STRATIGRAPHY OF AL-JAZIRA AREA

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ABSTRACT

The available stratigraphic data, including subsurface data, have been integrated to infer the stratigraphical evolution of the Miocene Basin in Al-Jazira Area, Northwest Iraq. The exposed rocks within the stratigraphic column are represented by four formations: Anah (Late Oligocene) Euphrates (Early Miocene), Fat'ha (Middle Miocene) and Injana (Late Mioccene). Moreover, twelve main types of Quaternary sediments are recognized. Whereas, the drilled wells in the area encountered five rock units of Miocene age (Euphrates, Dhiban, Jeribe, Fat'ha and Injana formations).

The stratigraphic sequence reflects the environmental changes progressively from marine, brackish and fresh water, respectively. The Miocene Basin incorporates sediments of two successive marine sedimentary cycles (Euphrates and Fat'ha formations), each cycle starts with sea oscillation, which delineate type and distribution of the sediments. The last sea regression was commenced in the Late Miocene due to the final phase of the Tethyan Sea closure that led to deposition of Injana Formation (Late Miocene) in fluvio – lacustrine environment, contemporaneously with cycles of terrigenous – continental clastics (pre-molasse facies). The molasse facies of Pliocene (Mukdadiya Formation) is not deposited in Al-Jazira Area due to influence of initial upheaval of the Sinjar anticline in that time.

The vertical tectonic movements were common in the Miocene Basin since late Early Miocene till Quaternary, as indicated by the development of Dhiban and Jeribe formations (subsurface) and the cyclicity of Fat'ha and Injana formations, as well as the presence of four levels of valley terraces.

طباقيـــة منطقة الجزيرة

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المستخلص

استخدمت المعطيات الطباقية ومعلومات الآبار لاستنتاج النشأة الطباقية في حوض المايوسين لمنطقة الجزيرة في شمال غرب العراق. ان العمود الطباقي لعصر المايوسين يتمثل بأربع تكوينات متكشفة: عنه (الأوليكوسين المتأخر) والفرات (المايوسين المبكر) والفتحة (المايوسين الأوسط) وانجانة (المايوسين المتأخر). إضافة الى تشخيص اثني عشر نوعا من ترسبات العصر الرباعي. بينما اخترقت الآبار المحفورة في المنطقة، خمسة تكوينات لعصر المايوسين (الفرات والذبان والجريبي والفتحة وانجانة).

ان التتابع الطباقي في حوض المايوسين قد عكس التغيرات البيئية المتدرجة من بحرية وشبه ملحية الى مياه عذبة، متمثلة بدورتين بحريتين متتاليتين (تكويني الفرات والفتحة)، انتظمت كل دورة بتذبذب مستوى البحر الذي حدد نوعية وتوزيع ترسباتها. وان آخر حركة انحسار بحري كانت في نهاية عصر المايوسين الأوسط نتيجة انغلاق بحر التيثس في هذه المنطقة، والتي سببت ترسيب تكوين انجانة في بيئة بحيرية – نهرية والذي تزامن مع بدء الدورة الرسوبية الفتاتية – القارية (قبل السحنة المولاسية). ان السحنة المولاسية لعصر البلايوسين (تكوين المقدادية) لم تترسب في منطقة الجزيرة بسبب تأثير النهوض الأولي لطية سنجار في ذلك الوقت.

بينت الدراسة ان الحركات التكتونية العمودية كانت شائعة في حوض المايوسين منذ نهاية المايوسين المبكر ولغاية العصر الرباعي، كما دلت عليها نشأة تكويني الذبان والجريبي (تحت السطح) والدورات المتكررة في تكويني الفتحة وانجانة، إضافة الى وجود أربع مستويات لشرفات الوديان.

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INTRODUCTION

The Jazira Area, which occupies about 29270 Km^2, is located in the northwestern part of Iraqi. It extends from the northern bank of the Euphrates River, in the south to flanks of Sinjar – Sheikh Ibrahim mountains (the line connecting between Wardiya – Tel Afar towns), in the north. From the west and east, it is bordered by the Iraqi Syrian borders and Tharthar Valley, respectively (Fig.1).

The stratigraphic succession of Al-Jazira Area is achieved through the regional geological survey by GEOSURV, which started in 1970 and terminated in 1977. It is built up by sedimentary rocks of carbonates, clastics and evaporates facies. Their ages range from Late Oligocene to Late Miocene with different Quaternary sediments.

This study is an attempt to review and explain the stratigraphy of Al-Jazira Area, aiming to elucidate the stratigraphical evolution of the Miocene Basin. The best available data including wells data are used to acquire this study.

GENERAL MORPHOLOGY

The Jazira Area, which is relatively of flat terrain, is sloping gently towards south – southeast and characterized by step topographic nature. The nature of the topography reflects the type of the exposed rock units, their thicknesses, denudational processes affect and regional inclination. Generally, three main different topographical parts could be recognized (Fig.2):

– **Ba'aj Plain,** which consists of flat area dissected by shallow valleys, with height range of (230 – 350) m (a.s.l.). It represents the younger exposed rock unit (Injana Formation).
– **Hadhr Plain,** which consists of flat area interrupted by depressions of karst nature and salt marshes, with height ranges of (200 – 230) m (a.s.l.). It represents the Middle Miocene rock unit (Fat'ha Formation).
– **Incision of Euphrates Valley,** which represents a slope of the northern side of the incision of Euphrates Valley, it is interrupted by shallow dry valleys, sinkholes and sand dunes. It consists of Late Oligocene, Early and Middle Miocene rock units (Anah, Euphrates and Fat'ha formations, respectively).

STRATIGRAPHY OF THE EXPOSED ROCK UNITS

Tectonically, Al-Jazira Area is located within the Stable Shelf, represented by Rutbah – Jazira Zone (Buday and Jassim, 1987) and Salman – Hadhar Zone (Al-Khadhimy *et al*, 1996). However, it is considered to be within the Unstable Shelf (Fouad, 2010); the tectonic effects have controlled the type of the exposed rocks, thickness and distribution of the formations. The Jazira Area is covered by sedimentary rocks that belong to four formations, which range in age from Early to Late Oligocene, with different types of Quaternary sediments.

The exposed geological formations, from the oldest to the youngest are described hereinafter; their geographical distribution is elucidated in a geological map, scale 1: 2000 000 (Fig.3).

1. Anah Formation (Late Oligocene)

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

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

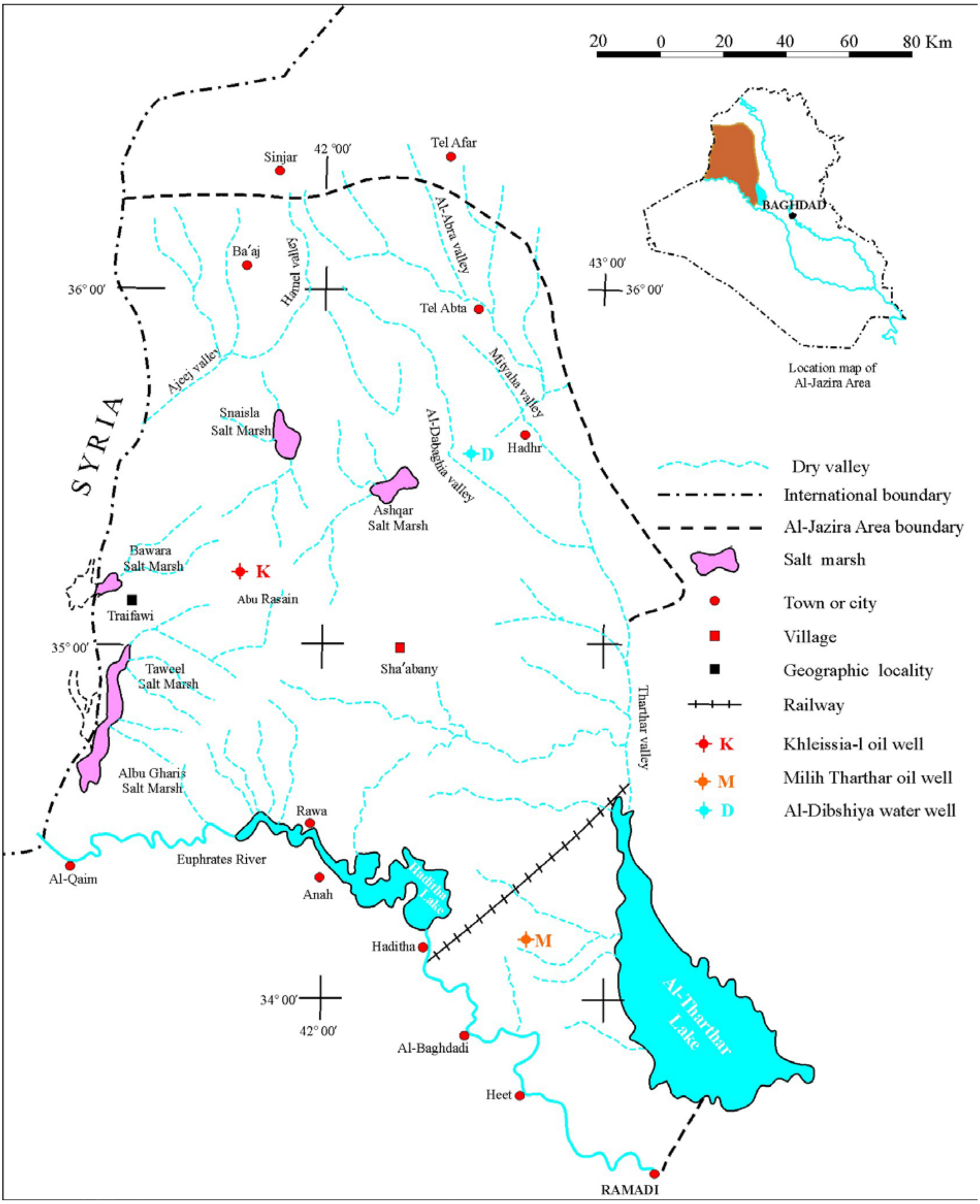

Fig.1: Location map of Al-Jazira Area

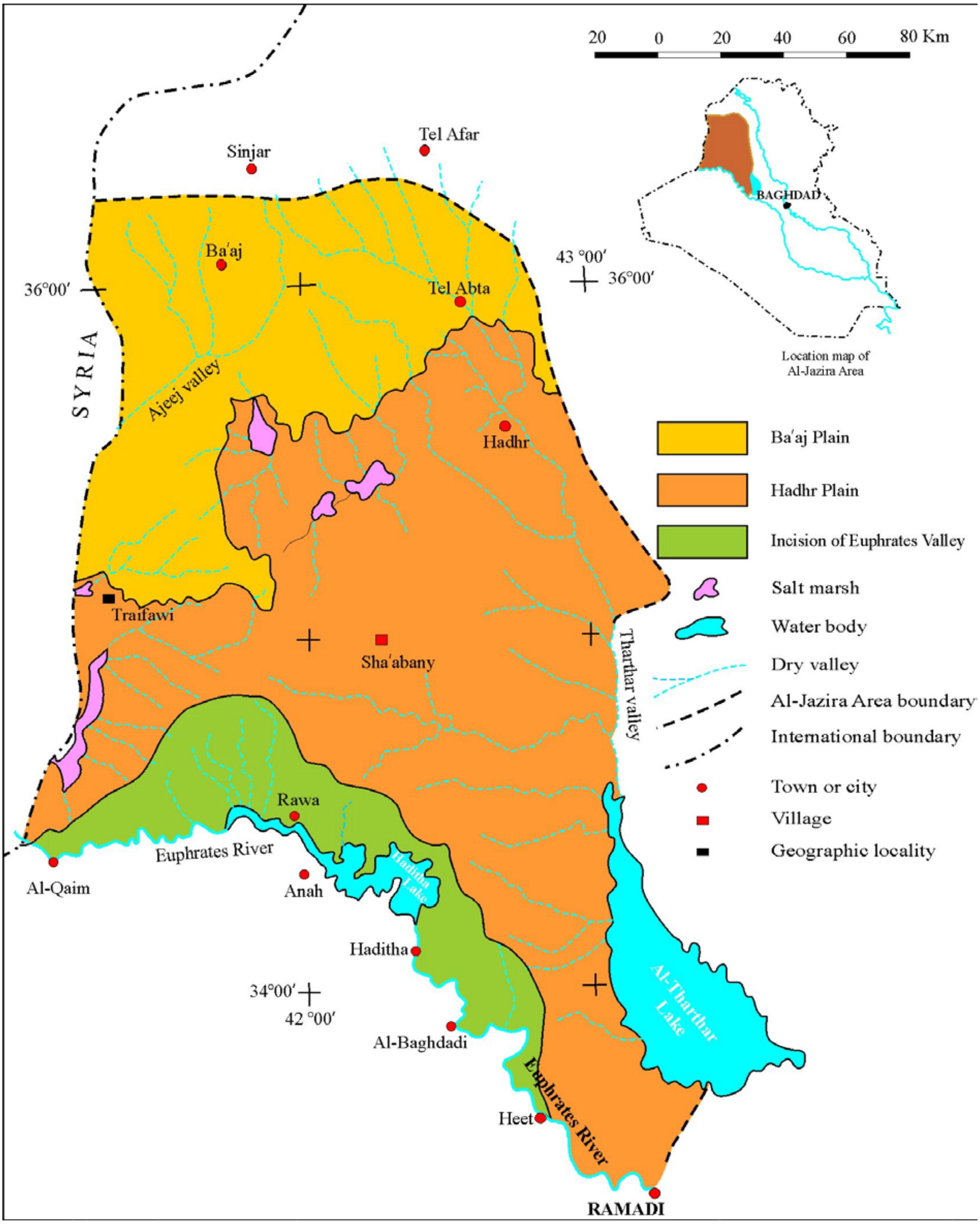

Fig.2: Map showing the topographic parts of Al-Jazira Area

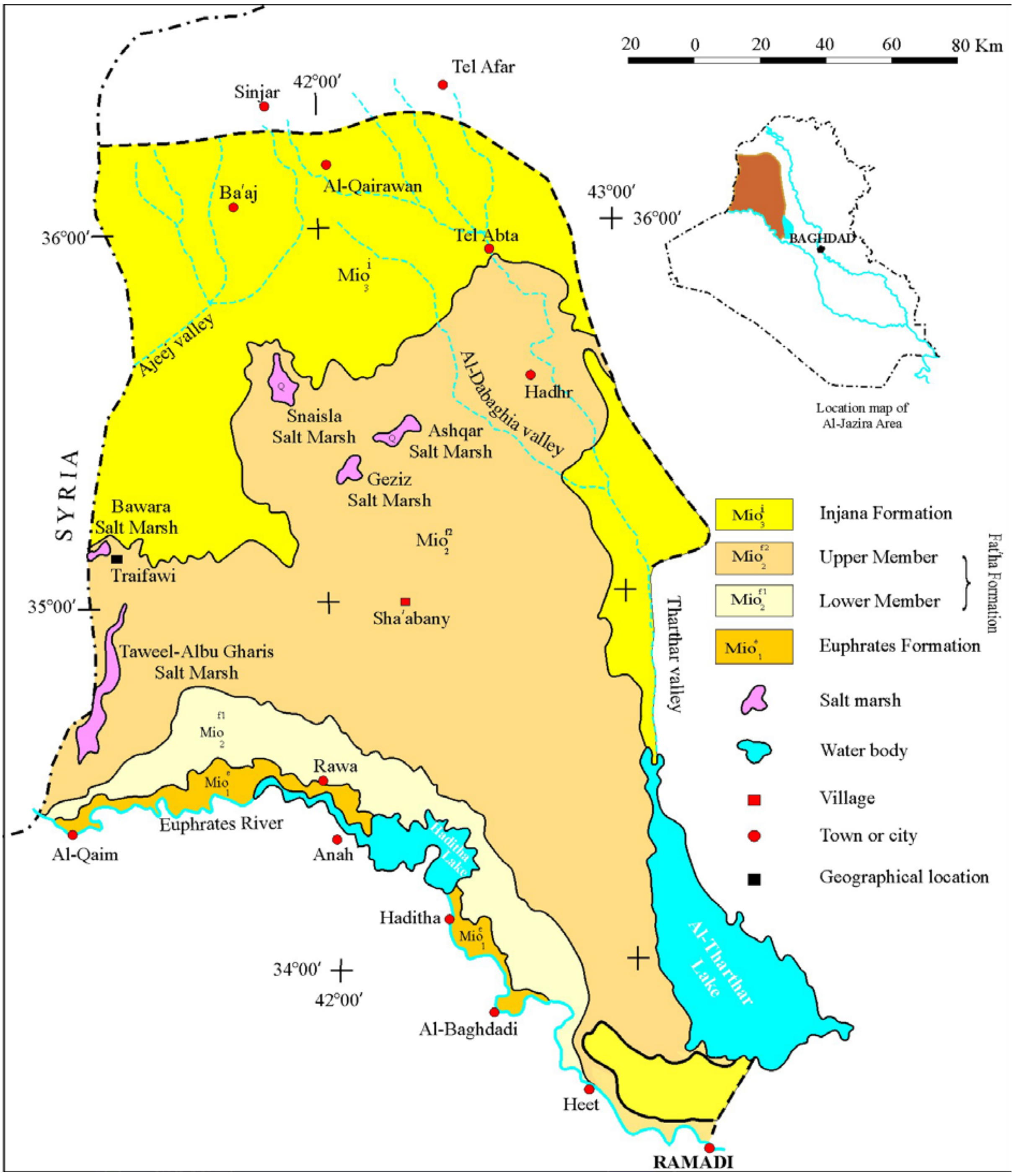

Fig.3: Geological Map of Al-Jazira Area (after Sissakian, 2000)

Exposure Area: The outcrops of Anah Formation occupy limited area in the extreme southern part of the Jazira Area. It crops out along the left bank of the Euphrates River, which extend from Rawa city for about 10 Km towards east. The subsurface extension of the Anah Formation is encountered in Khlessia-1 oil well and Milih Tharthar-1 oil well.
Remark: The formation is not represented on the enclosed geological map (Fig.1), due to scale limitations.
Lithology: The Anah Formation, in the type locality, consists of "grey breccious, recrystallized, detrital and coralline limestone" (Bellen *et al*., 1959). Al-Mubarak (1971) described the Anah Formation, in the extreme southwestern margin of the Jazira Area, as mainly of limestone; creamy in colour, fine crystalline, massive, very hard, coralline and fossiliferous.
Thickness: The thickness of the Anah Formation in the type locality is 45 m. (Bellen *et al*., 1959). The exposed thickness in the extreme southwestern margin of the Jazira Area is (1 – 3) m (Al-Mubarak, 1971).
Fossils: The following fossils are recognized by Ctyroky and Karim (1971) from Anah Formation: *Austrotrillina howchini* Schlumberger, *Rotalia viennoti* Greig, *Archaias* cf. *kirkukensis* Henson, *Miogypsinoides complanata* Schlumberger, *Opericulina* cf. *complanata* De France, *Peneroplis evolutus* Henson. *P. thomasi* Henson, *Triloculina gibba* d'Orbigny, *Hydrobia* sp., Conus sp., *Quinqueloculina* sp., Algae: *Subterraniphyllum thomasi* Elliot, *Ampulospira* cf. *oweni* Oarchiac and Haime, colonial corals, echinodermata, gastropoda.
Age: According to Bellen *et al*. (1959), the age of the Aanh Formation is Late Oligocene; Ctyroky and Karim (1971) claimed Late or Uppermost Oligocene; Fouad *et al*. (1986) claimed Late Oligocene age and Al-Twaijri (2000) designated that Anah Formation to be deposited during Late Chattian time in a successive superposition.
Depositional Environment: Bellen *et al*. (1959) inferred that Anah Formation represents reef-back and reef facies. Ctyroky and Karim (1971) concluded that Anah Formation is reef and back reef facies originated in shallow warm tropical euhaline sea. Fouad *et al*. (1986) concluded that Anah Formation includes three basic environments; reef (normal marine) in the lower part, back reef (hypersaline) in the middle part, and very shallow (brackish water) facies.
Lower Contact: The Anah Formation, in the type locality is underlain conformably by Azkand Formation (Bellen *et al*., 1959). In the Anah vicinity, it is underlain by Baba Formation, the contact is conformable and gradational (Al-Mubarak, 1971 and Fouad *et al*. 1986). The base of the Anah Formation is not exposed in the Jazira Area.

2. Euphrates Formation (Early Miocene)
Type Locality: The type locality of the Euphrates Formation is along Wadi Fhaimi, south of Rawa city (Bellen *et al*., 1959), it is defined by the following coordinates:

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

Remark: The type locality of the Euphrates Formation is inundated by Haditha Lake. As well, the chosen type locality by Bellen *et al.* (1959) is not a representative one. Jassim *et al*. (1984) recommended a supplementary type section in Wadi Chab'bab, in Anah vicinity, for the Lower and Middle Units (A and B) and another supplementary type section in Wadi Rabi, in Anah vicinity for the Upper Unit (C). But, the Upper Unit (C) was found to be another formation, which was named as Nfayil Formation (Sissakian *et al.* 1997, In: Sissakian and Mohammed, 2007).
Exposure Area: The outcrops of Euphrates Formation occupy limited area in the extreme southern part of the Jazira Area (Fig.3). It crops out along the incision of the Euphrates

Valley, which extends from Al-Qaim (in the west) to Heet vicinity (in the east). The subsurface extension of the Euphrates Formation is encountered in Khleissia-1 oil well and Milih Tharthar oil well 1 (Fig.1).

Lithology: The Euphrates Formation, in the type locality consists of "shelly, chalky, well bedded, recrystallized limestone" (Bellen *et al.*, 1959). The type section proposed by Jassim *et al.* (1984) consists of:

– **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, changes to coralline limestone.

– **Middle Unit (B)** consists of alternation of hard limestone and pseudoolitic limestone.

Al-Mubarak (1971) divided the Euphrates Formation, in the southern part of the Jazira Area into three members:

– **Lower Member** consists of basal conglomerate, followed by dolostone and dolomitic limestone.

– **Middle Member** consists of white, fossiliferous limestone, alternated with pseudoolitic chalky like limestone.

– **Upper Member** consists of alternation of grey limestone with green marl.

Al-Mubarak (1971) considered the brecciated rocks, which overly the Middle Member as a basal part of the Fat'ha Formation. But later on, the brecciated rocks were grouped with Euphrates Formation (Jassim *et al.*, 1984).

In Rawa – Al-Baghdadi vicinity, Ibrahim and Sissakian (1975) adopted the subdivision of Al-Mubarak (1971) of the Euphrates Formation, in the southern part of Al-Jazira Area. They divided the formation into the following members:

– **Lower Member** consists of two units: **Basal Clastic Unit,** which is composed of limestone fragments and pebbles (8 m thick), followed by **Dolomitic Unit** of (5 – 15) m thickness.

– **Middle Member** consists of two parts: The lower part is composed of grey massive fossiliferous and dolomitic limestone, while the upper part is well bedded chalky dolomitic limestone, interbedded with grey to whitish grey marl; the thickness is (25 – 40) m.

Remark: Ibrahim and Sissakian (1975) considered the Upper Member as the lowermost part of the Fat'ha Formation.

Stratigraphic Subdivisions: The diversity in the stratigraphic divisions may lead to confusions for the development of the regional study of Miocene Basin. Therefore, the present study adopted the divisions, which were suggested by Sissakian and Hafidh (1993 and 1994). Accordingly, the exposures of the Euphrates Formation in Al-Jazira Area are divided into the following members:

– **Lower Member** consists of basal conglomerate, well bedded dolomitic limestone and chalky oolitic limestone. **The basal conglomerate** consists of limestone fragments derived from the underlying Oligocene rocks, the fragments (angular to subrounded shape) range in size from pebbles to boulders (up to 2 m in size) cemented by carbonate and locally marl with quartz grains. The thickness is greatly variable; it ranges from less than 1 m up to 17 m (Al-Mubarak, 1971). Because of the rolling nature of the pre-Miocene surface, the basal conglomerate is occupying the bedrock topography (Tyracek, 1978).

Remark: Prazak (1978) pointed out three beds of basal conglomerate. The lower most bed (basal clastic) lies directly over the Oligocene bedrock, composed of a gritstone of variable grain size and thickness. The overlying conglomeratic breccia is divided into two horizons; the lower horizon contains large boulders (up to 0.5 m) of dark aphanocrystalline limestone, whereas the matrix is often missing either primarily or being washed out. The upper horizon is finer with decreasing amount of fragments, which are whitish creamy and thin to laminated. The boundary between both horizons is erosional and undulated, with secondary reddish brown color. Ibrahim and Sissakian (1975) pointed out that the basal conglomerate is derived from the underlying Anah Formation; the pebbles are decreasing in quantity and size upwards.

Dolomitic Limestone, which overlies the basal conglomerate, consists of well bedded dolomitic limestone, which is highly fossiliferous with (5 – 25) m thick.

Chalky dolomitic limestone: The above mentioned succession is followed (upwards) by dolomitic limestone of chalky texture (no real chalk exist there and the chalky like being related weathering only), its lower part is massive and becomes well thinly bedded fossiliferous, with two horizons of oolitic limestone. At the lowermost part, a green marl horizon occurs everywhere, which could be used as a good marker (Sissakian and Hafidh, 1993 and 1994). In the upper parts, marl and limestone horizons occur too. Some layers are rich with small size pelecypods. The thickness of this part ranges from (24 – 37) m. The thickness of the Lower Member is 79 m and its contact with the Upper Member is based on the bottom of the brecciated horizon or a thin horizon of green marl (Sissakian and Hafidh, 1993 and 1994).

– Upper Member consists of green marl horizon, brecciated horizon and crystalline limestone. Prazak (1978) named this member as Chalky Member. The main constituents are briefly described hereinafter (Sissakian and Hafid, 1993 and 1994):

Green Marl: The lowermost part of the Upper Member consists of green marl in form of bed or lenses (1 – 2) m in thickness. Locally, this bed disappears.

Brecciated Horizon: The Brecciated Horizon is divided into two parts: The lower part consists of fragments of silicified and fine crystalline limestone of grey color. The shape of the fragments is angular and subrounded, ranges in size from few millimeters up to 1 cm, which are cemented by green marl. The Brecciated Horizon is highly deformed, the deformation increases upwards without controlled direction, which may be related to slumping as a result of earthquakes (Bolton, 1954), associated with many sedimentary structures like load cast, convolute bedding and flame structure. The thickness of this horizon is (8 – 12) m. The upper part of the Brecciated Horizon consists of fragments (1 – 5 cm) in size, angular to subrounded, chalky limestone, cemented by calcareous material; the thickness of the upper part is 6 m.

Undulated Limestone: The Undulated Limestone, which is highly contorted (undulated), is thinly well bedded, light brown and grey, recrystallized and fossiliferous. The undulation varies in width and shape; it ranges from less than 1 m up to10 m, whereas their heights range from few centimeters up to 5 m. Locally, the undulated limestone is intervening with the underlying brecciated part (Al-Mubarak, 1971). The thickness of the limestone ranges from (0.5 – 20) m; the thickness of the Upper Member is 38 m.

Thickness: The thickness of the Euphrates Formation in the type locality is 8 m (Bellen *et al.*, 1959) and in the supplementary type section is 110 m (Jassim *et al.*, 1984). In Al-Qaim and Anah vicinities is 113 m, but usually it decreases towards southeast. In the Rawa – Al-Baghdadi vicinity is (38 – 63) m (Ibrahim and Sissakian, 1975). In Mileh Tharthar oil well 1 is 97.5 m, whereas in Khleissia-1 oil well is 71 m.

Fossils: The following fossils are recognized by different authors from Euphrates Formation: *Peneroplis evolutus* Henson, *P. farsensis* Henson, *Quinqueloculina aknariana* d'Orbigny, *Archais* sp., *Robulus* sp., *Triloculina* sp. *Nodosaria* sp., *Sigmoilina* sp., *Miogypsina globulina* Michelotti, *Borelis melo melo* (Fitchel and Moll) and rotaliids. Ostracods: *Cythereis* sp. and *Cyprideis* sp. Pelecypods: *Hydrobia* sp., *Macoma* sp., *Arca turonica* Dyjardian, *A.* sp., *Phacoides* cf. *columbella* Lamark, *Veneridue* sp., *Chione* sp., *Clycymeris pilosus* Linnaes, *Divaricella* cf. *ornate* Agassiz, *Milyah* sp., and *Donax* sp., Gastropods: *Trochus* sp., *Pirenella* sp., *Turritella* cf. *vermicularis, T*. cf. *angulata* Brocchi, *Mures* sp., *Fissurella* sp., *Acteonina* sp., *Conuns* sp., *Capulus* sp., *Fusus* sp., *Acaphander* sp., *Ficus conditus* Brongniart, *Bittium* sp. and *Ancilla* sp. Brachiopods: *Discinise* sp. and Echnoids: *Clypeaster* sp. and *Brissopsis* sp.

Age: The age of the Euphrates Formation based on the aforementioned fossils is Early Miocene (Early – Late Burdigalian) confirmed by the presence of *Miogypsina globulina* and *Miogypsina intermedia*, this is agreed upon by all considered authors.

Depositional Environment: The depositional environment of the Euphrates Formation is back-reef (shallow marine environment) due to the presence of Miliolids (*Peneroplis* and *Quinqueloculina* sp.), Algae, *Ammonia beccarii*, *Borelis melo melo* and *Miogypsina globulina*.

Lower Contact: The Euphrates Formation, in the type locality is underlain unconformably by Anah Formation (Bellen *et al*., 1959). In Al-Jazira Area it is underlain unconformably by Anah Formation; the contact is sharp and indicated by basal conglomerate (Al-Mubarak, 1971; and Ibrahim and Sissakian, 1975).

3. Fat'ha Formation (Middle Miocene)

Type Locality: The type locality of the Fat'ha Formation is in Makhul Range, it is defined by the following coordinates (Al-Rawi *et al*., 1992):

Longitude 43° 21′ 15″ E
Latitude 35° 10′ 00″ N

Exposure Area: The Fat'ha Formation is exposed in the middle and southern parts of Al-Jazira Area (Fig.3). The subsurface extension of the Fat'ha Formation is encountered in Khlesia-1 and Milih Tharthar oil wells (Fig.1).

Lithology: The distinctive feature of the Fat'ha Formation is the presence of the evaporate facies, which is represented mainly by thick beds of gypsum – anhydrite. This occurs as a part of a cyclic nature with the common rhythm being marl – claystone, limestone and locally halite. Four principal lithofacies are present within the Fat'ha Formation (from bottom to top):

– Marl – Mudstone: These fine-grained sediments are generally massive and structure less, although some contain thin limestone horizons. In the lower part of the Fat'ha Formation, the mudstone beds are typically grey or green and contain foraminifera together with some bivalves and ostracods (Al-Jumaily, 1976 and Ma'ala, 1976). The thickness in the lower part is (1.7 – 7) m, while in the upper part; the mudstones are thicker (2 – 11 m) with dominant red color and without fossils. The mudstone have (20 – 50) % of clay minerals such as illite, chlorite, palygorskite, while the non clay minerals are calcite, dolomite, gypsum and quartz.

– Limestone: Limestone horizons are less than 2 m thick and rarely reach to 3 m in the middle of the lower part. The most common types are peloidal limestone (pelsparites and pelmicrites). Etabi (1976) showed that the limestone is formed in various textures: sparites composed of allochem (oolites, fossils and intraclasts) as framework and spary calcite as a matrix and cement; micrite is composed without allochem intraclasts. Fossils, oolites, mixed rocks of both sparite and micrite also exist, which reflect a local change in depositional environment. When they are in contact with gypsum horizon, the gypsum fills the pore spaces and fossil cavities (this supports the fact that the rocks were precipitated in weak agitated part of the basin).

– Dolostone: Dolostone horizons are formed of calcareous dolostone and dolomitic limestone. They are thin to medium horizons (0.05 – 0.4 m) either alternating with limestone or occur as thin beds within mudstones. Lateral variation between limestone and dolostone is common and even transitional form exists.

– Gypsum – Anhydrite (Sulfate): Horizons of gypsum – anhydrite are widely distributed as thick beds, range in thickness from few centimeters to 14 m (Hadhr borehole 2/ 47)

(Ma'ala, 1976), exceptionally some may be thicker. In surface outcrops, the sulfate is present as gypsum, whereas in subsurface as anhydrite, the sulfate horizons are characterized by nodules generally range from (2 – 10) cm, with thin seems of claystone, calcite or dolomite between nodules. Etabi (1976) described gypsum horizons to have various textures: Granular (equigranular and optically unoriented, this could be re-deposited gypsum in which the grains welded to each other); Fibrous aggregate (different orientations and fluidal texture, this could be resulted from a deformation that created by the volume increase due to transformation of anhydrite to gypsum); Arenitic texture (anhedral, equal grains, equigranular, well sorted and lacking chemical cement and the matrix could be clayey and recrystallized texture (very coarse prismatic crystals, translucent, colorless).

– Halite: Halite horizons are not reported formerly within the exposures. There is inadequate information on halite occurrence in the Fat'ha Formation. Ma'ala (1976) mentioned that the halite horizons encountered at depths 63 m and 168.7 m by Al-Dibshiya water well located west of Hadhr town with coordinates Latitude 35° 36′ 12″ N and Longitude 42° 35′ 30″ E and height 63 m (a.s.l.) (Fig.1), that means, the halite horizons exit in the lower member.

In the Rawa – Al-Baghdadi vicinity, Ibrahim and Sissakian (1975) subdivided the Fat'ha Formation into six separated units with respect to the prevailing rock types:

– Brecciated Unit consists of marly limestone, breccia and brecciated limestone replacing laterally each other; the thickness is (5 – 20) m.

– Undulated Limestone Unit consists of well bedded highly deformed, warped chalky limestone; the thickness is (5 – 6) m.

– Marl and Gypsum Unit consists of alternation of marl and gypsum separated usually by thin interlayers of limestone, the thickness is 90 m.

– Marl and Limestone Unit composed of alternation of thick marl and thin limestone. Gypsum is either absent or interlayers of 10 cm thickness. This unit is repeated four times in cycling nature, the thickness is 60 m.

– Gypsum Unit consists of repeated three cycles; each cycle is composed of gypsum, which represents the prevalent rock type. Marl is subordinate and limestone occurs in thin horizons, the thickness is (65 – 70) m.

– Silty – Marly Unit consists of reddish brown silty facies and green marly facies with thin horizons of oolitic limestone, the thickness is (50 – 60) m.

Remark: The authors believe that the Silty – Marly Unit is referred to the Injana Formation.

In the Sha'abany and Hadhr vicinities, Al-Jumaily (1976) and Ma'ala (1976), respectively divided the exposures of the Fat'ha Formations into 11 separated cycles. Each cycle consists of mudstone or marl (at the base), limestone or dolomite and gypsum (at the top). The first six cycles belong to the lower member, whereas the last five cycles belong to the upper member, depending on the first appearance of red mudstone and/ or sandstone.

Stratigraphic Subdivisions

The lithology of the Fat'ha Formation is very complicated by repetition of marl – claystone, limestone – dolomite and gypsum – anhydrite; with cyclic nature. Locally, within a single cycle many subcycles may exist or missed. For this reason, the lithostratigraphy of Fat'ha Formation, in the Jazira Area, was divided into 11 exposed cycles by Al-Jumaily (1976) and Ma'ala (1976). Such division can be locally recognized, but can not be extend throughout the Fat'ha basin, which extends between Syria and Iran through Iraq. The only common point is that all the authors used the red claystone as a marker in their subdivisions of the formation into members; consequently the Fat'ha Formation is divided into Lower and Upper Members. The upper member is distinguished from the lower member by the first appearance of red claystone, which indicates a change in the facies indicating the upper member (Mahdi 1983 and Ma'ala *et al.*, 1989). The exposures of Fat'ha Formation are divided into the following members (Sissakian and Hafidh, 1993 and1994):

─ **Lower Member:** The lower member is exposed in the southern part of Al-Jazira Area along the northern side of the Euphrates Valley (Fig.3) in form of narrow cliffs. The lower member is of cyclic nature, each cycle starts with green marl, limestone and ends by gypsum facies (Ibrahim and Sissakian, 1975; Al-Jumaily, 1976; Ma'ala, 1976 and Sissakian and Hafidh, 1993 and 1994). Three main cycles are developed. Locally, within a single cycle many subcycles may exist, or on contrary within one cycle one of the three facies is missing. Lateral variation and lens forms are common. The marl is green, massive or papery, locally contains gypsum crystals (secondary). The limestone is light grey, well bedded, fossiliferous and locally recrystallized dolostone bands may exist. The gypsum is whitish grey, massive, thickly bedded in the upper part; locally it is nodular with some colored impurities. The thickness of the individual cycle is variable, ranges from (19 – 41) m. The thickness of the lower member, along the Euphrates Valley ranges from (80 – 100) m.

─ **Upper Member:** The upper member is exposed in the middle part of Al-Jazira Area which occupies wide area (Fig.3). It consists of cyclic nature, like the lower member, with main difference in the constituents of each cycle that is the appearance of the red claystone and sandstone. Seven main cycles are developed in the area (Ma'ala, 1976); as well many subcycles may exits locally within a single cycle. The claystone is red, reddish brown and brown, varies laterally to siltstone and/ or sandstone, sometimes, lenses of gypsum may exit. The sandstone horizons, which increase in thickness (gradually) upwards, include asymmetrical ripple marks (trending E – W), and three sets of planer cross bedding. Sometimes, the claystone horizons are graded gradually to overlying limestone horizons. The limestone horizons are thickly bedded, recrystallized and highly fossiliferous. The lower part of the limestone horizons is more sandy while its upper part is more gypsiferous; locally, changes laterally to soft, fossiliferous marl. It is worth to mention that there is a “sandwich limestone”, which is developed in the area between Tharthar Valley and Abu Rasain, it is thinning towards west and south. In the upper 25 m, the amount of clastic sediments is higher than evaporites and the claystone includes thin oyster shells (*Ostrea latimarginata*). The thickness of the individual cycle is variable, ranges from (8.5 – 24.35) m, the decreasing in thickness is upward; the thickness of the upper member is (40.5 – 75) m.

Thickness: The thickness of the Fat'ha Formation, in the type locality is 430 m (Jassim *et al.*, 1984 and Al-Rawi *et al.*, 1992). In Al-Jazira Area, the thickness is (120 – 175) m, in Khlesia oil well 1 the thickness is 515 m (Gaddo and Parker, 1959), whereas in Mileh Tharthar oil well 1 is 189 m (drilled thickness).

Fossils: The following fossils were recognized in Fat'ha Formation by Behnam (1976): *Nonion* sp., *Rotalia beccarii* (Linne), *Triloculina* spp., *Sigmoilina* sp., *Teatulavia* spp., *Quinquiloculina* sp., *Lagena* sp., *Ammonia beccarii* (Linne), *A.* sp., *Cibicides* sp., *Cribrononion* sp., *Eponides frigidus* (Cushman). *Elphidium* sp., *Pitar* sp., *Lutraria* sp., *Cleusinella* sp., *Tapes* sp. *Ostrea* sp., pelecypods, gastropods *Clusinella* cf. *persica* Cox, *Ostrea latimrginata* Vredenburg, *Nucula* cf. *nucleus* Lamarck, *Odostomia* sp., *Mohrenesternia* sp.

Age: The accurate age of the Fat'ha Formation, in Iraq has been a matter of some controversy. Sayyab and Kureshy (1967) assigned a Lower Miocene age; Owen and Nasr (1958); Al-Naqib (1959) and Al-Omari and Sadik (1972) considered the Fat'ha Formation to range from Lower to Middle Miocene. Bellen *et al*. (1959); Ctyroky and Karim (1971); Prazak (1978); Buday (1980) and Jassim *et al*. (1984) claimed Middle Miocene. Mahdi (1983) claimed Burdigalian age depending on two oyster species (*Ostrea latimarginata* Vredenburg and *Ostrea subangulata* d'Orbigny) as well as ostracods assemblage. Lawa (1988) claimed

Early to Middle Miocene, depending on *Miogypsina globulnia* and *Orbulina universa*, whereas, Lawa and Salman (1988) dated as Burdigalian to Early Langhian (Lower to early Middle Miocene). According to Ponikarov *et al*. (1967) it is Tortonian (Middle Miocene) stage.

Depositional Environment: The macro and microfossils of the Fat'ha Formation indicate shallow sea water, either near shore environment or lagoonal condition of tropical to subtropical water, depending on the presence of abundant *Ammonia beccarii*, *Elphidium* and miliolids. At the same time, the lithological analysis proved semi closed marginal basin rich in sabkha and saline tidal flats of carbonate and evaporate (Tucker and Shawket, 1980).

Lower Contact: The Fat'ha Formation is underlain conformably by Euphrates Formation (Al-Mubark, 1971; Ibrahim and Sissakian, 1975 and Al-Jumaily, 1976) in the southern part of the area, and by Jeribe Formation in both Jabal Sinjar (Buday, 1980) and Khlessia-1 oil well (Gaddo and Parker, 1959). The contact is considered at the base of the last primary layer of gypsum (Gaddo and Parker, 1959; Ibrahim and Sissakian, 1975; Al-Jumaily, 1976 and Buday, 1980).

4. Injana Formation (Late Miocene)

Type Locality: The type locality of the Injana Formation is along the northeastern limb of Himreen South Anticline at Injana locality, it is defined by the following coordinates (Jassim *et al*., 1984 and Al-Rawi *et al*., 1992):

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

Exposure Areas: The exposures of the Injana Formation are restricted to the northern part and very limited exposures as narrow strip along the western part of Tharthar Valley, as well south of Tharthar Lake (Fig.3), in forms of isolated hills (Sissakian and Hafidh, 1993).

Lithology: The Injana Formation, in the type locality consists of alternation of red, brown and grey claystone, siltstone and sandstone, with rare fresh water thin limestone and gypsum horizons, in the lowermost part (Jassim *et al.*, 1984 and Al-Rawi *et al.*, 1992). The Injana Formation has been described by all authors as alternation of sandstone and claystone layers with the former being increased upward.

In Al-Jazira Area the Injana Formation consists predominantly of red, brown and grey claystone, siltstone and sandstone, overlying the last gypsum bed of the Fat'ha Formation. Generally, the formation comprises of repeated cycles, each cycle consists of sandstone, siltstone and claystone. In the lower part, thin horizons of fossiliferous and oolitic limestone may occur, locally.

In Rawa – Al-Baghdadi vicinity, Ibrahim and Sissakian (1975) divided Injana Formation, along the southern sector of Tharathar Valley into two units:

– **Sandy – Silty Unit** (Lower Unit) consists of two facies: **Sandy Facies** consist of grey, medium grained; 8 m thick and **Silty Facies** consist of reddish brown and (5 – 8) m thick. Few horizons of limestone occur in the lower part with some thin beds of secondary gypsum, not exceeding 10 cm.

– **Alternation of Marl, Sand, Clay and Silt Unit** (Upper Unit), it is exposed outside of Al-Jazira Area.

In Al-Sha'abany and Hadhr vicinities, Al-Jumaily (1976) and Ma'ala (1976), described the Injana Formation without subdivision, due to the lateral variations, they described each rock type as follow:

– **Sandstone Beds** are mainly red, brown, locally greenish grey in color, fine to medium grained, partly cemented mainly by clayey material with subordinate gypsiferous material. Sandstones form thinly to thickly bedding, which may exhibit rapid lateral variation in thickness and lithology. Cross bedding and mud balls are widely spread, at the upper part of the formation. In the lower part, numerous buried channels have dissected the deltaic plains, at west and northwest of Snaisla Salt Marsh. They exhibit the stream directions from northeast and north running towards southwest and south, respectively (Ma'ala, 1976). The base of the Injana Formation is built up by sandstone beds (Ibrahim and Sissakian, 1975; Al-Jumaily, 1976 and Ma'ala, 1976), moreover, they become more dominant at the upper part (coarser in grain size and thicker beds) and the thickness of the single sandstone bed ranges from (0.2 – 4.5) m.

– Siltstone Beds are mostly reddish brown to grey or dark brown, but there are also greenish grey intercalations. They normally contain clayey material, which can be considered as mudstone. They appear as thinly bedded to massive up to several meters thick, which often change laterally and vertically to claystones and sandstones. Many fossils bearing horizons have been recognized including ostracods and algae (Al-Jumaily, 1976; Ma'ala, 1976 and Sissakian and Hafidh, 1993), but are not index fossils.

– Claystones Beds are predominantly of brown color; rarely are greenish grey, which can be used as local marker horizons. Most of the claystones are designated as silty and/ or calcareous, transitions to siltstones and sandstones are common. Alternations with sandstones and claystones are observed in many places. Claystones as well as other beds of Injana Formation include buried channels. The thickness of single claystone bed ranges from (0.3 – 5.8) m. Although, there is no regularity in variation of bed thicknesses, but in general the ratio of claystone decreases upwards, if compared with that in the lower part.

– Oolitic Limestone Horizon is exposed locally at the top of Jabel Al-Manaif and Al-Madb'ah localities, which are located south of Snaisla Salt Marsh. In Jabel Al-Manaif, it consists of massive, mainly coarse size oolites (up to 1 cm in diameter), often deformed and empty and cemented by carbonate material, locally cross bedded in the lower part. Finer sizes of oolites have been recorded in Al-Madb'ah locality and some other places (Ma'ala, 1976). The stratigraphic position of the oolitic limestone horizon is about (10 – 30) m above the base of Injana Formation (Ma'ala, 1976). Thin horizons (0.1 – 0.5 m thick) of fossiliferous, oolitic limestone occur at the base of isolated hills of Injana Formation, which are developed west of Tharthar Lake (Ibrahim and Sissakian, 1975; Sissakian and Hafidh, 1993).

Thickness: The thickness of the Injana Formation in the type locality is 620 m (Jassim *et al*., 1984 and Al-Rawi *et al.*, 1992). The exposed thickness is 160 m in the northern part (Ma'ala, 1976), (3 – 20) m (exposed thickness) in west of Tharthar Lake (Sissakian and Hafidh, 1993), 37.5 m (drilled thickness) in Khlesia-1 oil well (Gaddo and Parker, 1959) and 140 m in south of Sinjar mountain (Daoud, 1986).

Fossils: Mainly, fossils are rare or not well preserved. Gastropods and pelecypods are reported in the type locality (Al-Rawi *et al.*, 1992). The recognized fossils in Al-Jazira Area are: *Ammonia beccarii* (Linne), *A.beccarii* (Linne) *inflate* (Seguenza), *A. beccarrii* (Linne) *tepida* Cushman, *Cyprideis* sp., *C. torosa* Jones, *Caudita* sp., *Perissocytheridea* sp., *Echinocythereis* sp., *Balanus concavus* Conrad, crab fragments, teeth fragments, *Elkocythereis* cf. *mintidontis* Dickinson and Swain, *Candona* sp., *Limnocythere* sp., *Achistochara* sp.and *Techtochara* sp. (Behnam,1976).

Age: The age of Injana Formation is not definitely established. Al-Naqib (1959) and Bellen *et al.* (1959) assigned the formation to Late Miocene age. This age assignment was based on its stratigrophical position, rather than on its fossils content. Ibrahim and Sissakian (1975); Al-Jumaily (1976); Ma'ala (1976); Buday (1980); Jasim *et al.* (1984); Al-Rawi *et al.* (1992) and Sissakian and Hafidh (1993) considered the age of the formation as Late Miocene based on its stratigraphic position too.

Depositional Environment: It is mixed brackish and fresh water, which reflects environment of estuaries or lagoons fed by rivers. This suggestion is based on the assemblage of *Cypriders – Ammonia,* which live in brackish to fresh water (Grumann, 1977) and the presence of fresh water ostracodes, the genera *Elkocythereis* and *Limnocythere*. Lawa (1988) pointed out that the fluvial facies of the Injana Formation includes ichnofacies of scoyenia.
Lower Contact: The lower contact of the Injana Formation in the type locality is conformable and gradational with the underlying Fat'ha Formation; it is based on the top of the last gypsum bed (Jassim *et al*., 1984). In Al-Jazira Area, it is underlain conformably and gradationally by the Fat'ha Formation, the contact is based on the top of the last gypsum bed (Ma'ala, 1976).

5. Quaternary Sediments

Different types of Quaternary sediments are developed in Al-Jazira Area; they cover unconformably outcrops of all exposed formations with variable thicknesses ranging from few centimeters up to 10 m. Although, the stratigraphy of the Quaternary sediments is not precisely determined, due to lack of precise dating, but four main genetic types of Quaternary sediments were differentiated; these are (in descending age order)

- **Alluvial Sediments**

Sixs types of alluvial sediments are recognized:
─ **River Terraces** are the most significant Quaternary sediments in the area. They are concentrated locally in discontinuous strips along Euphrates River (in the south), Tharthar Valley (in the east) and Ajeej Valley (in the west). The terraces are preserved on various levels (above present day river level), but they are not well developed. The pebbles are well rounded to subangular, mainly limestone, chert, flint, sandstone, subordinate igneous and metamorphic rocks and gypsum (locally); their sizes range from few cm up to 15 cm and may reach 35 cm. The pebbles are cemented by calcareous, gypsiferous, sandy materials, occasionally clayey. The thickness of each level is highly variable, generally ranges from (1 – 3) m.
─ **Foothill Sediments** are developed on the southern slopes of the Sinjar and Sheikh Ibrahim mountains (in the north). They consist mainly of fine clastics with small rock fragments admixture. The thickness ranges from (9 – 12) m in Ba'aj vicinity (Ma'ala, 1977).
─ **Alluvial Fan Sediments,** some isolated patches of gravel accumulations are developed in different levels northwest of Snaisla Salt Marsh (Ma'ala, 1976). The gravels are well rounded to subrounded, mainly of limestone, chert and sandstone, their sizes are up to 2 cm, mixed with sandy, silty material and partly cemented by secondary gypsum, and locally cross bedding was observed. Ma'ala (1976) believed that the accumulation of gravels is related most probably to remnants of ancient alluvial fans.
─ **Valley Fill Sediments, t**he main valleys are filled by different clastic sediments, which are highly variable in composition, size and thickness. The main composition of sediments is carbonate, evaporate, the pebbles are rounded to subrounded, with average size of (1 – 10) cm, but may reach to 30 cm, the thickness ranges from (0.5 – 1.5) m.
─ **Flood Plain Sediments** are well developed along Tharthar Valley (ancient river) and the Euphrates River, they are composed of sand, silt and clay. Those of Tharthar Valley are highly gypsiferous (Sissakian and Hafidh, 1993). The thickness is variable, it is (1 – 2) m as average.
─**Depression Fill Sediments** are restricted to the middle part of the area (Fig.2), forming usually flat areas, which are called salt marshes or sabkha. The most famous depressions are Snaisla, Ashqar, Geziz, Albu Gharis, Taweel and Bawara. They are filled by light brown and

black mudy sediments with high amount of salty and gypseous material (Al-Jumaily, 1976; Ma'ala, 1976; Tobbia, 1996 and Jassim *et al*., 1999).

▪ **Evaporation Sediments**

Three types of evaporation sediments are recognized in the area:

– **Calcrete,** thin veneer of calcrete is restricted in the northern part, especially north of Bawara and Snaisla Salt Marshes (Fig.3). Remnants are found on top of isolated hills. Ma'ala (1976) described the calcrete as dense texture of irregular wavelike to horizontal horizon. Petrographically, it consists of carbonaceous material with sand grains of variable quantities, locally with rock fragments of variable diameters up to few centimeters, which increase downward (Etabi, 1976), the thickness is not more than 0.25 m.

– **Gypcrete,** it is well developed in the middle part of the area, especially in flat plains and top of hills. A typical gypcrete is composed of powdery to granular gypsum, mixed with weathered clastic sediments of underlying claystone, siltstone, sandstone, limestone and gypsum, certain percentage of aeolian sand admixture occurs too, the thickness ranges from few cm to 2 m.

– **Halcrete,** it is secondary halite accumulated in the central parts of the depressions like Snaisla, Bawara, Ashqar, Giziz, Albu Gharis and Taweel. It is composed of secondary halite with crystals of gypsum and sand grains. Halcrete is developed during summer seasons (Al-Jumaily, 1976; Ma'ala, 1976; Al-Khateeb, 1995; Tobbia, 1996 and Jassim *et al*., 1999).

▪ **Residual Soil**

Two types of residual soils are recognized in the area:

– **Sandy Silty Soil** covers the majority of the northern part of the area, with variable thicknesses (0.5 – 3 m).

– **Gypsious Soil** covers the majority of the middle part of the area, composed of mature sand, silt, clay and gypsum, with variable thicknesses range from (0.5 – 1) m.

▪ **Slope Sediments**

Slope sediments are accumulated along the slopes of the erosional cliffs, which extend between Bawara and Tel Abta. They are composed of reddish brown sandstones and siltstone fragments of variable sizes, sometimes mixed with wind blown sand, the thickness ranges from few cm to 0.5 m.

▪ **Aeolian Sediments**

Thin sheets of aeolian sediments are accumulated locally in the middle and lower parts of the area, in form of sand dunes and/ or sand sheets. They consist of light brown to grey and loose, generally fine grained composed of quartz and carbonates with small amount of evaporates, they are young and still active. Ibrahim and Sissakian (1975) believed that drift sand is observed in the area most probably because of the whole dunes being transformed in the direction of prevailing winds (NW – SE). Locally, Nebkhas are developed, especially in depression, with heights not exceeding 0.75 m.

DISCUSSION

The development of the Miocene basin is discussed hereinafter, concerning age and lithology.

▪ Early Miocene

The Miocene basin in Al-Jazira Area is expressed by the boundary between the Miocene and the underlying units, which is marked by a gap of sedimentation (erosional unconformity). Ctyroky and Karim (1971) believed that the gap includes an early part of the Early Miocene at least, as the closely underlying Oligocene is represented by its younger zone, the *Miogypsiniods complanatus*. As for the duration of the stratigraphic break, a time span of three million years has been estimated approximately (Buday, 1973: in Al-Jumaily, 1976). The Miocene transgression advanced from Mediterranean through Turkey and northeastern Syria (Prazak, 1978). This assumption is based on the following aspects:

– At the beginning of the Miocene sedimentation, the Mediterranean and Mesopotamia Basins were characterized by the following bivalve: *Nucula nucleus*, *Nuculana fragilis*, *Nuculana pella*, *Lucina columbella*, *Divaricella ornate*, *Tapes vertulus*, *Barbatia barbata*, *Chama grypheoides*, *Chlamys varia*, *Modiolus incrassatus*.

– The relatively deep sea deposits of the Serikagni Formation are thickly developed in Syria, reaching up to 400 m (called there Chilou Formation), but thinning eastward and southeast. Near the Iraqi – Syrian frontier (in the well Rhouna-1), the thickness is reduced to 270 m (Panikarov *et al*., 1967) and in Sinjar mountain (the type locality) the thickness is 150 m (Ma'ala, 1977).

The lowermost part of the marine Miocene sedimentation has been influenced by paleomorphology of the basin, which led to the deposition of three horizons of basal clastic sediments. The bed which lies directly over the Oligocene rock unit (along the right bank of Euphrates River) is most probably of terrestrial origin. The overlying conglomeratic – breccia (basal conglomerate) is comprised of two horizons, which are separated erosionally by reddish brown color, owing to the former weathering. These horizons contain big boulders, at the base, with decreasing in size to pebbles, upward. This situation caused the exposure of the marine transgression for short time. The short time of deposition carried out upwards with carbonate facies (intercalations of fossiliferous limestone of the Lower Member) toward the west, in Syria, the same depositional condition occurs, represented by Janoudiya Formation, which is an equivalent of Euphrates Formation.

Proceeding of Miocene Sea towards the central part of the basin led to the deposition of a basal evaporates facies in Early Miocene. This is known from the oil well Khlesia-1 (Gaddo and Parker, 1959). The basal evaporate facies (5 m thick) might be the equivalent of Kalhur Anhydrite as known by Bellen, *et al.* (1959) and Prazak (1978). The authors believe that the central part of the Mesopotamian Basin was separated as saline basin due to closure or shallowing of the Tethys Sea for short time after the sea transgression in Early Miocene.

The base of the Upper Member of Euphrates Formation consists of disturbed semi-brecciated horizon (1 – 20) m thick, with sharp lithological boundary. It is overlain by the undulated limestone. This sequence is usually called “Chalky horizon” but no real chalk exists there and the “chalky” look is due to weathering only. Such whitish outcrops extend tens of kilometers along the Euphrates Valley. Many of these horizons show an oblique lamination indicating that they have been deposited by strong currents in shallow water origin and frequently reworked and re-deposited (Prazak, 1978).

The abundant brecciated horizons are explained by Bolton (1954) in Jassim *et al*. (1984) by slumping and escape of gases with possibility of earthquakes triggering that led to the slumping processes. The present authors believe that the brecciated horizons were formed by contemporaneous rework and redeposition owing to the first uplift activity and accompanied earthquakes in the site of Anah Trough during the late Early Miocene. Therefore, the brecciated rocks can be described as intraformational breccias. It is worthy to mention that the first uplift in the Anah Trough is dated with the same time of uplifting and volcanic activity in the northeast of Syria (Panikrov *et al*., 1967).

The Euphrates Formation thins rapidly to 71 m towards the center of the Jazira Area, where the **Jeribe** (44 m thick) and **Dhiban** (5 m thick) **formations** were deposited, as encountered in oil well Khlesia-1 (Gaddo and Parker, 1959). The authors believe that these two formations might be the equivalents of the Upper Member of the Euphrates Formation, as well as the presence of the Jeribe and anhydrite facies of Dhiban Formations elucidate that the aforementioned Anah Uplift might have arrested the sea transgression towards south and prevailed the evaporation and hyper-salinity in the middle and north parts of the Jazira Area.

The Dhiban Formation is exposed in Sinjar mountain, north of Al-Jazira Area. Salt occurs in wells drilled south of Sinjar and in northeast Syria, Ponikarove *et al*., (1967) discovered halite beds in the formation. The formation was deposited in the basin-centered sabkha and saline (Buday and Jassim, 1987 in Jassim and Goff, 2006). The anhydrite facies of Dhiban Formation lies directly over Serikagni Formation, interfingers with Euphrates Formation and is overlain by the Jeribe Formation (Ma'ala, 1977). Therefore, its age has been established as Early Miocene. Ma'ala (1977) mapped several tongues of Euphrates limestone within Serikagni Formation; they have the following fossil contents: *Peneroplis farrieusis* Henson, miliolids (*Quinqueloculine* sp. and *Triloculina* sp.), *Eliphidium advenum*, *Miogypsina intemedia*, bryozoa, ostracods. These fossils reflect the interfingering between shallow and deep environments.

The age of the Euphrates Formation is late Early Miocene (Burdigalian), proved by the presence of *Miogypsina globulina* and *Miogypsina intermedia* (Ctyroky and Karim, 1971). *Miogypsina globulina* appears to be restricted to the Early – Middle Miocene (Burdigalian – Early Langhian). Prazak (1974) claimed that only *Orbulina* beds are present (Pre-Middle Miocene).

- **Middle Miocene**

Along the southern margin of Al-Jazira Area, the Upper Member of the Euphrates Formation consists of rugged and undulated thinly bedded limestone, which is believed to mark the beginning of a new sedimentary cycle, named “Lagoonal Second Miocene Sedimentary Cycle” (Tyracek and Younan, 1975). This cycle represents a new transgression covering the Jazira Area, considerably overlapping the former basin (Buday, 1980) owing to sinking of Euphrates – Jazira Basin. Therefore, a new submergence took place during the Middle Miocene and Fat'ha Formation has been laid down conformably in the area (the northwestern part of the Mesopotamian Basin). The basin had been connected with the Indo-Pacific bio-province, which is corroborated by re-appearance of Miogypsinids (Prazak, 1978). Consequently, the hyper-saline environmental conditions were submerged, which stretch from Syria through Iraq into Iran (Ponikarove *et al*., 1967; Prazak, 1978; Tucker and Shawkat, 1980 and Mahdi, 1983 and 1988). Mahdi (1988) pointed out that the Lower Fars Formation in Syria, the Fat'ha Formation in Iraq and Gaschsaran Formation in Iran have essentially the same lithological character (e.g. a rock type and cyclic deposition) and also the fauna are common, including bivalves, *Ostrea latiamarginata*, *Ostrea subangulata*, *Clementia race* and *Clausinella persica* and foraminifera *Borelis melo*, *Peneroplis* sp., *Miogypsina* sp., *Elphidium* sp. and *Dendertina* sp.

The hyper-saline environmental conditions defined set the lithology of Middle Miocene Basin. It is worthy to mention, the Miocene in the Alpine – Mediterranean area, was characterized by active plate movements (Dewey *et al*., 1973) and arid climate. The latter existed at least during the precipitation of gypsum – anhydrite and halite of Fat'ha Formation, whereas, the former may have affected sea level in the Mesopotamia Basin, which could be contributed in developing of the cyclicity.

The Middle Miocene sequence in Al-Jazira Area has rhythmic sedimentation, which is characterized by repeated alternation of mudstone – carbonate – evaporate (Al-Jumaily, 1976 and Ma'ala, 1976). These lithofacies are characterized by remarkable lateral variations (in lithology and thickness) (Al-Jumaily, 1976; Ma'ala, 1976; Mahdi, 1983 and Ma'ala *et al*., 1989). The lateral variations are known from anhydrite to mudstone, limestone to marl or dolostone.

The depositional model of the Fat'ha Formation was suggested as semi-berried, shallow lagoonal model by Mustafa (1980), on contrary of coastal sabkha (Tucker and Shawkat 1980). The present authors believe that the contradiction in scientific opinions is due to the development of the paleomorphology of the basin, which possibly had produced different lithofacies from place to another by different mechanisms (e.g. from lagoon to flat areas or from the center to the margin of the depositional basin). Therefore, we could assume that Al-Jazira Area possibly was the shallower part of the Mesopotamia Basin, on contrary to the Sinjar area, which was relatively deeper. Therefore, the present authors adopted the depositional model of Tucker and Shawket (1980), due to the presence of lateral variations in thickness and lithology, as well the presence of two major ichnofacies. Lawa (1988) recognized Planolites in the carbonate rocks of the Lower Member of Fat'ha Formation and Skolithos in the grey sandstone of the Upper Member. Buday and Jassim (1987) in Jassim and Goff (2006) pointed out that the Fat'ha Formation was deposited in rapidly subsiding sag basin, which periodically became evaporates with formation of sabkha and salinas.

The Jazira Area was relatively flat and slowly subsiding, which owe to change, from time to time, to intertidal, supratidal and subtidal. The grey and green marls of the Lower Member of Fat'ha Formation are interpreted as quiet and deeper water deposits with thin limestone horizons, which represent storm layers (Tucker and Shawket, 1980).However, the red mudstone and claystone with some gypsum horizons, of the Upper Member are regarded as shallow water to subaerial deposits. According to postulation of Tucker and Shawket (1980), the limestones were deposited in subtidal to intertidal, whereas the gypsum – anhydrite was formed in both subaqueous and subaerial environments. The nodular gypsum of the Fat'ha Formation shows many similarities to anhydrite being precipitated at the present time within supratidal sediments of sabkha, along coast of Abu Dhabi (Shearman, 1966 and Butler, 1970 in Tucker and Shawket1980). The presence of halite, according to the literatures, is restricted to the central part of the basin or sub-basins, e.g. in the Sinjar area.

The Lower Member of the Fat'ha Formation consists of limestone – gypsum cycles; they represent sedimentation of supratidal sediments (anhydrite) built over intertidal and subtidal carbonate sediments, which in turn deposited over deep water mud or grey and green marl. The latter are interpreted by Tucker and Shawket (1980) as quiet deeper water deposits. The fossils are found rarely due to the hypersaline character. The assemblages are mostly minute foraminifera, mainly miliolids, besides ostracods that were more frequently found (Prazak, 1978).

The Upper Member of the Fat'ha Formation is characterized by limestone and red mudstone and claystone with some gypsum horizons. The predominance of red mudstone and limestones in the upper part of the Upper Member is a consequence of the greater influx of terrigenous material during end of the Middle Miocene. In correlation with Syria, Ponikarov *et al*. (1967) stated that the upper part of Lower Fars (Fat'ha) Formation contains finer grained terrigenous clastics and lesser amount of evaporates.

Mustafa (1980) and Tucker and Shawket (1980) believed that the tectonic context of the basin have been an important factor in deposition and the development of the cyclicity. Consequently, the thickness of cycles is variable depending on the proceeding or delay of sinking time.

It is worth to mention that the primary dolostone is associated with gypsum beds, which precipitated in the hyper-saline environment. Al-Marsoumi (1980) pointed out that the precipitation of gypsum caused a significant rise in the magnesium to calcium ratio; therefore, the dolostone might be freely deposited.

The contact of the Fat'ha and Injana formations is defined by the origin of the rocks indicated by the shallow marine Fat'ha Formation on contrary of freshwater Injana Formation. According to this suggestion, the contact must be placed on top of the last gypsum layer (Henson, 1959; Nedeco, 1959 and Ma'ala *et al*., 1989). Some of non-fossiliferous limestone beds of fresh water origin above the level of this contact may exist. Therefore, the interfingering of both formations occurs there. In such case, both sedimentations are partly contemporaneous. Consequently, Ibrahim and Sissakian (1975) placed the contact at the base of thick group of alteration of sandstone with siltstone. Ma'ala (1976) tried to separate these disputable beds by calling them as "Transition Bed". This means, two contacts will limit Fat'ha – Injana formations instead of one. Therefore, the present authors denied this suggestion and prefer the contact to be placed on the top of the last primary gypsum layer.

The sedimentation of the uppermost part of the Upper Member of the Fat'ha Formation acquires the characters of rare shallower evaporites and plenty of lateral changes, which might be attributed to last regression of the Miocene Sea. As well, the faunal assemblage is limited to brackish species (*Rotalia beccarii*). Whereas, the clastic sediments increase and the first appeared intercalation containing freshwater ostracods may refer to Injana Formation. However, the lower contact seems to be gradational, according to the field observations (Al-Jumaily, 1976 and Ma'ala, 1976).

- **Late Miocene**

At the uppermost part of the Upper Member of Fat'ha Formation, the Miocene Sea had been affected by the last regression, which terminated evaporatie type sedimentation. Therefore, a new cycle of terrigenous – continental clastic sedimentation was commenced in Late Miocene. This cycle of sedimentation reflects a progressive change from marine (Fat'ha Formation) into fluvio – lacustrine (Injana Formation) environments. Buday and Jassim (1987) in Jassim and Goff (2006) pointed out that the Injana Formation comprises fine grained sediments deposited initially in coastal area and later in fluvio – lacustrine environments. Ma'ala (1976) recognized in two localities oolitic limestone horizons in Jabel Al-Manaif and Al-Mdhb'ah (30 Km south of Snaisla Salt Marsh), which is possibly attributed to short invasions of the Middle Miocene Sea to infill few isolated depressions.

The sandstones were derived from the rising Zagros Mountains by the last Alpine Orogeny. The sandstone beds of Injana Formation comprise igneous (basic, acidic and intermediate), metamorphic and reworked sedimentary rocks (Arteen and Al-Mukhtar, 2002). These sediments are transported by numerous ancient rivers, as indicated by buried channels, mud balls and cross bedding. The individual rhythm exhibits rather quiet deposits (claystone) rather than agitated deposits (sandstone). The missing of mud cracks indicates that the area was covered by permanent water during that time. The influx of ancient rivers has been temporal as indicated by the presence of mud balls within sandstone horizons. As well, presence of fresh water fossils (e.g. charaphyte, *Lyocypris* sp., *Candona* sp., *Cypridopsis* sp. and gastropods); Lawa (1988) recognized Seoyenia (Ichynofacies) too.

The Injana Formation is extremely difficult to be divided into units, due to its close similarity in lithology and predominant lateral variations, but locally it is possible to divide it to units depending on the dominance of sandstone and/ or claystone. The exposed thickness is 60 m (in the Bawara and Snaisla Salt Marshes) and 500 m (south of Sinjar mountain) due to the effect of long-run denudational processes (Pliocene – Recent) and continuous uplifting in Al-Jazira Area.

- **Pliocene – Quaternary**

The arrival influx, from the north and northeast, of molasse facies had been rapidly arrested during the Pliocene Period, probably due to the initial upheaval of the Sinjar area (Ma'ala, 1977). Therefore, the molasse facies of Mukdadiya Formation did not exceed the northern flank of Sinjar anticline. Accordingly, the Mukdadiya Formation was not deposited in Al-Jazira Area. However, Gaddo and Parkers (1959) pointed out that Khlesia-1 oil well encountered conglomerate and silty sandstone at depths of (0 – 19.5) m, they referred these rocks to the Bakhtiari – Recent Formation? (i.e. Mukdadiya Formation). The present authors believe that the pebbles are attributed to the calcrete sediments of the Quaternary.

Most of the Jazira Area is covered by thin veneer of Quaternary sediments, due to the long period of denudation (extends from Pliocene to present day) and local accumulation. These sediments are not precisely dated due to lack of precise dating techniques in Iraq. Therefore, relative ages for the main stratigraphic divisions are suggested.

The main Quaternary sediments in Al-Jazira Area are characterized by four levels of river terraces, which originated even in the valleys of ancient ephemeral streams, such as Ajeej and Tharthar Rivers. They reflect together with calcrete and gypcrete the periodical climatic changes during Quaternary. Ponikarov *et al*. (1967) believed that caliche (calcrete) refers to the basal Pliocene Beds. The present authors are not in accordance with Ponikarov *et al*. (1967) in their assumption, because the calcrete exists over gypsiferous soil, containing fragments of limestone and sandstone up to 5 cm in diameters (Ma'ala, 1976).The halcrete accumulation (salt crust) is reflecting seasonal climatic changes during the late Holocene.

CONCLUSIONS

- The stratigraphic sequence of the Oligocene and Miocene sediments reflects the environmental changes progressively from marine, brackish and fresh water, respectively.
- The Miocene Basin incorporate sediments of two successive marine sedimentary cycles (Euphrates and Fat'ha formations), each cycle started with sea level oscillation, which delineates type and distribution of the sediments.
- The fluvio – lacustrine environment, which started after the last regression in the Late Miocene due to the final phase of the Tethyan Sea closure, led to deposition of Injana Formation, contemporaneously with cycle of continental clastics (pre-molasse facies).
- The molasse facies of Pliocene (Mukdadiya Formation) is not deposited in Al-Jazira Area due to the initial upheaval of the Sinjar mountain.
- The Upper Member of the Euphrates Formation corresponds, the anhydrite and carbonate facies, which are referred to the Dhiban and Jeribe formations, respectively. The variation in facies might be related to a phase of basin emersion during late Early Miocene.
- Sea level oscillation in the Miocene Basin, as well the climatic changes might be an important factor for development of the cyclicity in the Middle and Late Miocene sediments (Fat'ha and Injana formations).
- The Jazira Area has been uplifted during the Quaternary period according to presence of four levels of valley terraces.
- Twelve main types of Quaternary sediments were originated with climatic changes.

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