located 15 Km east of Nahiyah village, west of Anah, along the Euphrates River, on the southern side of the road; it is defined by the following coordinates (Bellen *et al*., 1959) (Fig.3):

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

Exposure Areas: The Anah Formation is exposed in Zakho, Qara Dagh, Bammu, Shalwerdir, Bawgaru, and Bezniyan (north of Khanaqeen vicinity). Moreover, it may be exposed overlying the Pila Spi Formation along the extreme southern margins of the High Folded Zone. The subsurface extensions of the formation in the High Folded Zone are obscure. The authors believe that the formation has no subsurface extensions within the zone. However, the subsurface extensions of the Bajwan Formation south and southwest of the High Folded Zone is not clear, since it is encountered in few oil wells, like Kor Mor 2, Butmah 1, Dujaila 1, Gusair 1, Ain Zala 1, 22 and 27, Bai Hassan 4, 12, and 22. However, in the southwestern parts of the Low Folded Zone and the northern parts of the Western Desert, the Anah Formation is not differentiated in some oil wells, but the Oligocene rocks are recorded as Kirkuk Group (I.P.C., 1963).

Lithology: The Anah Formation, in the type section consists of "Limestone, grey, breccious, recrystallized, detrital and coralline" (Bellen *et al*., 1959). In Zakho vicinity, it consists of crystalline, splintery, well bedded limestone, with few large gastropods (Abdullaziz, 1978). In north of Khanaqeen vicinity, it consists of white and grey, often conglomeratic limestone bearing large reef fossils (Youkhanna and Hradecky, 1978).

Thickness: The thickness of the Anah Formation, in the type section is 45 m (Bellen *et al*., 1959), in Bammu 6 m; however, a thickness of 178 m is estimated in a faulted sequence in Bammu anticline (Youkhanna and Hradecky, 1978).

Remark: The authors did not accept such huge thickness, they attributed the claimed thickness to tectonic disturbance.

Fossils: The following fossils were recorded in Anah Formation by Bellen *et al*. (1959); Raji (1978), Youkhanna and Hradecky (1978), 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 the Anah Formation is Late Oligocene (Bellen *et al*., 1959; Youkhanna and Hradecky, 1978, and Karim *et al*., 2012), 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, 1973; Karim, 1977; Al-Biaty, 1978, and Jassim and Buday in Jassim and Goff, 2006). The formation includes Pg50 MFS (Aqrawi *et al*., 2010).

Lower Contact: The Anah Formation, in the type locality is underlain conformably by the underlying Azkand Formation (Bellen *et al*., 1959). In Zakho vicinity, it is underlain unconformably by the Pila Spi Formation; the contact is marked by reddish brown claystone (Abdullaziz, 1978). In Bammu, it is underlain by Avanah or Shurau Formation, in Bawgaru, Bezniyan and Shalorader anticlines it is underlain unconformably by the Bajwan Formation (Youkhanna and Hradecky, 1978).

3.4. Early – Middle Miocene

The Savian movements caused development of broad and shallow basins; small and isolated parts of the main basin were developed within the southern marginal parts of the High Folded Zone, in which carbonates were deposited. Moreover, small semi-closed basins were developed on the margins of the main basin, in which marine clastics and very rare evaporates were deposited.

The formations of Miocene Epoch are exposed only in very restricted areas (Fig.2). The sequence is represented by three formations, which represent the middle part of the Late Eocene – Recent Megasequence (AP11), established by Sharland *et al*. (2001). The three formations are described hereinafter.

Remark: It is worth to mention that the hereinafter described formations are considered only along the northeastern and northern slopes of the first ridge of Pila Spi Formation, within the

High Folded Zone, which represents the contact between the Low Folded and High Folded Zones and also when they are exposed within the High Folded Zone too.

3.4.1. Euphrates Formation (Early Miocene)

Type Locality: The Euphrates Formation is defined by De Boechkh *et al*. (1929) and was amended by Bellen (1957); the type section is in wadi Fhaimi (western part of Iraq), near the police post; it is defined by the following coordinates (Bellen *et al*., 1959) (Fig.3):

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

Remark: It is worth to mention that the type section of the Euphrates Formation is inundated by Haditha Dam Lake. Moreover, the chosen type section 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.3), for the Lower and Middle Units (A and B) and another supplementary type section, at wadi Rabi, in Anah vicinity (Fig.3) 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 anticline, and probably in Bawgaru anticline (Youkhanna and Hradecky, 1978). Moreover, it is exposed in Qara Dagh anticline, both limbs (Khanaqa *et al*., 2009) and may be it is exposed overlying the Oligocene rocks, when they overly the Pila Spi Formation in the extreme southern margins of the High Folded Zone. The Subsurface extensions of the formation within the High Folded Zone and south and southwest of the zone are wide. The formation is encountered in many oil wells, like Najmah 1, Sasan 1, Qalian 1, Ibrahim 1, Adayah 1, Jambur 2, 11 and 13, Pulkhana 5, Injana 5, Hamrin 1, Mkhul 2, Cham Chamal 1, Kor Mor 1, Qara Chouq 1, Musaiyib 1, Kifl 1, Gullar 1, Gusair 1, Ain Zala 16 and 22, Butmah 2, Alan 1, Atshan 1, Khlesia 1, Anah 2, Milih Thathar 1, Awasil 5, Fallujah 1, and Samarra 1 (Fig.3) (I.P.C, 1963).

Remark: The authors' believe that the Euphrates Formation is exposed in different parts of the High Folded Zone, but it is not mapped and presented on the geological maps. This is attributed to the existing geological maps, since majority of the High Folded Zone is not mapped systematically, and the geological maps are compiled from interpretation of aerial photographs (Ibrahim, 1984). Therefore, it is almost impossible to differentiate between the Pila Spi and Euphrates formations, with the existence of Oligocene rocks. Therefore, the two formations with the Oligocene rocks are interpreted as Pila Spi Formation only.

Lithology: The Euphrates Formation in the type section 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 Dahqan anticline, it consists of white to pale grey, massive to poorly bedded, fossiliferous, finely crystalline dolostone (Taufiq and Doma, 1977). In Bawgaru anticline, the formation consists of conglomeratic limestone and conglomerate (Youkhanna and Hradecky, 1978).

Thickness: The thickness of the Euphrates Formation in the type section is 8 m (Bellen *et al*., 1959) and in the supplementary type section is 110 m (Jassim *et al*., 1984). In Dahqan anticline 16 m (Taufiq and Domas, 1977), in Bawgaru 11 m (Youkhanna and Hradecky, 1978), in Qara Dagh 11 m (Khanqa *et al*., 2009).

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* cf. *varia* LINNE (Al-Biaty, 1978). *Turritella angulara* BROCCHI, *Murex* sp., *Actaeon* sp., *Conus* sp., *Ficus conditus* (BRONGNIART), *Glycymeris pilosus* LINNAEUS, *Arca turonica* DUJARDIAN, *Phacoides* cf. *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 *Miogypsina globulina* and *Miogypsina intermedia*. All authors have agreed 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). The base of the formation is defined by Ng10, moreover it may include another MFS (Ng?) (Aqrawi *et al*., 2010).

Lower Contact: The Euphrates Formation, in the type section is underlain unconformably by the Anah Formation. The presence of thick conglomerate between the two formations indicates an erosional unconformity (Bellen *et al*., 1959). In Dahqan anticline, the Euphrates Formation is underlain by the Pila Spi Formation unconformably; the contact was based on the last bed of chert bearing dolostone (Taufiq and Domas, 1977). In Bawgaru anticline, the formation is underlain by the Anah Formation, the contact is marked by 1.5 m of fragmentary limestone (Youkhanna and Hradecky, 1978).

Remark: In many places in the High Folded Zone, the Euphrates Formation is present and underlain by Oligocene rocks, which in tern are underlain by the Pila Spi Formation, but both the Euphrates Formation and the Oligocene rocks are not mapped separately, and grouped together. However, the Euphrates Formation when underlain by Oligocene rocks, the contact is unconformable marked either by basal conglomerate or by the presence of red claystone, which may represent fossil soil.

3.4.2. Jeribe Formation (Middle Miocene)

Type Locality: The Jeribe Formation is defined by Damensin (1936), and then was defined by Bellen (1957); the type section is near Jeribe village in Sinjar Mountain, it is defined by the following coordinates (Bellen *et al*., 1959) (Fig.3):

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

Exposure Areas: The Jeribe Formation is not mentioned from surface sections within the High Folded Zone. However, Youkhanna and Hradecky, (1978) described a conglomeratic horizon in Bawgaru anticline and considered it as the equivalent of the Jeribe Formation. The subsurface extensions of the Jeribe Formation are very wide, it extends south of the Low Folded Zone, and more southwestwards into the Jazira Plain, since it is encontrated in Milih Tharthar well (Bellen *et al*., 1959) and many other oil wells in the Low Folded Zone (I.P.C., 1963).

Remark: Although the Jeribe Formation was not described from the exposures of the High Folded Zone, but the authors have introduced the formation within the stratigraphic column of the exposed rocks, because they do believe that, the formation may occur overlying the Euphrates Formation, where the latter is exposed, but not differentiated due to the large lithological similarity. Moreover, the Jeribe Formation is exposed in Aj Dagh anticline (off the High Folded Zone), which is located about 15 Km south of the Qara Dagh anticline.

Lithology: The Jeribe Formation, in the type section consists of "Limestone, recrystallized and dolomitized, generally massive, with beds of (3 – 6) feet (0.3 – 2.6 m) thick. 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 Bawgaru anticline, the formation consists of conglomerates, conglomeratic limestone and sandy to pebbly limestone (Youkhanna and Hradecky, 1978).

Thickness: The thickness of the Jeribe Formation, in the type section is 73 m (Bellen *et al*., 1959), in Bawgaru anticline it is 70 m.

Fossils: The following fossils are recorded from Jeribe Formation by Amer (1977); Karim (1977); Youkhanna and Hradecky (1978), 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., *Triloculina* sp., *Spirolina* sp., miliolids, algae and shell fragments.

Age: The age of Jeribe Formation is probably Lower Miocene (Bellen *et al*., 1959). However, Jassim *et al*. (1984) claimed a Middle Miocene age, and all other workers have agreed upon the assigned age.

Depositional Environment: The Jeribe formation is homogenous in lithology and in faunal assemblages. 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 Youkhanna and Hradecky (1978), the depositional environment of the formation is shallow, near shore warm marine environment. The Jeribe Formation includes Ng20, whereas Ng30 represents its top, moreover, it may include another MFS (Ng?) (Aqrawi *et al*., 2010).

Lower Contact: The Jeribe Formation in the type section is underlain unconformably by the Serikagni Formation, as no Dhiban anhydrite formation occurs (Bellen *et al*., 1959). In Bawgaru anticline, Youkhanna and Hradecky (1978) considered the Jeribe Formation to be older than the Euphrates Formation, as they described the conglomeratic sequence of 100 m to include Jeribe, Euphrates and Fatha (Lower Fras) formations.

Remark: The authors do not accept this division, becasue of the age difference between the Euphrates and Jeribe formations. Moreover, Youkhanna and Hradecky (1978) described the Euphrates Formation and mentioned that it is directly underlain by the Anah Formation.

3.4.3. Fatha Formation (Middle Miocene)

The Fatha Formation was formerly known as the Lower Fars Formation; it was defined 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). It is worth mentioning that the Lower Fars Formation is abandoned and is renamed as Gachsaran Formation. 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.

Type Locality: The type locality of the Fatha Formation is in Makhul Range, the type section is defined by the following coordinates (Jassim *et al*., 1984 and Al-Rawi *et al*., 1992) (Fig.3):

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 in Zakho, Dohuk, Amadiya, Sar Sang, Mangesh, Ain Sifni, Shaqlawa, Salah Al-Deen, Hareer, south and southwest of Sulaimaniyah, Kolos anticline, and around the Darbandi Khan lake. The subsurface extensions of the formation towards and south east are very wide, since it is very widely exposed in the Low Folded Zone and Al-Jazira Plain, and furthermore in the Mesopotamian Plain (I.P.C., 1963, Sissakian and Deikran, 1998, and Sissakian and Fouad, 2012).

Remark: In some parts of the High Folded Zone, the gypsum beds in the Fatha Formation are either very thin, or totally absent. Therefore, many workers have described the Fatha Formation as the Injana Formation, attributing the absence of the former formation to tectonic effect.

Lithology: The Fatha Formation in the type section 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 thicknesses, manifesting the basin configuration, in certain areas. Moreover, the main constituents exhibit lateral and vertical variations, even in a short distance" (Jassim *et al*., 1984 and Al-Rawi *et al*., 1992).

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) in Fatha – Mosul vicinity; latter on it was used almost in different parts of Iraq, although some modifications were introduced in many localities. However, in the High Folded Zone this subdivision is not applicable, because the Fatha Formation is not well developed as it is in the Low Folded Zone. This is due to the basin configuration, where the formation was deposited on the marginal parts, with almost very rare or total absence of evaporates, which were replaced by fine clastics.

Remark: Along the extreme southern marginal parts of the High Folded Zones; in Shaqlawa and Salah Al-Deen areas 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 very 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 range between (1 – 35) m. The limestone beds are the second main constituent and range in thickness between (0.1 – 12) m, exceptionally reaching 20 m in Koi Sanjaq area at the lowermost part of the formation. The gypsum forms minor constituents and range 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 everywhere within the High Folded Zone. Near Halabja, it consists of red marl and grey sandstone with rare marly limestone, without gypsum (Bolton, 1954c). The same case is developed in Aqra, Sar Sang, Amadiya, southwest of Barzan vicinities.

Because each of the main constituents of the Fatha Formation within the High Folded Zone has almost similar characteristics (Fig.19); therefore, the authors have summarized the description of each rock type as mentioned hereinafter.

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 Shaqlawa – Koi Sanjaq vicinity (Sissakian and Youkhanna, 1979).

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 beds within the cycles is variable, the individual beds ranges between (0.5 – 8) m in thickness.

Limestone: Light grey, white and pale brown in color, thinly to thickly bedded, hard to very hard, fossiliferous, occasionally recrystallized, fine crystalline, and dolomitized. The thickness of the limestone beds within the cycles is variable, the thickness of the individual beds ranges between (0.1 – 5) m, exceptionally may reach 20 m.

Fig.19: Cyclic clastics of the Fatha Formation, note the absence of gypsum beds, along the northeastern limb of Qara Dagh anticline

Gypsum: White and different tones of grey, medium hard to hard, thickly bedded to massive and very rarely are thinly bedded; then have wavy lamination, occasionally nodular and banded. The thickness of the individual beds is very wide, it ranges between (0.5 – 5) m.

Remark: In north of Khanaqeen vicinity, especially in Bezniyan anticline, Youkhanna and Hradecky (1978) divided the Fatha Formation into two units: **Lower Unit**, consists of alternation of limestone, gypsum and red claystone. **Upper Unit**, consists of 7 cycles, each cycle consists of red and green claystone, thinly bedded limestone, grey sandstone and gypsum.

Thickness: The thickness of the Fatha Formation in the type section is 445 m (Jassim *et al*., 1984 and Al-Rawi *et al*., 1992), near Halabja it is about 300 m (Bolton, 1954c) (most probably with the Injana Formation). In Sar Sang it is 125 m (Hagopian *et al*., 1982). In Salah Al-Deen, the thickness is 310 m, in Shaqlawa 130 m, near Qadyan village 200 m, in Degala 100 m, and in Koi Sanjaq 200 m (Sissakian and Youkhanna, 1979). In Bawgaru, 432 m, in Nafit Khana 200 m (exposed part), in Sharweldir 160 m, in Bammu 20 m (reduved thickness due to faulting) (Youkhanna and Hradecky, 1978).

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 (Amer, 1977; Behnam, 1977; Al-Biaty, 1978; Buday, 1980 and Al-Hashimi and Amer, 1985). Hazim (1979) in Sissakian and Youkhanna (1979) recorded the following fossils: *Rotalia beccari* (LINNE), *Elphidium* spp., *Triloculina* sp., *Polymorphina* sp., *Crustalaria* sp., *Balanus* sp., *Turritella* sp., *Ammusum* sp., *Clausinella* sp. and *Pina* sp.

Age: The age of the Fatha Formation is Middle Miocene as agreed upon by all 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 authors was a closed lagoon of hypersaline condition. However, in the High Folded Zone, the lagoon was not closed and was a marginal isolated basin, as indicated by the the presence of thin and few gypsum beds, or total absence of the gypsum in the northern parts of the area involved. The Fatha Formation is bounded between Ng30 and Ng40 MFS (Aqrawi *et al*., 2010).

Lower Contact: The Fatha Formation; in the type section is underlain conformably by the Euphrates Formation, the contact is taken at the base of the first green marl (Jassim *et al*., 1984 and Al-Rawi *et al*., 1992). In majority of the High Folded Zone, the Fatha Formation is underlain unconformably by the Pila Spi Formation. However, locally Early Miocene rocks may underlie the Fatha Formation, then the contact is conformable, this special development was found in the extreme southeastern marginal parts of the zone, and may be present in other localities, but not recorded because the Euphrates Formation was mpped with the Pila Spi Formation as one unit. In Shaqlawa – Koi Sanjaq vicinity, the contact between Fatha and the Pila Spi formations is unconformable, locally is marked by a basal conglomerate, which attains 4 m in thickness, like in Topzawa village near Koi Sanjaq and at the northwestern plunge of Permam anticline. In other areas, red claystone marks the contact, which may represent fossil soil; like on the top of Permam anticline, along the road between Salah Al-Deen and Sara Rash (Sissakian and Youkhanna, 1979).

Remark:

1) In Khanaqeen vicinity, Youkhanna and Hradecky (1978) unfortunately did not mention the details why the Fatha Formation is underlain by Oligocene formations, although Euphrates and Jeribe formations are exposed in the area. According to the authors' opinion, the contact was missed due to the structural complexity and the development of conglomeratic beds in both Euphrates and Jeribe formations described by Youkhanna and Hradecky (op. cit). These conglomeratic beds might hinder the contact and make it obscure. However, a structural contact due to tectonic disturbances could not be ignored.

2) In those areas, within the extreme northern parts of the High Folded Zone where the gypsum is not developed in the Fatha Formation and the succession there includes mainly red clastics with some pale gray and olive green marls and thin limestone beds in the lowermost part, then the authors believe that the succession does not belong to the Fatha Formation, but to another formation, which is the equivalent of the Fatha Formation. Therefore, the authors suggest the announcement of a new formation and recommend a name of "Sar Sang Formation". This new recommended formation extends more northwards into the Imbricate Zone. The mutual relation with the Red Beds should be studied and clarified too.

3.5. Late Miocene – Pliocene – Pleistocene

During the Late Miocene – Pliocene major thrusting occurred during the collision of the Sanandaj – Sirjan Zone with the Arabian Plate, 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 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 and Imbricate Zones. Parts of this foredeep was extending as isolated basins within the southern margins of the High Folded Zone too. The erosion products of the northern and northeastern parts of the High Folded and Imbricate Zones were laid down in the extreme southern marginal parts of 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 Pleistocene, the Alpine Orogeny reached its climax; the sediments of the Bai Hassan Formation also reached its climax in the size of the pebbles and the thickness of the individual conglomerate beds. Quaternary sediments developed in different geomorphological forms and units, and the present landscape was formed.

The Late Miocene – Pleistocene sequence is represented by three formations, which have very restricted coverage areas in the High Folded Zone (Fig.2). They represent the uppermost part of the Late Eocene – Recent Megasequence AP11, established by Sharland *et al*. (2001). The three formations are described hereinafter.

3.5.1. Injana Formation (Late Miocene)

The Injana Formation was formerly known as the Upper Fars Formation, it was defined 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 abandoned in Iran (James and Wynd, 1965 and Jassim and Goff, 2006) and is now called Mishan Formation. 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.

Type Locality: The type locality of the Injana Formation is along the northeastern limb of Himreen South anticline at Injana, the type section is near the old police station along Baghdad – Kirkuk road, 120 Km northeast of Baghdad, and it is defined by the following coordinates (Jassim *et al*., 1984) (Fig.3):

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 exposed in Zakho, Dohuk, Amadiya, Sar Sang, Mangesh, Ain Sifni, Shaqlawa, Sala Al-Deen, Hareer, south and southwest of Sulaimaniyah, Qara Dagh, Kolos anticline, around Darbandi Khan lake, and north of Khanaqeen.

Remark: In some parts of the High Folded Zone, the gypsum beds in the Fatha Formation are either very thin, or totally absent. Therefore, many workers have described and mapped the Fatha Formation as the Injana Formation, attributing the absence of the former formation to tectonic effects.

Lithology: The Injana Formation, in the type section 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). Generally, in all exposure areas, the formation has the same lithological characters, it consists of cyclic repetition of claystone, siltstone and sandstone (Fig.20), and the cycles are coarsening upwards. Locally, in the lowermost parts of the formation, (2 – 3) thin horizons, usually the thickness ranges between (15 – 100) cm of fresh water limestone and gypsum, and/ or selenite may occur.

Because each of the main constituents of the Injana Formation within the High Folded Zone has almost similar characteristics, therefore the authors have summarized the description of each rock type as mentioned hereinafter.

Claystone: The claystone beds are 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 – 20) 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 carbonates, quartz, feldspar and volcanic rock fragments, the matrix forms (25 – 40) % of the rock. The thickness of the individual bed ranges between (0.2 – 20) m.

Sandstone: The sandstone beds are reddish brown, dull brown, grayish 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 1 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 – 10) m, but occasionally may reaches 15 m.

Fig.20: Red clastics of the Injana Formation, near Diwana Stream,
south of Derbanedi Khan

Thickness: The thickness of the Injana Formation in the type section is 620 m (Jassim *et al*., 1984 and Al-Rawi *et al*., 1992). Near Halabja, it is 300 m (Bolton, 1954c) (most probably with Fatha Formation), in Dohuk 200 m, in Shaqlawa 150 m, in Sar Sang and Amadiya vicinities it ranges from (100 – 300) m.

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 Upper Fars Formation 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 other workers agreed upon this age.

Depositional Environment: The lower part of the Injana Formation has been interpreted as shallow water to subcontinental 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 section 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, working in all localities within the High Folded Zone adopted the same contact.

Remarks:
1) 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) In some parts of the High Folded Zone, the gypsum beds in the Fatha Formation are either very thin, or totally absent. Therefore, many workers have described the Fatha Formation as the Injana Formation, attributing the absence of the Fatha Formation to tectonic effect.

3.5.2. Mukdadiya Formation (Late Miocene – Pliocene)

The Mukdadiya Formation was formerly known as the Lower Bakhtiari Formation, it was defined 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). It is worth mentioning that the name Lower Bakhtiari is abandoned in Iran, and the formation is called as Agha Jari Formation. 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.

Type Locality: The type locality of the Mukdadiya Formation is along the northeastern limb of Himreen South anticline in Mukdadiya; the type section is near Himreen Lake, it is defined by the following coordinates (Jassim *et al*., 1984) (Fig.3).

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

Al-Rawi *et al*. (1992) adopted the same aforementioned type locality.

Exposure Areas: The Mukdadiya Formation is exposed in Zakho, Dohuk, and Amadiya, southwest of Barzan, Sar Sang, Mangesh, Ain Sifni, Shaqlawa, Hareer, Qara Dagh, Kolos anticline, and south and southwest of Sulaimaniyah.

Lithology: The Mukdadiya Formation, in the type section 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 High 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 (Fig.21); the pebbles within the pebbly sandstones are up to 6 cm in size, mainly of chert, quartz, carbonates, and subordinate igneous and metamorphic rocks.

Because each of the main constituents of the Mukdadiya Formation within the High Folded Zone has almost similar characteristics, therefore the authors have summarized the description of each rock type as mentioned hereinafter.

Fig.21: Mukdadiyah Formation capped by calcrete, Amadiya Plateau

Sandstone: The sandstone beds are 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 7 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 very absent. The thickness of the individual bed ranges between (0.5 – 8) m, but occasionally may reaches 20 m.

Claystone: The claystone beds are light brown, pale brown, brownish grey, rarely yellowish grey and greenish grey in color, soft to fairly hard, thinly bedded to massive, conchoidally fractured, usually silty and sandy; very rarely contains very fine pebbles, fractured and jointed; fractures and joints are filled by secondary gypsum forming vein shapes. The thickness of the individual bed ranges between (0.5 – 12) m, exceptionally may reach 20 m.

Siltstone: The siltstone beds are 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 – 5) m.

Remark: Usually, bitumen and bentonite occur in the lower part of the formation, the latter is found in many localities within the claystone beds, in the Low Folded Zone. It is light brown, grey and light pink in color, with greasy texture and not more than 1 m in thickness. Such occurrences may be observed in the High Folded Zone too.

Thickness: The thickness of the Mukdadiya Formation in the type section is 2000 m (Jassim *et al*., 1984 and Al-Rawi *et al*., 1992). Near Halabja it is 600 m, in Dohuk 50 m, in Shaqlawa 150 m, in Amadiya, Sar Sang, Darbandi Khan it ranges from (100 – 350) m.

Fossils: The fossils within 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, charaphytes and bryozoans. Hazim (1979) in Sissakian and Youkhanna (1979) recorded the following fossils: Reworked *Elphidium* sp., *Balamus* sp., gastropods and miliolids.

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 a 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 geologists of GEOSURV and other workers 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 section 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 High Folded Zone and elsewhere adopted the same contact.

Remarks:
1) 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 bed, which is considered as the contact between Injana and Mukdadiya formations 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 and friable 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.

3.5.3. Bai Hassan Formation (Pliocene – Pleistocene)

The Bai Hassan Formation was formerly known as the Upper Bakhtiari Formation, it was defined 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), which is now called as Bakhtiari Formation. 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.

Type Locality: The type locality of the Bai Hassan Formation is in Bai Hassan anticline, northwest of Kirkuk city (Jassim *et al*., 1984 and Al-Rawi *et al*., 1992) (Fig.3).

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

Exposure Areas: The Bai Hassan Formation is exposed in Zakho (McCarthy and Hall, 1954), Dohuk, Amadiya, Sar Sang, Mangesh, Ain Sifni, Shaqlawa, Hareer, Qara Dagh, Kolos anticline, south and southwest of Sulaimaniyah.

Lithology: The Bai Hassan Formation, in the type section 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 (Fig.22), with exceptional slight changes in particular details, and because each of the main constituents of the Bai Hassan Formation within the High Folded Zone has almost similar characteristics; therefore, the authors have summarized the description of each rock type as mentioned hereinafter.

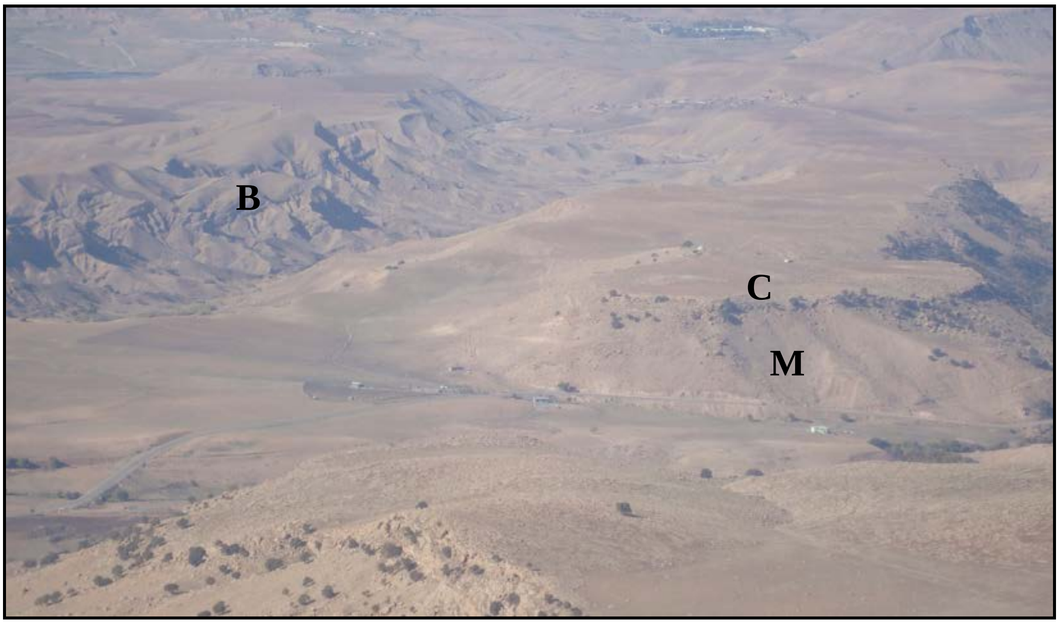


Fig.22: Conglomerates of the Bai Hassan Formation (**B**). Note calcrete (**C**) capping the Mukdadiya Formation (**M**), south of Derbendi Khan

Conglomerate: The conglomerate beds consist of gravels of different sizes that range between few millimeters to 25 cm; exceptionally may reach 35 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 30 m; in the upper parts. The pebbles are subrounded to well rounded, varicolored, elongated, semispherical, rode 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.

Claystone: The claystone beds are 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 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 5 m, in the lower part to about 50 m, in the uppermost part of the formation.

Sandstone: The sandstone beds are 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 – 5) m, but occasionally may reaches 10 m. It is worth mentioning that many beds exhibit erosional contact with the overlying conglomerate beds, indicating fluvial and alluvial fan deposition style.

Siltstone: The siltstone beds are 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 section is 638 m (Jassim *et al*., 1984 and Al-Rawi *et al*., 1992), near Halabja it ranges from (100 – 200) m (Bolton, 1954c), in Shaqlawa 125 m (Sissakian and Youkhanna, 1979).

Fossils: Fossils in the Bai Hassan Formation are very rare, but some smooth ostracods, charophytes, bryozoa and Mammalian bones were recorded by Behnam (1977) 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 a Pliocene age for the formation, but he did not exclude the 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 geologists of GEOSURV and other workers 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 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 section 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 High Folded Zone and elsewhere adopted the same contact.

Remarks:

1) The aforementioned information 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 High 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 and Upper. The Lower Member has the same normal characters of the formation, whereas the Upper Member, which they named it as "Maidan Unit" has special development and consists of coarse grained sandstone, conglomerate and claystone. The conglomerate beds are unusual, hence the cobbles may reach up to 1 m in diameter and in the uppermost parts reach 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).
4) Sissakian and Fouad (2012) denied the presence of the "Bammu Conglomerate". It was found that the Bammu Conglomerate, north of Khanaqeen is tallus sediments, whereas north of Kalar it is thrusted beds of Bia Hassan Formation of the southwestern limb of Cham Chamal South anticline over beds of the same formation within the northeastern limb of Kalar anticline.

3.6. Quaternary Sediments

The Quaternary sediments have restricted coverage areas in the High Folded Zone (Fig.2). They include different types of Pleistocene and Holocene sediments, which are not well studied, described, mapped and dated. The presented Quaternary sediments include 10 types. They represent the uppermost part of the Late Eocene – Recent Megasequence (AP11), established by Sharland *et al*. (2001). The ten types of the sediments are reviewed, hereinafter, briefly.

3.6.1. Terraces (Pleistocene)

The Greater Zab, Lesser Zab and Diyala (Sirwan) rivers have deposited many terrace levels, which have different extensions, thicknesses and heights from their riverbeds. Large streams (Fig.7) and valleys 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. 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 – 25) 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.

3.6.2. Moraine Sediments (Pleistocene)

Wright (1986) reported the occurrence of Moraine sediments in Rawandooz, Diyana, Seeda Kan, Galala, Barsarine areas. He mentioned that the sediemnts could be seen above (40 – 150) m of the existing river beds, and extends for few kilometers. The size of the cobbles attain more than one meter, consisting of silicates, igneous and metamorphic rocks and quartz, cemented by carbonate materials. The estimated age is Early Pleistocene. Moreover, he attributed many meanderings in the rivers and streams to the action of the moraine.

Remark:
1) It is worth mentioning that none of the ex-workers mentioned the presence of moraine in the area involved.

2) Wright (1986) mentioned the presence of moraine sediments north of Seeda Kan village, north of Rawandooz. The described moraine in that location coincides with the mapped Qulqula Conglomerates, which are thrusted over Walash and Naopurdan Groups (Stevenson and Cobbett, 1954). The authors are not in accordance with the presence of thrusted Qulqula over Walash and Naopurdan Groups; therefore, they do believe that those conglomerates may represent moraine sediments. However, this assumption must be studied well, before being considered, scientifically.

3.6.3. Dokan Conglomerate (Pleistocene)

This is very special development of conglomerates along the southern and eastern margins of Dokan Lake and the top of Khalikan Mountain (Fig.23). Karim and Taha (2012) called it as "Dokan Conglomerate", Sissakian and Fouad (2012) adopted this term. The Dokan Conglomerate is indurate and weathering resistant, mostly consists of blocks, boulders and gravels derived from Qamchuqa Formation, with some clasts from Kometan Formation, and at the upper part; rare clasts derived from the Pila Spi Formation can be observed. The conglomerate is folded, in some places, the dip is more than 30 degrees, and angularly overlies the Kolosh, Tanjero, Shiranish, and Kometan formations with more than 20 degrees difference in the dip. In other areas, the conglomerate shows, more or less equal dip with the aforementioned formations. In Khalikan anticline it is almost horizontally lying, with a thickness of about 300 m (Karim and Taha, 2012).

Fig.23: Dokan Conglomerate overlying the Kometan, Shiranish and Tanjero formation, along Dokan – Bustana road

3.6.4. Anthropogenic Sediments (Pleistocene – Holocene)

Anthropogenic Sediments in the High Folded Zone are very rare. They are restricted to some caves, like Shnider in Bradost Mountain, west of Rawandooz, where skeletons of Neanderthal man were found. Wright (1986) estimated the age of the found bones, using C^{14} to be about 12000 years B.P. of Mesolithic Stage. It is worth mentioning that eight skeletons of Neanderthal man were found in the cave. Moreover, Wright (1986) mentioned that the found skeleton fragments in Shnider cave indicate the Mousterian Stage of the Upper Paleolithic Phase of 29000 years B.P. However, this difference in the recorded ages could be attributed that the trees growing line receaded down to 700 m (a.s.l.), which is lower than the cave's elevation, therefore, the cave was not habitauted during the mentioned time span. Such sediments might be preserved in other caves, but not discovered yet.

3.6.5. Calcrete (Pleistocene – Holocene)

Although calcrete is well developed in different parts of the High Folded Zone, especially along main scarps, but it is not well mapped and studied. The rock fragments are mainly of limestone, cemented by clayey and calcareous materials, the size of the fragments and/ or pebbles ranges between (< 5 – 45) cm (Figs.22 and 24). The thickness may reach up to 10 m (Sissakian, 2012), but usually ranges between (1 – 5) m. They form horizontal cover above the tilted pre-Quaternary rocks, forming mesas of different dimensions and heights, like in Amadiya Plateau (Fig.21) (Sissakian and Fouad, 2011) and south of Darbandi Khan; along the main Pila Spi Ridge (Sissakian, 2012).

Remark: The authors believe that locally they are relics of old alluvial fan sediments, which are eroded and the remaining parts are still preserved. Good examples are in Amadiya, near Degala, Bana Bawi, Permam, Haibat Sultan, Darbandi Bazian, Darbandi Khan, Qara Dagh and Sharwaldirl, along their slopes.

Fig.24: Calcrete (**C**), brown residual soil (**R**) and toppled rock blocks, along Bammu Mountain. Note the curved tree indicating creep of the sediments

3.6.6. Alluvial Fan Sediments (Pleistocene – Holocene)

Alluvial fan sediments are well developed within the High Folded Zone, as in Ranya, along Dokan and Darbandi Khan lakes. They have different coverage areas, ranging from (1 – 15) Km^2. Those, which are surrounding Dokan and Derbandi Khan lakes, consist mainly of clayey soil, usually occupied as agricultural lands. Whereas, those, which are developed along mountain ranges, consist mainly of rock fragments, which are derived directly from the exposed formations in near by areas, locally covered by calcrete.

3.6.7. Colluvial Sediments (Pleistocene – Holocene)

Colluvial sediments are developed in the High Folded Zone, especially in areas where soft rocks are exposed. However, along the main ridges of hard rocks, continuous belt of colluvial sediments are developed too (Fig.25). The size and constituent of the sediments depend on the source rocks, usually formed of carbonates and silicates, which are cemented by clayey and carbonate materials. The thickness of the sediments ranges from (1 – 5) m, locally they are weathered, but, the preserved parts form flat areas capping folded strata in form of plateaus.

Fig.25: Colluvial sediments in Bmmu Mountain, south of Derbaendi Khan

3.6.8. Flood Plain Sediments (Holocene)

Flood plain sediments are well developed along side the Greater Zab, Lesser Zab, and Diyala (Sirwan) rivers and large streams and valleys. The thickness and width of the plains are highly variable, but usually the thickness ranges between (< 1 – 3) 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 and clay are dominant, with subordinate clay and very fine pebbles.

3.6.9. Valley Fill Sediments (Holocene)

The valley fill sediments in main streams and valleys have thickness ranges of (< 1 – 3) m, but may exceed 10 m. The main composition of the pebbles is carbonates and silicates with subordinate igneous and metamorphic rocks, which increases north and northeastwards. The pebbles are rounded to subrounded (Fig.26), with average size of (1 – 20) cm, but may reach to more than 100 cm, spheroidal and rode shaped, with rare disk shape. 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, except in flat areas; like Shari Zoor Plain.

Fig.26: Valley fill sediments in Diwana valley, south of Derbedi Khan

3.6.10. Residual Soil (Holocene)

Residual soil covers small parts of the High Folded Zone, usually in main plains, like Shahri Zoor in Sulaimaniyah vicinity. The soil is brown to reddish brown (Fig.24), locally black in color, calcareous and clayey, with small rock fragments of limestone, which increase in size and abundance depth wards. The thickness is highly variable it ranges between (< 0.5 – 3) m.

DISCUSSION

The oldest exposed rocks in the High Folded Zone (HFZ) are of Triassic age. Therefore, the depositional history of the Triassic and onwards is discussed hereinafter.

During the **Triassic** (252.6 – 201.3 ± 0.2 Ma) the Neo-Tethys ocean progressively was widened; during Early Triassic and a breakup unconformity formed on the northeastern margin of the Arabian Plate. The thermal subsidence led to the formation of passive margin megasequence along the eastern and northern margins of the Arabian Plate. It is worth mentioning that Al-Qaim *et al*. (2012) renamed the Arabian Plate as the "Afro – Arabian Plate". During **Middle – Late Triassic** further extension occurred around the eastern margins of the Arabian Plate (Jasim and Buday, 2006 in Jassim and Goff, 2006). The separation of Iranian Plate from the Arabian Plate expectedly required stretching and consequent thinning of the continental crust. This caused rapid subsidence that was filled by thick (200 m) Mirga Mir Formation. The decreased thickness (64 m) of the overlying red shales of Bedu Formation is attributed to very slow subsidence caused by slow drifting away from the thermal bulge, i.e. the newly formed mid-oceanic ridge, due to the break-up of the continent into two drifting passive margins. The red colour of Bedu shales is attributed to Triassic volcanicity (Bellen *et al*., 1959). Following drifting, a thermal decay accelerated the subsidence and caused the deposition of thick (575 m) Geli Khana Formation (Numan, 1997). The same scenario was repeated causing deposition of thin (36 m) Baluti Formation, underlain by thick (834 m) Kurra Chine Formation.

During the **Early Jurassic** (201.3 ± 0.2 – 174.1 ± 1.0 Ma), the rate of subsidence on the northern margins of the Arabian Plate slowed and relatively uniform marginal marine clastics, evaporites and shallow water lagoonal carbonates were deposited (Sarki and Sehkaniyan formations). This is attributed to the maximum attended thickness of the Neo-Tethys, because no obduction was evidenced, and "passive continental margins overlooked the Neo-Tethyan southern and northern shores (Yilmaz, 1993), which were undergoing thermal subsidence".

During **Middle – Late Jurassic** (174.1 ± 1.0 – 145.0 ± 0.8 Ma), the deposition occurred during isolation of the main intra-shelf basin of the Mesopotamia from the Neo-Tethyan Ocean; probably due to renewed rifting along the northeastern margin of the Arabian Plate. Deposition in the basin occurred in restricted, relatively deep water, environment during Middle Jurassic, and became evaporitic during Late Jurassic. Sargelu, Naokelekan and Barsarin formations were deposited during Middle – Late Jurassic. The reduced thicknesses of Naokelekan and Barsarin formations (14 and 17 m, respectively) are attributed to subduction, where strain was accumulating in the oceanic crust, causing at the beginning of the passive Arabian continental margin (Numan, 1997).

During the **Early Cretaceous** (145.0 ± 0.8 – 100.5 Ma), the deposition occurred in a large intra-shelf basin contemporaneous with the new phase of ocean floor spreading in the Neo-Tethys. The opening of the Neo-Tethys led to the drifting away of a narrow microcontinent; a new passive margin formed along the northeastern margin of the Arabian

Plate. This passive margin was formed by a carbonate ridge along the north facing passive margin of the Neo-Tethys (Jassim and Buday, 2006 in Jassim and Goff, 2006). In the foreland basin (passive margin), Chai Gara, Garagu, Sarmord, Qamchuqa, Dokan, Kometan, Mergi and Gulneri formations were deposited. In the deep-water slopes of the foreland basin, Balambo Formation was deposited, with diachronus contacts with some of the aforementioned formations; Bellen *et al*. (1959) proved the nature of the contact. It is worth mentioning that the presence of the Qamchuqa and Sarmord tonges in the Balambo Formation near Sulainmaniyah vicinity, indicate the presence of shallow parts in the deep foreland basin in which the tonges of the Qamchuqa and Sarmord formations were deposited.

During the **Late Cretaceous** (100.5 – 66.0 Ma), the split of micro-continent from the Arabian Plate had approached the trench of the intra-oceanic subduction zone. The onset of deformation of the north facing passive margin of the Neo-Tethys is recorded by the deposition of the Qulqula Conglomerate; north and northeast location of the present days HFZ. A foreland basin formed around the northern margin of the Arabian Plate in response to loading of the crust by thrust sheets generated because of compression. In the Late Campanian – Early Maastrichtian, the Neo-Tethyan Ophiolites were thrusted further onto the Arabian Plate, elevated above sea level and rapidly eroded, the erosion products were deposited as flysch sediments representing Tanjero Formation, whereas, in the subsided extensional basins the Shiranish Formation was deposited, locally contemporaneously (Jiassim and Buday, 2006, in Jassim and Goff, 2006). This is evidenced by the interfingering of Shiranish and Tanjero formations, especially in the eastern margins of the HFZ, while in the central and western margins, no interfingering occurs, due to the far distances from the source areas of the flysch sediments. Moreover, the basin was continuously shifted southwest wards, due to the thrusting of the Iranian Plate. In Late Maastrichtian, the ophiolites obduction ceased and the flysch basin shallowed. The Cretaceous thrust belt was onlapped passively by carbonates representing Aqra – Bekhme Formation, which interfingers locally with Shiranish and/ or Tanjero Formation, due to the same aforementioned reason. However, the interfingering of Tanjero and Shiranish formations indicates continuous obduction and subduction. The huge thickness of Shiranish and Tanjero formations is attributed to "flexural subsidence resulting from the loading of obducted sheets" (Al-Qayim *et al*., 2012). Moreover, Al-Qayim *et al*. (1986) suggested that the sediments of the Shiranish Formation were brought into the basin by turbidity currents. This assumption was based on the presence of sandy limestone beds, which are charcterized by skeletal grainstone microfacies, and are thickening upwards and intercalated with basinal marl, which prevails the sediments of the formation. The presence of the turbidites confirms the obduction, which accelerated the erosion and deposition of the clastics in the Shiranish and Tanjero formations.

It is worth mentioning that Karim *et al*. (2009) claimed that the described Qulqula Conglomerates (Bolton, 1958 in Bellen *et al*., 1959) are part of the Tanjero Formation. The coarse clasts of the conglomerate and its thickness, which are not present in proper Tanjero Formation, are attributed to the close distance of the source area, as compared to other areas where the Tanjero Formation is deposited. The authors' are in full accordance with this assumption, because during the obduction of the ophiolites above sea level, the extensive erosion products were in form of coarse conglomerates. However, to confirm this assumption, detailed field observation should be carried out to deduce the relation between the concerned conglomerates with the proper Tanjero Formation. Although Karim *et al*. (2009) mentioned that they traced the conglomerates for about 30 Km continuously in Said Sadiq – Chuwarta area; and claimed that the conglomerates merge with the conglomerate of the lower part of Tanjero Formation (Early Maastrichtian) near Chuwarta town.

During the **Middle Paleocene – Late Eocene** (61.6 – 33.9 Ma), the Neo-Tethys was narrowed and closed during the final phase of subduction. A foredeep; within the foreland basin was developed in the northeast of Iraq; meanwhile two pulses occurred in Paleocene and Eocene, respectively along the northeastern margin of the Arabian Plate. The old Late Cretaceous thrust belt was uplifted and delivered sediments to the new foreland basin, in which Kolosh and Gercus formations were deposited (Jassim and Buday in Jassim and Goff, 2006). The presence of conglomerate and pebbly sandstone in the top of the Tanjero Formation indicate the break in sedimentation and subareal weathering, which marks the Cretaceous/ Tertiary contact (Al-Shaibani *et al*., 1986). Alongside the foredeep and within shallow lagoons the Pila Spi Formation was deposited. In the developed foredeep (within the foreland), which was progressively migrating towards southwest; Sinjar and Khurmala formations were deposited. 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 in the High Folded Zone. However, Karim and Al-Jibouri (1992) discovered the Danian rocks in Bekhme section representing the Aaliji Formation with a thickness of 17.5 m. Moreover, Sharbazheri *et al*. (2011) discovered the Early Paleocene rocks in the High Folded Zone represented by the Early Danian also. They divided the studied sequence into five biozones, indicating continuous sedimentation from Late Maastrichtian onward. If this holds good, then the Neo-Tethys was narrowed and closed since Early Paleocene and not Middle Paleocene, as mentioned by many workers, among them are Jassim and Buday (2006) in Jassim and Goff (2006). The presence of the flysch sediments of detrital grains and the type of the Shiranish, Tanjero and Kolosh formations, indicate the evolution of the foreland basin in front of the obducted blocks (Al-Qayim, 1993, 1994, and 2004, and Karim, 2004 in Al-Qayim *et al*., 2012).

At the end of **Eocene** and during **Oligocene** (33.9 – 23.03 Ma), the main intraplate basin became narrower due to the tilting of west Arabia, and uplifting of the present days area of the High Folded Zone. Therefore, great sea level drop was witnessed; consequently, the eastern shore line receded far from the HFZ to the southwest boundary of the Low Folded Zone. This is indicated by the unconformable contact between Eocene rocks, represented by the Pila Spi Formation and overlying Oligocene and/ or Miocene rocks. According to Amin (2009), the unconformity is overlain by Oligocene limestone, which may represent Anah Formation. Therefore, the conglomerate must be called "Anah Basal Conglomerate" instead of "Fatha Basal Conglomerate". The existence of sedimentary breccias indicates some steep slopes. The unconformity consists of type one sequence boundary without deposits of distal lowstand system tract, which is attributed to weathering resistance of the Pila Spi Formation during Oligocene time. The authors are in full accordance with this assumption. It is worth mentioning that Al-Qaim *et al*. (2012) confirmed that the filled foreland basin is of clastic-free sediments.

During the **Oligocene**, the closed Neo-Tethys was a narrow seaway in which carbonates were deposited (Jassim and Goff, 2006). 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, Ghafor *et al*., 2013, and Sissakian and Fouad, 2012) and extends northwest wards alongside the present day contact between Low Folded and High Folded Zones and slightly exceeds it.

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 Mountain within the HFZ. Moreover, Sissakian and Fouad (2012) found that Oligocene rocks form the core of Aj Dagh and Qara Wais anticlines, south of Qara Dagh Mountain (though off the High Folded Zone), and some undifferentiated Oligocene rocks occur overlying the Pila Spi Formation in different parts of the HFZ. It is worth mentioning that 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; 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 Bammu and Shalwedir anticlines (Youkhanna and Hradecky, 1978).

During the **Early – Middle Miocene** (23.0 – 11.62 Ma)**,** the Savian Orogeny caused development of broad and shallow basins in which carbonates of the Euphrates Formation were deposited on the platform, with wide closed basins (lagoons) in which evaporites of the Fatha Formation were deposited (Tucker and Shawket, 1980). However, the northwards extensions of the lagoons in which Fatha Formation was deposited, manifested different types of sediments, due to renewed compression. 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 representing the Fatha Formation, forming the main constituent. The authors believe that this is attributed to the basin configuration and sediments supply, where the environment for deposition of gypsum was not prevailing, due to open lagoon and gradational change towards continental sedimentation, as had started from the Late Miocene.

The exposed Euphrates Formation, in the High 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 proper Euphrates Formation somewhere off the High Folded Zone and 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 coverage areas of the Jeribe Formation were not well defined during the regional geological mapping of the Iraqi territory. This is mainly due to the large lithological similarities between the rocks of the Euphrates and Jeribe formations. This leads to a conclusion that in some localities, the Jeribe Formation was missed and mapped with the Euphrates Formation, as one unit.

The lithology of the exposed Fatha Formation in the High Folded Zone is not the same like that in the Low Folded Zone and in the Jazira Plain. 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 the announcement of a new formation, instead of the Fatha Formation, in the High Folded Zone.

The syncline between Gara and Matin anticlines is suggested to be the type locality, with a suggested name as "Sar Sang Formation". Moreover, the authors believe that the proper Fatha Formation passes to the suggested new formation (Sar Sang) along the northern marginal limits of the basin. It is the same area, where the remnants of some Oligocene formations with the Euphrates Formation can be recognized, along the slopes of the Pila Spi Formation; in the contact area between the High Folded and Low Folded Zones. This is attributed to the continuously rising nowadays High Folded Zone area behind the sinking foredeep, which was also continuously forwarded southwestward, and in which the Oligocene, Early and Middle Miocene rocks were deposited, representing proper and thick Oligocene formations, and the Euphrates and Fatha formations; of the Low Folded Zone.

Al-Qayim *et al*. (2012) claimed that "the second major event is related to the post-Mid-Miocene continental collision of the Arabian Plate margin with the attached formerly obducted slives on one side and the Sanandaj – Sirjan Block on the other. The Intra-orogenic quiescent interval was characterized by a clastic-free sedimentation in a sag-interior basin over the Arabian Plate (Al-Qayim, 2006 in Al-Qayim, 2012). The clastic sedimentation resumed in the area by the introduction of the shallow-marine mixed siliciclastic – carbonate sediments of the Mid-Miocene Fatha Formation, which signaled the commencement of the early stage of the continent – continent collision. Uplift and shortening due to this collision was responsible for the major deformation observed in the Zagros Suture Zone (Oweiss, 1984 in Numan, 1997). The Zagros Orogenic Belt thus evolved progressively, with continuing shortening with degree of deformation increasing towards the Zagros Suture Zone". The authors are in full accordance with the mentioned statement concerning the type of the sediments in the Fatha Formation, which explained dominating of the clastics and rare occurrence of gypsum and limestone beds, as it is usual in the typical lithology of the formation.

During the **Late Miocene – Pliocene** (11.62 – 2.588 Ma), a major thrusting occurred during the collision of the Sanandaj – Sirjan Zone with the Arabian Plate, causing the end of the marine phase and beginning of the continental phase. Consequently, a major foredeep (fresh water basin within the foreland) formed, parts of this basin extends in the High Folded Zone, which was filled by continental molasse sediments that increased the size of the sediments; continuously, due to continuous and intensely increasing areas behind the High Folded Zone. The erosion products were laid down in the foredeep (within the foreland) as continental molasse sediments (Injana and Mukdadiya formations) 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 (within the foreland), 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 represents the transition zone between the marine and continental sedimenst with the Injana Formation. It is worth mentioning that GEOSURV geologists have mapped the formation separately during the regional geological mapping of the Iraqi territory. 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 areas; during the regional geological mapping. Therefore, the present contact between the Injana and the underlying

Fatha formations is not 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 the aforementioned problem too. Because a pebbly sandstone horizon marks the contact, the pebbly sandstone is not a well stratigraphic marker, it may disappear within hundreds 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, and the position within it, which 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 be always considered as a diachronous contact.

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. It is worth mentioning that the source rocks were the exposed sedimentary, igneous and metamorphic rocks of different ages; in areas located behind the present day of the High Folded Zone, which continuously was rising behind the foreland. However, some local deep troughs existed within the rising areas in which the Bai Hassan Formation was deposited; this is evidenced by the size of the pebbles and the thickness of the formation, as compared to those in Bai Hassan Formation in the Low Folded Zone. Meanwhile, the main rivers, streams and valleys deposited their own terraces after continuous incision of their courses forming different terrace stages. 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 formation 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; however, the reverse case cannot be ignored. The intensity of folding started to decrease after mid Pleistocene, but it is still continuous. It is worth mentioning that the "final suturing further complicated the area by generating a progressive shortening and intensify deformation of the Arabian margin and the successor foreland sequence with ultimate growth of the Zagros Suture Zone, Zagros Imbricate Zone and Zagros Folded Zone (Al-Qayim *et al*., 2012)".

In Rawandooz, Diyana, Barsarine, Galala, Seeda Kan areas, Wright (1986) reported about moraine sediments with elevations of (40 – 150) m above the stream and river beds, indicating that the middle and last glaciation phases have arrived the areas of the HFZ.

During the **Holocene** (0.0117 – Present), the continuous folding, though at very slow rate accompanied with continuous weathering and erosion produced the nowadays landscapes, with their different stratigraphic and geomorphological units, like flood plains, valley fill sediments, residual soil, 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

Reviewing the data presented in this article on the stratigraphy of the High Folded Zone, the following can be concluded:

- During Triassic, the Neo-Tethys Ocean progressively widened and a breakup unconformity formed. Thermal subsidence led to the formation of passive margin megasequence. During Middle – Late Triassic further extension occurred around the eastern margins. The separation of Iranian Plate from the Arabian Plate caused rapid subsidence of the basin, followed by shallow subsidence; caused by slow drifting away from the thermal bulge. Following the drifting, a thermal decay accelerated the subsidence and caused thick deposition of carbonates.
- During the Early Jurassic, the rate of subsidence in the northern margins of the Arabian Plate slowed and relatively uniform marginal marine clastics, evaporites and shallow water lagoonal carbonates were deposited. During Middle – Late Jurassic, the deposition occurred during isolation of the main intra-shelf basin of the Mesopotamia from the Neo-Tethyan Ocean.
- During the Cretaceous, the deposition occurred in a large intra-shelf basin contemporaneous with the new phase of ocean floor spreading in the Neo-Tethys. The opening of the Neo-Tethys led to the drifting away of a narrow microcontinent; a new passive margin formed along the northeastern margin of the Arabian Plate.
- During the Late Cretaceous, a foreland basin was developed around the northern margins of the Arabian Plate, due to obduction. This basin was filled partly by carbonates and marl; meanwhile, flysch sediments were filled in the basin, which was continuously moving southwestward. In the Late Maastrichtian, the ophiolites obduction ceased and the flysch basin shallowed. The Cretaceous thrust belt was onlapped passively by carbonates. The existing interfingering of Shiranish and Tanjero formations indicates continuous obduction and subduction of the ophiolites.
- During the Middle Paleocene – Early Eocene, the Neo-Tethys was narrowed and closed during the final phase of subduction. A foredeep within the foreland basin was developed within the High Folded Zone and more north and northeastwards; this foredeep was separated from the existing basin to the southwest by a belt of nummulitic limestone shoals, whereas, flysch sediments and lagoon sediments were deposited in the foredeep basin, which covers vast areas within the High Folded Zone.
- During the Middle Paleocene – Late Eocene, the Neo-Tethys was narrowed and closed during the final phase of subduction. A foredeep within the foreland basin was developed in the northeast of Iraq. The old Late Cretaceous thrust belt was uplifted and delivered sediments to the new foreland basin, as flysch sediemnsts. Alongside the foreland and within shallow lagoons carbonates were deposited.
- At the end of the Eocene and during the Oligocene (33.9 – 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 far from the HFZ 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; it extends northwest wards alongside the present day contact between the Low Folded and High Folded Zones. This is evidenced by the presence of some Oligocene rocks overlying the Pila Spi Formation; in different locations within the contact line between the High Folded and Low Folded Zones. The Oligocene rocks form a complex reef system, including backreef – reef – forereef sediments. However, not always, the three components are present in each cycle; this is

attributed to the change in the basin configuration and upwards tectonic movements, which contributed in the oscillation of the eustatic sea level.

- During the Early – Middle Miocene, the Savian movements caused development of broad and shallow basins in which carbonates were deposited on the platform, with wide closed basins (lagoons) in which fine clastics and rare evaporites were deposited. In some localities, the Jeribe Formations was deposited within the carbonates, but was missed and mapped with the Euphrates Formation, as one unit.
- During the Late Miocene – Pliocene major thrusting occurred during the collision of the Sanandaj – Sirjan Zone with the Arabian Plate, causing the end of the marine phase and beginning of the continental phase. A major foredeep formed in the Zagros Foreland; small parts of the foredeep were formed as isolated basins within the High Folded Zone. Continental sedimenst filled those basins, the molasse sediments increased in size continuously, due to continuous and intensely increasing of the Imbricate and Zagros Suture Zones; the erosion products, which were laid down in the foreland basin represent Injana, Mukdadiya and Bai Hassan formations.
- During the Pleistocene – Holocene, the present landforms started to be developed, the main rivers and streams incised their riverbeds forming terrace systems, usually (2 – 4) levels. Some moraine sediments were deposited in Rawandooz – Diyana vicinity?. Alluvial fans and calcrete were deposited along main mountain chains. The main rivers, streams and valleys also exhibit a well developed system of flood plains and infilled valleys, during the Holocene and are continuously depositing their sediments, but with less intensity, due to extreme climatic changes; towards decreasing in annual rainfall and increase in the temperature.

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