STRATIGRAPHY

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ABSTRACT

The stratigraphy of the Southern Desert is reviewed. Paleocene rocks represented by Umm Er Radhuma Formation are the oldest rock exposed in the area. The youngest rock represented by Pliocene – Pleistocene age, belong to Zahra Formation. For each exposed formation, the exposure areas, main lithology, thickness, fossils, age, depositional environment and the lower contact is described. Many Quaternary sediments are described in the area too, such as, terraces, gypcrete, alluvial fan, valley fill sediments and depression fill sediments. Al-Batin Alluvial fan, is the biggest fan in the Southern Desert of Pleistocene age, it extends from northeastern Saudi Arabian border northwards into Iraq and has been formed by four depositional stages. Jabal Sanam is the highest isolated hill presented in the area, probably formed by piercing of the Infracambrain salt forming the Sanam plug.

الطباقيـــة

رافع زائر جاسم و بثينة سلمان الجبوري

المستخلص

تمت مراجعة طباقية الصحراء الجنوبية. إن صخور عصر الباليوسين الممثلة بتكوين أم رضمة هي أقدم الصخور المتكشفة، واحدث الصخور تعود لعمر البلايوسين – البلايستوسين والممثلة بتكوين الزهرة. تم وصف التوزيع الجغرافي لكل تكوين متكشف بالإضافة الى الوصف الصخاري والسمك والمتحجرات والعمر والبيئة الترسيبية والحد الأسفل. تم وصف ترسبات العصر الرباعي، مثل ترسبات المصاطب النهرية وترسبات الجبكريت وترسبات المراوح النهرية والترسبات المالئة للوديان والمنخفضات. تعتبر مروحة الباطن الغرينية من عمر البلايستوسين من اكبر المراوح في الصحراء الجنوبية، والتي تمتد من شمال شرق المملكة العربية السعودية شمالا إلى داخل الأراضي العراقية، وهذه المروحة قد تكونت بأربعة مراحل ترسيبية. ويعتبر جبل سنام من أعلى التلال المعزولة في المنطقة الذي يحتمل أن يكون أصله اندفاع ملحي نحو الأعلى مكونا قبة سنام.

INTRODUCTION

Extensive field works have been executed in the Iraqi Southern Desert by many geologists, mostly in the State Company of Geological Survey and Mining. In these works all aspects of geology including stratigraphy have been studied. The aim of this work is to gather the data included in the geological reports in the library of GEOSURV. The age of the exposed sedimentary rocks in the Southern Desert ranges from Paleocene to Pleistocene. The Paleogene sediments (Umm Er Radhuma and Dammam formations) are distributed in the southern and south western parts of the Southern Desert. The Neogene sediments (Euphrates, Ghar, Nfayil, Dibdibba and Zahra formations) are distributed in the Southern Desert, as shown in Fig. (1).

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LOCATION

The Iraqi Southern Desert covers about 7600 Km². It extends from the Euphrates River, in north and northeast, and Wadi Al-Khir in the northwest to the Iraqi – Saudi Arabian borders in the south, southwest and the Iraqi – Kuwaiti International borders, in the southeast (Fig.1).

GENERAL TOPOGRAPHY

The Southern Desert forms relatively flat terrain, slopping gently towards East and Northeast. The elevated part (300 – 400 m, a.s.l.) extends along the Iraqi – Saudi Arabian borders (Ansab and Al-Ma'aniya), while the apparent lowest part (20 – 50 m, a.s.l.) is developed along the Euphrates River. The area is interrupted by several depressions.

STRATIGRAPHY OF THE EXPOSED ROCKS

The exposed geological formations in the Iraqi Southern Desert are divided, age wise, into Paleogene and Neogene Epochs. Moreover, each formation is described in a systematic style, starting with the type locality, exposure areas, surface extensions, lithology, as divided into members and/ or units, fossils, age, depositional environment and the lower contact.

Each formation, generally, is divided by different authors into many members and/ or units. The name of the members and units are mentioned in bold letters, as it is proposed by different authors, from different geographic locations. The adopted age by GEOSURV is mentioned between parentheses, beside the name of each formation.

The adopted description of the formations with their geographical distribution and other mentioned data is based on the Regional and Detailed Geological Survey reports. These are utilized in compilation of geological maps of scale 1: 100 000, based on the original base maps (scale 1: 25 000), which were used in compilation of the published geological maps of scale 1: 250 000.

The exposed geological formations in the Southern Desert are mentioned in Table (1); from older to younger and as shown in Fig. (2):

Table 1: Exposed geological formations in the Southern Desert and their ages

Formation	Age
Umm Er Radhuma Formation	Middle – Late Paleocene
Dammam Formation	Early – Late Eocene
Euphrates Formation	Early Miocene
Ghar Formation	Early Miocene
Nfayil Formation	Middle Miocene
Dibdibba Formation	Pliocene – Pleistocene
Zahra Formation	Pliocene – Pleistocene

1. PALEOGENE

The Paleogene rocks were deposited during period of renewed subduction associated with final closure of the Neo Tethys Ocean (Jassim and Buday in Jassim and Goff, 2006; Sissakian and Mohammed, 2007). The exposed formations are divided, age wise and described hereinafter:

1.1. PALEOCENE

One formation is exposed within this period, this is:

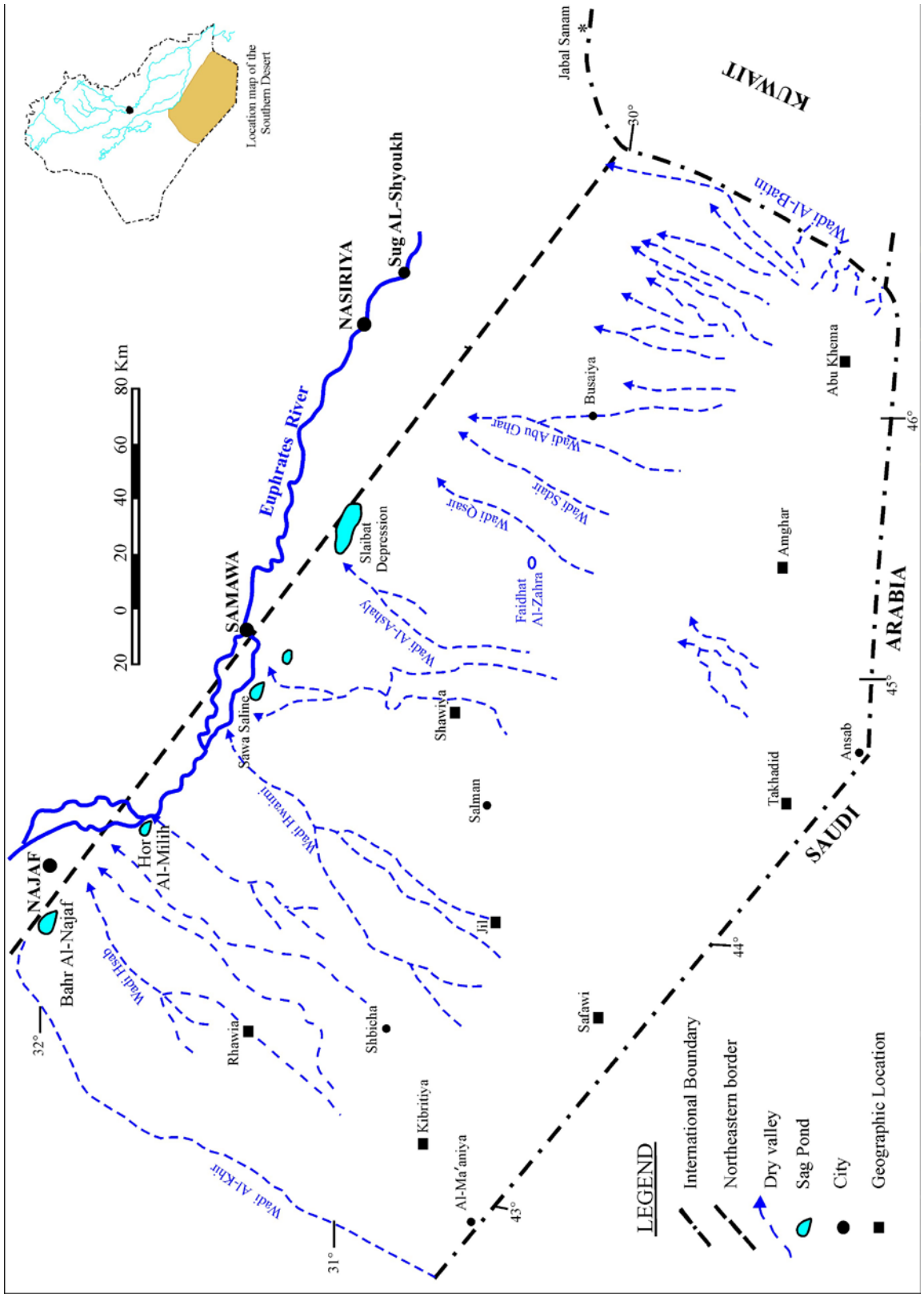

Fig.1: Location map of the Iraqi Southern Desert

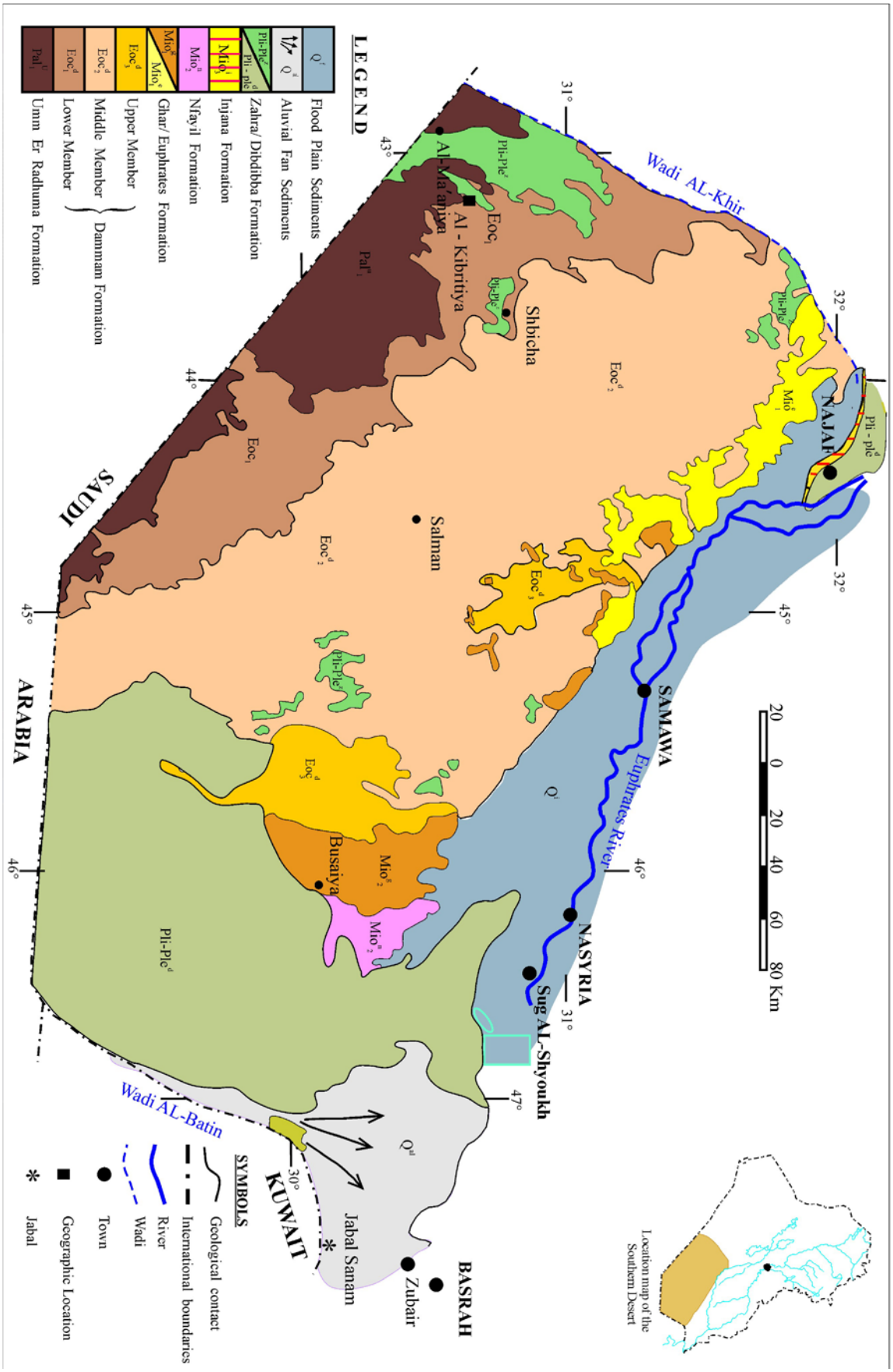

Fig.2: Geological map of the Iraqi Southern Desert (after Sissakian, 2000)

1.1.1. Umm Er Radhuma Formation (Middle – Late Paleocene)

Type Locality: Umm Er Radhuma Formation was first described by Steineke and Bramkamp in 1952 (Bellen *et al*., 1959). The type locality is in Saudi Arabia in Umm Er Radhuma Oil Well. In Iraq, it was first described by Owen and Nasr (1958) from a supplementary type section in Zubair Oil Well 3 (Bellen *et al*., 1959). It is defined by the following coordinates:

Longitude 47º 43' 29" E
Latitude 30º 23' 01" N

Jassim *et al*. (1984) introduced a surface supplementary type section from Nukhaib area in the Western Desert after the regional geological survey of the area by Al-Mubarak and Amin (1983).

Exposure Areas: Umm Er Radhuma Formation is exposed in the southwestern part of the Southern Desert, where it forms a belt following the Iraqi – Saudi Arabian borders, from Al-Birret to Ansab vicinities (Fig.2) (Al-Mubarak and Amin, 1983 and Yacoub and Hamid, 2001)**.**

Lithology: Powers *et al*. (1967) in Buday (1980) described the formation to be composed of light colored aphanitic and calc arenitic limestone, dolomitic limestone and dolomite, locally silicified and cherty. In the supplementary type section in Iraq, the formation is composed of anhydritic and dolomitic limestone, mostly dull, white or buff microcrystalline and porous, chert occurs in the higher part of the formation (Bellen *et al*., 1959). According to Al-Mubarak and Amin (1983), Umm Er Radhuma Formation is subdivided into two members based on the lithological and faunal variations, the **Lower Member** (Middle Paleocene) and the **Upper Member** (Late Paleocene). The two members are further subdivided into mapable lithological units; these are:

1- Lower Member, subdivided into:
- Lower Chalky Unit
- Lower Shelly Unit

2- Upper Member, subdivided into:
- Shelly – Chalky Unit
- Upper Chalky Unit
- Upper Shelly Unit

The exposed part of Umm Er Radhuma Formation in the Southern Desert is represented only by the upper two unit**s** of the **Upper Member**, these are described hereinafter:

▪ **Upper Chalky Unit**

It is exposed in the Southern Desert along Tar Al-Leefiyah and Tar Al-Mafak (SE of Al-Ma'aniya Police Station) (Fig.2). Its maximum thickness is about 80 m and is well exposed in Tar Al-Leefiyah. The Upper Chalky Unit has been subdivided into two sub-units according to lithological variations and physical properties, these are:

– Marly Subunit (45 m thick): It represents the lower part of the Upper Chalky Unit. It consists of alternation of thick beds (2 – 2.5 m) of marly to chalky limestone, and thin beds (0.5 – 1 m) of recrystallized, shelly, calcareous dolostone forming steep slopes. The marly to chalky beds are white to whitish gray and yellowish gray, hard to fairly hard, conchoidally fractured and highly jointed, laminated to thinly bedded (5 – 15 cm), porous, cavernous, the cavities are occasionally filled by secondary calcite crystals, slightly fossiliferous with small burrows. Few black chert lenses and geodes of different sizes (5 – 10 cm in diameter) are present in the upper part. The recrystallized shelly calcareous dolostone beds are gray to whitish gray, hard to very hard, bedded; the thickness of individual bed is (10 – 15) cm.

– Chalky Subunit (30 – 35 m): It represents the upper part of the Upper Chalky Unit and comprises the whole parts of the outcrop area of Umm Er Radhuma Formation. This unit is composed of chalky limestone beds. They are white to yellowish white in color, soft to fairly

hard, bedded, the thickness of each bed is (10 – 25) cm at the lower part; thickly bedded to massive at the upper part of the subunit, highly jointed and fractured, slightly fossiliferous and slightly marly at the lower and upper parts. The chalk to chalky carbonate beds, at the upper part are intercalated with thin beds (thickness of each is 10 – 25 cm) and lenses of black, yellowish brown and dark brown banded chert, and chert nodules of different sizes (1 – 2 cm in diameter).

According to Yass (1980) in Al-Mubarak and Amin (1983), the chalk and chalky carbonate beds in the Southern Desert are described petrographically as aphanocrystalline dolomite.

The upper contact of the Upper Chalky Unit with the overlying Upper Shelly Unit is conformable, based at the top of the last banded chert horizon, at Tar Al-Leffiyah and Tar Al-Mafak in the Southern Desert. While, in Al-Ghurabiya and Tar Al-Lagahiya, the last banded chert horizon is sandwiched between two beds of gray to dark gray, brecciated quartzitic limestone or calcareous quartzitic sandstone.

- **Upper Shelly Unit**

This unit (30 – 35 m thick) is exposed over large areas in the Southern Desert. It is composed of bedded, highly recrystallized, shelly, dolomitic limestone, interbedded with many horizons of chalky carbonate beds at the lower part; thickly bedded, recrystallized, shelly limestone, with silicified, phosphatic limestone at the middle part and massive highly fossiliferous, dolomitic limestone, with small nummulites at the upper part.

The lower part of this unit is composed of (12 – 15) m of highly jointed and fractured, limestone slightly fossiliferous; the fossils are small in size. A different degree of recrystallization is observed.

The middle part of this unit is composed of 20 m of recrystallized, shelly limestone beds; light gray to gray and yellowish gray in color, hard to very hard, compacted, thickly bedded, containing large gastropods and pelecypods, phosphatic at the upper part, alternating with thick horizons (thickness of each is 1 – 2 m) of white or light gray, friable and chalky carbonate beds.

The upper part of this unit is composed of 5 m thick light gray and brown at lower part, gray, brown, pink and violet at upper part, hard to very hard, massive to thickly bedded, highly fossiliferous and dolomitic limestone.

This unit was divided in south of Salman – Ansab area into five micro-facies by Khalil (1983) in Al-Mubarak and Amin (1983) as follows:

- Very fine and aphanocrystalline dolomite
- Fine and Medium crystalline dolomite
- Very fine and aphanocrystalline biogenic dolomite
- Fine crystalline biogenic dolomite
- Limestone

Thickness: The thickness of Umm Er Radhuma Formation, as recorded from boreholes drilled in the Southern Desert, ranges from (310 – 412) m and in the supplementary type section in Iraq (Zubair Oil Well 3) is 451 m (Owen and Nasr, 1958, in Bellen *et al*., 1959). The exposed thickness of the Lower Member in the Southern Desert is (15 –35) m, whereas the exposed thickness of the Upper Member is (85 – 115) m thick (Al-Mubarak and Amin, 1983).

Fossils: The fossils recognized within the Shelly – Chalky Unit by Shaker (1983); Mahmood (1984) and Abdul Munium (1984) are: small planktonic forams, *Globigerniids, Gravelenlla* sp., *Dorothia oxyeona* (REUSS), *Dorothia* sp., *Textularia* sp., *Coskiolina* sp., *miliolids, Quinqueloculina* sp., *Spiroloculina* sp., *Triloculina* sp., *Dasycladacean* (Algae), echinoid spine, gastropods, pelecypods, ostracods, bryozoa and shell fragments. In the Upper Chalky

Unit the recognized fossils are: miliolids, *Textularids, Arca* sp., *Cardium* sp., gastropods and echinoid spines.

The fossil assemblages recorded from the Upper Shelly Unit, in the south Salman – Ansab area are: *Saudi labyrinthica* GRIMSDALE, *Alveolina primaeva* (REICHEL), *Alveolina globosa* (LEYMERIE) *Tritaxia* sp., *Orbitolites* sp., *Valvulina* sp., *Spiroloculina* sp., *Nodosaria* sp., *Dentalina* sp., *Pyrgo* sp., *Gaudryina* sp., *Dictyoconus* sp., *Coskinolina* sp., *Idalina* sp., *Quinqueloculina* sp., *Anomalina* sp., *Miscellanea* sp., *Globortalia* cf. *aequa, Globigerina* sp., *Chilogumbelina* sp., *Discorbis* sp., *Cibicides* sp., *Dacycladacea* (Algae), miliolids, gastropods and echinoid spines (Yousif, 1981 and Shaker, 1983).

Age: The age of the formation is estimated as Paleocene – Early Eocene (Bellen *et al*., 1959), but the recent work on the formation's supplementary type section, in Zubair Oil Well 3, carried out by Al-Hashimi (1972) indicated Late Paleocene for the uppermost part of Umm Er Radhuma Formation, instead of Early Eocene. Mahmood (1983 and 1984), suggested Middle – Late Paleocene. Jassim and Buday in Jassim and Goff (2006) suggested Paleocene age. According to the fossil assemblages recorded above, the authors confirmed the age as Middle – Late Paleocene.

Depositional Environment: Skocek and Hussein (1980) in Jassim *et al*. (1984) indicated that the basal part of the Umm Er Radhuma Formation was deposited in sub tidal marine environment. The sediments were deposited in distal part of the carbonate platform, indicated by the occurrence of very finely crystalline dolostone. The faunal evidences indicate that the Umm Er Radhuma Formation was deposited in an inner shelf (0 – 50 m), hyper saline marine conditions. The alternating shelly horizons indicate very active marine environment, with depth of less than 20 m. These active periods alternate with periods of quiet warm water of depth not more than 50 m, as indicated by the presence of alveolinids, miliolids and other porcellaneous foraminifera. The presence of *Nummilites* and *Operculina* in the uppermost part of the formation indicate deposition in shallow, tropical to subtropical marine environment of normal salinity of central shelf depth (shoals) (Shaker, 1983; Abdul Munium, 1984 and Jassim *et al*., 1984).

Lower Contact: The lower contact of the Umm Er Radhuma Formation in the Southern Desert is not exposed. In B.P.C. and INOC oil wells of the Southern Iraq and hydrogeological investigation boreholes by GEOSURV in Blocks 1, 2 and 3 in the Southern Desert, the formation underlain by Tayarat Formation with a break. In KH 7 borehole, the contact is conformable and based on the top of a black bituminous claystone bed (Tamar-Agha, 1984).

1.2. EOCENE

The Eocene sediments were deposited during the final phase of subduction and the closure of the remnant Neo-Tethys Ocean (Buday and Jassim in Jassim and Goff, 2006). One formation is exposed within this period in the Southern Desert, it is described below:

1.2.1. Dammam Formation (Early – Late Eocene)

Type Locality: The type locality of Dammam Formation is in Saudi Arabia on the Dammam Dome, it was first described by Brampkamp (1941) in Bellen *et al*. (1959). The supplementary type section in Iraq was described by Owen and Nasr (1958) from B.P.C Oil Well Zubair 3, in Basrah area (Bellen *et al*., 1959). It is defined by the following coordinates:

Longitude 47º 43' 29" E
Latitude 30º 23' 01" N

Exposure Areas: The main exposure areas of Dammam Formation in the Southern Desert starting from east Ansab, along the Iraqi – Saudi Arabian borders and extends north and northwestwards till Samawa and Nukhaib, in the Western Desert, respectively. Also it covers

vast area that lies parallel to Euphrates River in the northeast and extends southwards to the Iraqi – Saudi Arabian borders (Fig.2).

Lithology: The formation was subdivided into ten informal lithological units by Huber and Ramsden (1945) in Bellen *et al*. (1959), while Ramsden and Andre (1953) in Bellen *et al*. (1959) reduced them to four informal units. Al-Hashimi (1974), based on the biostratigraphy, subdivided these lithological units into four informal units, but with different stratigraphic positions as compared to those of Ramsden and Andre (1953).

Al-Mubarak and Amin (1983) during the Regional Geological Survey subdivided this formation, in the Southern Desert into three members Lower Member, Middle Member, and Upper Member. They are described hereinafter from bottom to top, as follows:

- **Lower Member:** It is exposed widely in the Southern Desert (Fig.2), and is subdivided into three units:
  1. Wagsa Unit — Early Ypresian (Early Eocene)
  2. Sharaf Unit — Late Ypresian (Early Eocene)
  3. Shbicha – Lower Huweimi Unit — Late Ypresian (Early Eocene)

1-Wagsa Unit: It is exposed in the area located from Tar Al-Rowak until Ansab Police Station and composed of flaky marl and changes completely to chalky limestone. Geomorphologically, this unit forms a continuous ridge, extends from Tar Al-Leefiyah up to the Ansab Police Station, and it is characterized by lateral variations in lithology from well bedded nummulitic limestone, occasionally alternated with one or two thin horizons of flaky marl to marly limestone. The Wagsa Unit overlies unconformably the Upper Shelly Unit of the Umm Er Radhuma Formation. This unit is farther subdivided into two subunits:

– Lower Subunit: Consists mainly (in the western part) of alternation of 2 – 3 thick horizons of yellowish grey, hard to very hard, bedded, highly jointed and fractured, recrystallized, nummulitic limestone. The thickness is about (3 – 14) m. This subunit in the southern part (Ansab Unit) consists of white to whitish grey, well bedded, chalky, hard, recrystallized, porous jointed, cavernous (cavities are filled by secondary calcite crystals), nummulitic limestone. The thickness is about (4 – 6) m.

– Upper Subunit: Consists (in the western part) of massive, recrystallized, slightly chalky, fossiliferous, fragmented, hard marly limestone, nummulitic in the lower part. The thickness is (8 – 10) m. In the southern part (Ansab Unit) it consists of white, pale yellow, hard, highly jointed, fractured, marly limestone. The marl decreases upwards. The thickness is (4 – 5) m. The upper contact with the Sharaf Unit is conformable; the contact was based at the base of well bedded chalky limestone beds. The maximum thicknesses of Wagsa Unit is about 26 m south of the Wagsa water wells and generally decreases towards NW and reaches up to 16 m and 6 m in the SE direction.

1-Sharaf Unit: It is developed in the Southern Desert only and exposed as a continuous ridge from Tar Al-Leefiya, in the northwest (eastern bank of Wadi Al-Khar) to the Ansab Police Station, in the extreme southeast (Fig.2). Geomorphologically, this unit forms continuous ridge with steep slope. The Sharaf Unit is composed of well bedded, at the lower part and thickly bedded to massive at the upper part, chalk to chalky limestone at northwest and central parts (from Tar Al-Leefiyah to Jill Water wells) of the Southern Desert. Towards southeast, from Garat Al-Batin to north of Ansab Police Station, the chalk and chalky limestone beds are alternated with one or two thin horizons (1 – 2 m thick) of yellowish green marl. The upper contact of the Sharaf Unit with the overlying Shbicha – Lower Huweimi Unit is conformable; the contact was based at the top of last thickly bedded to massive chalky limestone at northwest and central parts, and the base of the first thick green marl (2.5 – 3 m thick) in the southeastern part of the Southern Desert. The thickness of Sharaf Unit varies from northwest to southeast, in Tar Al-Leefiyah, the exposed thickness is about (3 – 4) m,

while in the central part (north of Jill Water well) and in the southeast part (north of Ansab Police Station) the maximum thickness reaches up to 20 m.

1- Shbicha – Lower Huweimi Unit: It represents the upper part of the Upper Ypresian age in the Southern Desert. It is exposed as continuous ridge overlying the Sharaf Unit, from Tar Al-Leefiyah in the northwest to the Ansab Police Station in the extreme southeast. Geomorphologically**,** the Shbicha – Lower Huweimi Unit is characterized by cliff forming. Lithologically; it could be divided into two parts (Fig.2):

– Shbicha Beds: The lower part (20 m thick) consists of grey, hard to very hard, thickly bedded to massive, highly recrystallized, partly silicified and fossiliferous limestone. The upper part (20 – 22) m consists of grey to whitish grey, hard, thickly bedded, fossiliferous limestone, alternated with grey and whitish grey, very hard, splintery recrystallized lithographic limestone. Chert nodules of yellowish brown color are developed in this part. The thickness is 42 m.

– Lower Huweimi Beds: Consist of white yellowish grey, massive, fairly hard, chalk to chalky limestone, alternated with thin horizons of grey, recrystallized fossiliferous limestone, partly sandy, especially in the uppermost part. The thickness of these beds ranges from (10 – 12) m.

The upper contact of this unit with the overlying Upper Huweimi Unit is unconformable; the contact is marked by (1 – 3 m) of breccias or conglomerate. In the area around and west of the Shbicha town the upper contact of this unit with overlying Zahra Formation is unconformable; the contact is marked by thick clastic sediments.

- **Middle Member:** It is subdivided into four units, as follows (from bottom to top):

1. Upper Huweimi Unit	Early Lutetian (Middle Eocene)
2. Shawiya Unit	Late Lutetian (Middle Eocene)
3. Chabd Unit	Late Lutetian (Middle Eocene)
4. Radhuma **–** Barabak Unit	Late Lutetian (Middle Eocene)

1. Upper Huweimi Unit: This unit is developed in the Southern Desert only, and cropping out along continuous ridge from west of Shbicha town in the northwest to the east and southeast of Takhadid water wells, in the eastern part. Lithologically, it is subdivided into two subunits:

– Lower Subunit: It consist of (1 – 3) m breccia or conglomerate, pebbles are mainly of grey fossiliferous limestone, cemented by calcareous and clayey materials, overlain by (0.5 – 2) m white to whitish grey, hard, well bedded, limestone occasionally intercalated with yellowish white marl to marly limestone. The upper part (3 – 5 m) consists of grey, yellowish white, hard, well bedded slightly rusty and chalky, recrystallized, fossiliferous dolostone and grey lithographic limestone, interbedded with yellowish white, chalky limestone(0.5 – 1) m with continuous large secondary calcite crystals and phosphatic pellets and fragments.

– Upper Subunit: The lower part consists of (0.2 – 1) m of grey highly weathered phosphatic limestone, overlain by (3 – 4) m of nummulitic, marly calcareous dolostone, with chert nodules. The middle part consists of (5 – 6) m of fossiliferous calcareous, grey, whitish grey slightly rusty, very hard, splintery well bedded silicified dolostone; occasionally with chert nodules. The upper part (4 – 5 m) consists of grey, hard to very hard, fossiliferous, well bedded, fragmented limestone with calcareous dolostone. The maximum thickness of the Upper Huweimi Unit is about (20 – 25) m.

2. Shawiya Unit: This unit is exposed as continuous ridge from west of Wadi Abu Khamssat, in the northwest to the north and northeast of Salman town then it is exposed south of Salman town till northeast of Takhadid water wells. It is characterized by high lateral variation in lithology. In the **northern part**, it consists of thickly bedded to massive, recrystallized, nummulitic limestone, alternated with thin horizons of saccharoidal limestone and

(2 – 3) horizons of shelly limestone. The nummulitic limestone is yellowish grey, whitish grey and creamy with pink patches, thickly bedded to massive, hard, with few chert nodules. The saccharoidal limestone is yellow to yellowish grey, bedded, fairly hard to hard, fossiliferous, occasionally with chert nodules. The shelly limestone is yellowish brown to brown, hard, thickly bedded to massive, silicified and blocky with chert nodules and fragments. In the **southern part,** it consists of yellow, massive, saccharoidal, fairly hard to hard, partly fossiliferous limestone, with chert nodules, alternated with yellowish brown hard to very hard, and thickly bedded, partly silicified, shelly limestone, with small chert nodules and fragments; locally, with lenticular horizons of red claystone. In the **southeastern part**, it consists of red to reddish brown, partly yellow, claystone, slightly silty, alternated with (1 – 2) lenticular horizons of yellowish brown to light brown, hard to very hard, thickly bedded, partly silicified, highly recrystallized, shelly limestone.

3. Chabd Unit: The lower part (15 – 20 m) consists of yellow, saccharoidal, hard, massive, sugary limestone, overlain by whitish grey, hard to very hard, thinly bedded, nummulitic limestone, followed by (11 – 14) m of yellow, white with pink patches, hard, massive and sugary, crystalline limestone, slightly marly. This sequence is alternated with (2 – 3) thin horizons of light grey to whitish grey, hard, thinly bedded, porous, recrystallized nummulitic limestone. The middle part (5 – 10 m) consists of alternation of thick horizons of white, hard to fairly hard, thickly bedded, porous, recrystallized, nummulitic limestone. The upper part (15 m) consists of whitish grey, hard, thickly bedded to massive, porous, highly recrystallized, nummulitic limestone, slightly marly.

4. Rudhuma – **Barabak Unit:** It is subdivided into two beds:

– Rudhuma Bed: Consist of light grey, yellowish to whitish grey, hard to very hard, thinly and thickly bedded, and highly recrystallized, shelly dolomitic limestone, slightly marly; alternated with light grey and white, very hard, splintery, blocky, cavernous, burrowed limestone, the burrows are filled by red and secondary calcite crystals. The thickness ranges from (12 – 15) m.

– Barabak Bed: Consist of white and yellowish white, fairly hard to hard, thickly bedded to massive, slightly recrystallized and fossiliferous, chalky limestone, with thin horizons and nodules of reddish brown and grey chert, alternated with white to whitish grey, hard, thickly bedded, highly fossiliferous limestone, which is partly chalky and marly. The thickness ranges from (25 – 27) m.

▪ **Upper Member:** This member, in the Southern Desert includes only one unit, it is:

– Ghanimi Unit: The lower part (10 – 15 m) consists of yellow to pale yellow, hard to very hard, thickly bedded to massive, cavernous, the cavities are filled by red claystone and secondary calcite crystals, and blocky fractured, slightly fossiliferous limestone, alternated with thin horizons of white to yellowish white with pink patches, fairly hard to hard, chalky to marly limestone. The middle part (10 – 15 m) consists of white with yellow patches, fairly hard, thinly bedded becomes thickly bedded to massive upwards, cavernous (the cavities are filled with secondary calcite crystals), slightly fossiliferous, marly to chalky limestone, alternated with pink and yellow saccharoidal limestone. The upper part (8 – 10 m) consists of greenish grey to yellowish grey, soft marl to marly limestone, rich with yellow and yellowish brown chert nodules overlain by grey and brown, hard, highly silicified and recrystallized limestone, rich with brown chert nodules and horizons. The thickness of this unit ranges from (35 – 40) m.

Al-Sharbati and Ma'ala (1983b) subdivided this formation in southwest of Busaiya vicinity into six units, using the same termination of Huber and Ramsden (1945) in Bellen *et al*. (1959). They are from bottom to top:

– Lower Huweimi Unit: The thickness of this unit is 2 m; it consists of whitish gray, fossiliferous limestone, locally, chalky and a discontinuous silicified limestone horizons cap this unit.
– Upper Huweimi Unit: The thickness of this unit is 11.2 m; it consists of bedded and massive, yellowish gray, crystallized, fossiliferous and dolomitic limestone, with nummulitic limestone. The Upper bed is yellowish creamy and chalky limestone with chert nodules.
– Shawiya Unit: The thickness of this unit is 15.5 m; it consists of light gray to white, bedded to massive, hard and nummulitic limestone, alternated with white massive recrystallized, sugary and chalky limestone, oyster shells were recorded from the upper part of the unit.
– Chabd Unit: The thickness of this unit is 11.5 m; it consists of whitish gray, hard fossiliferous and dolomitic limestone alternated with gray to white, fossiliferous limestone with chert nodules were recorded from the upper part of the unit.
– Radhuma – Barabak Unit: The thickness of this unit is 11 m; it consists of the lower part is an alternation of yellowish gray thickly to thinly bedded dolomitic limestone with chalky limestone. The upper part represented by gray thickly bedded dolomitic limestone; interbedded with fossiliferous and chalky limestone. The uppermost beds contain silicified beds, locally with chert nodules.
– Ghanimi Unit: The thickness of this unit is 16 m; the lower part consists of gray, thickly bedded, very hard, recrystallized and dolomitic limestone. The upper part consists of gray massive, fossiliferous dolomitic limestone, with silicified bands and chert nodules at the uppermost part of the unit. South of Samawa vicinity, Al-Ani and Ma'ala (1983a), recognized only four units of the formation; these are Shawiya, Chabd, Radhuma – Barabak and Ghanimi Units.

North of Busaiya vicinity, the exposed unit as described by Al-Ani and Ma'ala, (1983b) are:
– Radhuma – Barabak Unit: The lower part (5 m thick), is white to yellow, massive, highly cavernous dolomitic limestone. The middle part (1.5 m thick) is well bedded, marly dolomitic limestone. The upper part (3.5 m thick) is gray, massive, dolomitic limestone. Locally, in Wadi Qasair, the uppermost beds consist of alternation of dolomitic limestone and silicified limestone and chert nodules. The thickness of this unit is 11 m.
– Ghanimi Unit: The lower part (3.5 m thick) consists of yellowish and pinkish gray, hard, massive, recrystallized limestone of sugary texture. The upper part (4.5 m thick), consists of whitish gray and creamy, well bedded, fine crystalline dolomitic limestone. The thickness of the unit is 8 m.
Thickness: Dammam Formation shows variation in thickness of its units from place to another. The maximum thicknesses of Wagsa Unit is about 26 m, south of the Wagsa water wells and generally decreases towards northwest and reaches up to 16 m, in the southeast direction. Ansab Unit is (8 – 11) m thick. The thickness of Sharaf Unit varies from northwest to southeast, in Tar Al-Leefiyah the exposed thickness is about (3 – 4) m, while in the central part (north of Jill water well) and in the southeast part (north of Ansab) the maximum thickness reaches up to 20 m. The maximum thickness of the Shbicha – Lower Huweimi Unit is about 62 m around the Shbicha town. The Middle Member is (110 – 149) m thick, it includes the Upper Huwiemi Unit (20 – 25 m thick), Shawiya Unit is (20 – 44) m thick, Chabd Unit is (35 – 40) m thick, Radhuma – Barabak Unit (35 – 40 m thick) whereas, the Upper Member (Ghanaimi Unit) is about (35 – 40) m thick. In South of Samawa, the thickness of Shawiya, Chabd, Radhuma – Barabak and Ghanimi Units are (15 – 20) m, (25 – 30) m, (17 – 25) m and (7 – 12) m, respectively, and the total thickness of the formation is (54 – 87) m (Al-Ani and Ma'ala 1983a). In Southwest of Samawa, the thickness of the Lower Huweimi, Upper Huweimi, Shawiya, Chabd, Radhuma – Barabak and Ghanimi Units

are 2.2 m, 11.20 m, 15.5 m, 11.5 m, (17.5 – 25) m and 16 m, respectively and the total thickness of the formation is (74 – 80) m (Al-Sharbati and Ma'ala, 1983b). In north of Busaiya, the thickness of Radhuma – Barback and Ghanimi Units are 11 m, and 8.5 m, respectively.

Fossils: Different fossil assemblages were found in the Dammam Formation (Al-Hashimi, 1972; Raji and Said, 1984; Salman, 1984; Shaker, 1984; and Al-Hashimi and Amer, 1985) these are:

- **Lower Member:** Includes, *Nummulites frassi* **(**DE LAHARPE**),** *N. deserti* **(**DELAHARPE), *N. atacicus* (LEYMERIE*), N. planulatus* (LAMARCK), *Operculina libyca* (SCHWAGER*), Assilina* sp., *Lopha* cf. *sifa* (OQUARD), *Lopha* sp., *Mytilus* sp., *Ostrea* cf. *multicatats* (DESHAYES) and shells of pelecypods, gastropods and Echinoids**.**
- **Middle Member:** Includes, *Nummulites gizehensis zeitteli* (DE LAHARPE**)**, *N. discorbinus* (SCHLOTHEM), *N. perforatus* (MONTFORT), *N. perforatus var bayhariensis* (CHECCHIARISPOLI), *N. atacicus* (LEYMERIE), *N. irregularis* (DESHAYES), *Coskinolina basilliei* (DAVIES), *Coskinolina* sp., *Linderina brugesis* SHLUMBERGER, *Linderina* sp., *Alveolina elliptica* (SOWERBY), *A. elliptica var flosculina* (SILVESTRI), *A. lepidula* (SCHWAGER), *A. padermitana* (HOTIINGER), *A. oblongu var bassani* (CHECCHIARISPOL), *A. elliptica var nutal* (DAVIES), *Assilina spira* (DEROISS), *A. exponens* (SOWERBY), *Dictyoconoides cooki* (CARTER), *Lockartia alveolata* SILVESTRI, *L. condita* (NOTTAL), *Kathina* sp., *Orbitolites* sp., *Praerhapydionina* sp., *Rotalia trochidiformis* LAMARCK, *Textularia* sp., *Valvulina* sp., *and* miliolids, bryozoa, shell fragments, algae and echinoid spines.
- **Upper Member:** Includes the following fossils: *Articulina amphoralis* GRIMSDALE, *Articulina* sp., *Valvulina kitchini* HENSON, *Spirolina* cf. *cylindracea* (LAMARK), *Peneroplis gervillei* D'ORBIGNY, miliolids, gastropods, pelecypods and echinoid spines.

Age: The age of Dammam Formation is a matter of controversy between different authors. Bellen *et al*. (1959) estimated the age from the supplementary type section as Middle Eocene. Early – Late Eocene is not excluded as it is considered in the type locality in Saudi Arabia (Powers *et al*., 1966 in Buday, 1980). Al-Mubarak and Amin (1983) suggested Early – Late Eocene age (Early Ypresian – Early Priabonian) from most of the Southern Desert. Al-Ani and Ma'ala (1983b) suggested Middle – Late Eocene age (the lower part is not exposed) from north of Busaiya and south of Samawa vicinities. Al-Sharbati and Ma'ala (1983b) suggested Early – Late Eocene age from southwest of Busaiya.

Depositional Environment: The depositional environment of Dammam Formation was described by different authors in different localities. Buday (1980) concluded the environment, for the formation in the Western and Southern Deserts, to be mostly shallow neritic environment. Al-Mubarak and Amin (1983) described the depositional environment of the Lower Member of the formation as shoal facies of tropical – subtropical quiet marine, with depth not more than 100 m; the Middle Member as shallow marine tropical – subtropical with depth not more than 100 m and the Upper Member as near shore (Lagoon). In southwest of Busaiya, it is tropical and subtropical marine with depth not more than 20 m (Al-Sharbati and Ma'ala, 1983b). In south of Samawa, it is tropical and subtropical marine (Al-Ani and Ma'ala, 1983a). Jassim *et al*. (1984) described the environment to be started with shallow marine of inner shelf to shelf depth followed by well defined warm normal marine conditions, giving rise to extensive shoals of large nummulites and mollusk fauna. These conditions were of higher salinity, as indicated by abundant miliolids and alveolinids. Al-Hashimi and Amer (1985) suggested typical restricted marine platform (lagoon) facies prevailed over the area of the Dammam Formation deposition, which characterized by dolomitic limestone and dominant occurrences of miliolids and peneroplis.

Lower Contact: The lower contact of the formation is not exposed in majority of the exposed area; Wagsa Unit of the Lower Member is unconformably underlain by the Umm Er Radhuma Formation. The contact is based at the bottom of thick yellowish green, flaky marl (Al-Mubarak and Amin, 1983). In the subsurface sections in Basrah vicinity, the Dammam Formation is underlain unconformably by the Rus Formation, while westward in Salman vicinity, the Rus Formation (anhydrite) is most probably leached out by solution, leading to extensive collapse structures and cavities, characterizing the outcrop area (Bellen *et al*., 1959; Buday, 1980 and Sissakian and Abdul Jabbar, 2001).

Remark about the Rus Formation in the Southern Desert

Al-Mubarak and Amin (1983) observed that the Wagsa Unit of the Early Ypresian age is interfingering with the Rus Formation in one locality (Kibritiya sinkhole), and in Umm Al-Hashim Borehole (KH 2), the Late Ypresian age is represented by interfingering of the Rus Formation with the Shbicha – Lower Huweimi Unit of the Dammam Formation (Abdul Muniem, 1983). According to this relation, the Rus Formation should be equivalent to the Lower Member (Wagsa, Sharaf and Shbicha – Lower Huweimi Units) of the Early Eocene age of the Dammam Formation, in the Southern Desert.

1.3. OLIGOCENE

The Oligocene sediments in Iraq have a relatively restricted area of distribution, with reduced thicknesses. No rocks are exposed in the Southern Desert due to the uplifting of the Salman Zone and the Euphrates and Zubair Subzones of the Mesopotamian Zone in Oligocene time (Jassim and Buday, 2006 in Jassim and Goff, 2006).

2. NEOGENE

2.1. MIOCENE

The Savian movements caused development of broad and shallow basins in which carbonates were deposited, whereas in the coastal parts clastics were deposited. Both deposits pass to each other laterally indicating irregular shore line of the basin (Sissakian and Mohameed, 2007). Three formations represent this period, they are described hereinafter:

2.1.1. Euphrates Formation (Early Miocene)

Type Locality: The type locality of the formation is in the Western Desert along Wadi Fhami (Bellen *et al*. 1959); it is defined by the following coordinates:

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

This type section is inundated by Haditha Dam Lake. Therefore, a supplementary type section was recommended by Jassim *et al*. (1984) in Wadi Chab'bab, in Anah vicinity for the Lower and Upper Units (A and B) and another supplementary type section in Wadi Rabi, in Anah vicinity for the Upper Unit (C). Sissakian *et al*. (1997) found that the Upper Unit (C) was found to be a different formation, which was named as the Nfayil Formation (Sissakian *et al*., 1997).

Exposure Areas: Euphrates Formation crops out in different parts of the Southern Desert and generally trending from northwest (west of Al-Rahba town) to the southeast (northeast of Al-Salman town) for a distance of about 160 Km southeastwards of Taq-Taqana, which is located about 60 Km west of Al-Najaf (Fig.2). The last exposures of the Euphrates Formation in the Southern Desert are about 120 Km south of Al-Nasiriya (Fig.2). In Al-Busaiya vicinity, there it is interfingering with the Ghar Formation in a very complicated exposure pattern, and therefore it is mapped together with the Ghar Formation as Euphrates – Ghar Formation.

Lithology: Bellen *et al*. (1959) described the Formation in the type locality as "shelly, chalky, recrystallized and dolomitized limestone, generally massive, with beds ranging in thickness from (1 – 2) m". Al-Mubarak and Amen (1983) subdivided the Euphrates Formation in the Southern Desert in to three units, based on the lithological and physical variations: Lower, Middle and Upper Units. The Lower and Middle Units are exposed in the northern part of the Southern Desert only .The Upper Unit is exposed in the northeastern and eastern parts of the Southern Desert.

– Lower Unit: It is exposed in the northern part of the Southern Desert only, the thickness of this unit ranges between (10 – 16) m. Geomorphologically, it is characterized by cliff forming along valley banks. Lithologically, it is composed of (4 – 6.5) m, occasionally reaches up to 8 m of basal breccia that consists of white, chalky limestone with shell and shell fragments. The fragments are subangular to subrounded, ranging in size from (1 – 5) cm, cemented by carbonate and sandy materials. Overlain by 3.5 m of alternation of well thinly bedded (thickness of each is 5 – 15 cm), becomes thicker upwards, of pinkish grey, cross bedded, fine grained calcareous sandstone; pink, partly yellow, sandy limestone and green conchoidally fractured claystone. Overlain by (4 – 5) m of white, at lower part, slightly pink at the upper part, hard, massive, cavernous sandy and chalky limestone, with pelecypod and gastropod shells.

– Middle Unit: It is exposed in the northern part of the Southern Desert only (the same areas of the Lower Unit). The thickness of this unit is about (10 – 16) m. Geomorphologically, this unit is characterized by semi flat terrain, with some isolated hilly topographic areas. Lithologically, the lower part of this unit is composed of (3 – 6) m of basal conglomerate or pebbly sandstone, overlain by (3 – 5) m marl or marly limestone, partly sandy, with few oyster shells. Overlain by (3 – 5) m of white, cross bedded coquina, mainly of peleycypod and gastropod shells.

– Upper Unit: It is exposed in the northeastern and eastern parts of the Southern Desert and overlain resting directly over the Dammam Formation. The maximum thickness of this unit is about (20 – 25) m. Geomorphologically, this unit forms isolated hills and continuous ridges, because the soft constituents form the major parts of this unit. Lithologically, the base of this unit is composed of (2 – 3) m either of red claystone or basal breccia. The rest of this unit is composed of alternation of thick horizons of greenish grey, soft, well laminated to papery marl, at lower part, massive at the middle and upper parts, slope forming with oyster shells. In some places, the Upper Unit is capped by (1.5 – 2.0) m of white and brown recrystallized shelly limestone partly sandy.

Remark: The authors believe that this unit belongs to the Nfayil Formation.

Thickness: Al-Mubarak and Amin (1983) recorded a thickness of about (40 – 51.5) m in the western part of the Southern Desert. Its exposed thickness south of Samawa is 6 m (Al-Ani and Ma'ala 1983a), while in north of Busaiya is 5 m (Al-Ani and Ma'ala, 1983b). In subsurface section in Kifil Oil Well 1, the measured thickness of Euphrates Formation is about 50 m.

Fossils: Al-Hashimi and Amer (1977); Abdul Munium (1984); Shaker (1984); and Salman (1984) found the following fauna:

Miogypsina intermedia MICHELOTTI, *Miogypsina globulina* MICHELOTTI, *Quinqueloculina angulars* DORBIGNY, *Q. seminulum* LINNE, *Q. collumesa* CUSHMAN, *Q. quadrata* NORUANG, *Triloculina* cf. *trigonula* LAMARCK, *Spiroloculina limbata* DORBIGNY, *Spirolina cylindracea* LAMARCK, *Ammonia baccarrii globules* COLOM, *A. baccarrii koeboenisis* LEORY, *A. baccarrii parkinsoniana* D'ORBIGNY, *Rotalia convexa* LEORY, *Elphidium articulatum* DORBIGNY, *E. avarezianum* DORBIGNY,

E. chepolense CUSHMAN, *E. minutum* REUSS, *E. taiwanum* NAKAMURA, *Nonion densepunctatum* EGGER, *Discorbis* sp.
Barbatia varvata LINNE, *Cardium facetum* ZHIZCHENKO, *Cultellus prolus* MERKLIN and *Nucula nucleus prolus* MERKLIS.
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*.
Depositional Environment: The Euphrates Formation is deposited in marine, warm tropical to sub tropical environments, with reef – back reef, near shore (10 – 50 m) depth; the shelly beds indicate shallowing events during the whole depositional period of the Euphrates Formation (Al-Mubarak and Amin, 1983 and Al-Hashimi and Amer, 1985). The interfingering of the Euphrates Formation with the Ghar Formation indicates near shore areas, which are under the influence of fresh water sedimentation.
Lower Contact: In the Southern Desert, the Euphrates Formation is underlain unconformably by the Dammam Formation. The contact is sharp and clear, marked by basal breccias; which are (4 – 6.5) m thick and occasionally reaches 8 m. The fragments are composed of white marly limestone, nummulitic, recrystallized, and silicified with some chert fragments. The fragments are subrounded, reaching in size up to 20 cm, cemented by carbonate materials.

2.1.2. Ghar Formation (Early Miocene)

Type Locality: Ghar Formation was described by Owen and Nasr (1958) in Bellen *et al*. (1959) from B.P.C. oil well Zubair 3. It is defined by the following coordinates:

Longitude 47º 43' 29" E
Latitude 30º 23' 01" N

Exposure Areas: The first appearance of the Ghar Formation in the Southern Desert as interfingering within the Euphrates Formation is in the eastern bank of Faidhat Umm Al-Hashim. The Ghar Formation is well developed in Wadi Abu-Ghar, then extends towards southeast, as discontinuous ridge till east of Faidhat Al-Shawiya (northeast of the Salman town) (Al-Mubarak and Amin, 1983). It is exposed south of Najaf, south of Samawa, north, south and southwest of Busaiya **(**Al-Sharbati and Ma'ala, 1983a and b and Al-Ani and Ma'ala, 1983a) (Fig.2).
Lithology: In the northwestern part of the Southern Desert (South Najaf), Al-Mubarak and Amin (1983) described the Ghar Formation as" the base is composed of (2 – 3) m thick of either basal breccia or red claystone. The basal breccia is whitish gray fairly hard composed of fragments of buff and whitish gray nummulitic limestone; yellow recrystallized limestone; greenish gray marly to chalky limestone; silicified limestone and some chert fragments. The fragments are subangular to subrounded, ranging in size from few centimeters up to 8 cm in diameter; in some places reach more, cemented by sandy, clayey and calcareous materials. The claystone is reddish brown to dull brown in color, highly weathered, conchoidally fractured and forming slopes. Generally, the claystone beds are sandy and contain either lenses or thin lenticullar horizons (thickness of each is 5 – 15 cm) of brownish gray to dirty brown siltstone to fine grained calcareous sandstone. The rest of the sequence consists of alternation of pebbly sandstone, partly conglomeritic, calcareous sandstone and sandy limestone. The pebbly sandstone horizons (thickness of each is 1 – 2.5 m) are pink, yellow and brownish gray, fairly hard, the pebbles consist of different rock fragments and occasionally small pelecypod and gastropod shells fragments are present. The pebbles are rounded to subrounded, ranging in size between (1 – 10) cm, cemented by sandy, clayey and calcareous materials. The recrystallized sandy limestone horizons (thickness of each is 1.0 – 1.5 m) are whitish gray, creamy and partly pink on fresh surface, yellowish brown on

weathered surface, hard to very hard, splintery, thickly bedded (0.5 – 1.0 m) at lower part, massive at the top, highly jointed and fractured, fragmented, partly silicified, slightly marly. The sandy limestone horizons are rich with burrows and partly contain fossils (mainly small gastropods and miliolids). In south Samawa area and Busaiya vicinity, Ghar Formation is composed of well bedded and massive, blocky, grayish white and gray dolomite and dolomitic limestone (about 6.0 m thick) at the lower part. The upper part is composed of white to grayish white massive, hard, calcareous sandstone; overlain by grayish white sandy limestone (1.0 m thick) with fine burrows filled by dark recrystallized calcareous material. The total thickness of this part is about 5.0 m (Al- Ani and Ma'ala, 1983a and Al-Sharbati and Ma'ala, 1983a and b).

Thickness: The thickness of the Ghar Formation in the Southern Desert ranges between (10 – 26) m; the maximum thickness is about 17 m, in Wadi Abu-Ghar (Al-Mubarak and Amin, 1983). It is 12 m in Samawa area and 26 m in Busaiya area **(**Al-Sharbati and Ma'ala, 1983; and Al-Ani and Ma'ala, 1983). In subsurface sections, it is 175 m in Jraishan, 129 m in Khiddr Al-Mai and 129 m in Zubair Oil Well 3.

Fossils: According to Owen and Nasr (1958) in Bellen *et al.* (1959); Buday (1980); Al-Sharbati and Ma'ala (1983a and 1983b), no fossils were recorded in Ghar Formation. According to Al-Ani and Ma'ala, (1983a) the following fossils were recorded: reworked *Nodosaria* sp., *Textularia* sp., ostracods, pelecypods, gastropod shells and echinoid spines. Karim in Jassim *et al*., (1984), recorded the following fossils: abundant shell fragments, *Peneropli*s sp., and *Ammonia beccarii* LINNE, miliolids, charaphytes, reworked planktonic and large amount of organic mater.

Age: Owen and Nasr, (1958) stated the age of Ghar Formation as Oligocene – Miocene, while Bellen *et al*. (1959) assigned Middle Miocene age. Al-Naqib (1967) claimed it as Early Miocene. Ditmar *et al*. (1972) in Buday (1980) considered original age of Oligocene – Early Miocene. Amer (1976) and Abdul Muniem (1983) claimed the age of the Ghar Formation as Early Miocene, according to its stratigraphic position. Buday (1980) claimed late Early Miocene age depending on the age of the Euphrates Formation. Jassim *et al*. (1984) claimed Early Miocene age (Upper Burdigalian) on surface sections.

Depositional Environment: The Ghar Formation represents fluvio-marine environment possibly of deltaic origin, ranging from delta top to inner shelf conditions (Amer, 1976 and Abdul Muniem 1983).

Lower Contact: The Ghar Formation overlies unconformably many formations, Umm Er Radhuma Formation, in Wadi Ubayidh and the Dammam Formation near Busaiya, the contact is marked by basal conglomerate (Al-Mubarak and Amin, 1983; Al-Sharbati and Ma'ala, 1983a and b and Al-Ani and Ma'ala, 1983a)**.**

2.1.3. Nfayil Formation (Middle Miocene)

The Nfayil Formation was previously known as the Lower Fars Formation in the Southern Desert, but due to the absence of evaporite beds from the lithological sequence, it is recently renamed by Sissakian *et al.* (1997) as Nfayil Formation**.**

Type Locality: The type locality of the Nfayil Formation is of composite type. The Lower Member is defined from "Garat Al-Nfayil", which is located 23 Km west of Haditha town. The following coordinates define it:

Longitude	42 º	24'	10"	E
Latitude	34º	07'	30"	N

Whereas, the Upper Member is located at about 3 Km south of Al-Habbaniyah Lake and defined by the following coordinates:

Longitude 43 º 27' 30" E
Latitude 33º 10' 00" N

Exposure Areas: It is exposed in north and south of Busaiya area, south of Samawa and west of Zubair areas (Al-Ani and Ma'ala 1983b and Al-Sharbati and Ma'ala 1983b) and described it as Fat'ha Formation. South of Al-Nasiriya it covers an area about 70 Km in length and 30 Km in width (Sissakian, 1999).

Lithology: Nfayil Formation around Busaiya area is subdivided by Al-Ani and Ma'ala (1983b) into two members depending on its lithology:

– **Lower Member**: It is 5.25 m thick composed of claystone beds, grayish green, massive, alternated with thin beds of fossiliferous marly limestone. The sequence is underlain by basal conglomerates (0.30 – 0.75 m thick) composed of sandy limestone and iron oxide fragments, cemented by calcareous and sandy materials. The upper part of this member, (5.50 m thick), is composed of alternation of green claystone and yellowish brown calcareous sandstone. These beds are capped by massive fossiliferous marly limestone, (1.20 m thick), which laterally becomes more sandy towards south and disappear at Khashmat Al-Haniya. Generally, the sequence of the Lower Member wedges out gradually towards south of Busaiya and replaced by the Upper Member.

– **Upper Member:** It consists of 9.65 m thick of alternation of yellowish grey and reddish brown sandstone with reddish brown and green claystone. These beds are well developed towards north and interbedded with many horizons of fossiliferous marly limestone, (0.3 – 0.5) m thick. The upper part of the Upper Member, (11.5 m thick), is composed of alternation of green and reddish brown claystone layers (thickness of each layer1.5 m) with pale yellow and reddish brown sandstone (thickness of each layer is 0.5 – 1.5 m), the upper most beds are massive pebbly sandstone, overlain by two horizons of fossiliferous marly limestone.

Towards the west of Busaiya area, the exposed thickness of the formation is 3.0 m, it is composed of 1.8 m pale green, fine to very fine grained calcareous sandstone and 1.2 m of brown to dark brown, massive, claystone (Al-Sharbati and Ma'ala 1983b). In south Samawa area the formation is composed of 3.0 m thick, greenish gray massive sandy marl, capped by 0.5 m thick of whitish gray cavernous dolomitic limestone, highly fractured filled with selenite (Al-Ani and Ma'ala, 1983b). Al-Mubarak and Amin (1983), described sequence of (20 – 25 m) of either red claystone or basal breccia, and thick horizons of greenish grey, soft, well laminated to papery marl, at lower part, massive at the middle and upper parts, with oyster shells, as "Upper Unit" of Euphrates Formation, which the authors believe it belongs to Nfayil Formation.

Thickness: The total thickness of the Lower Member in north of Busaiya is 15.25 m. (Al-Ani and Ma'ala, 1983b), west of Busaiya 3.0 m and 21 m towards north of Busaiya (Al-Sharbati and Ma'ala 1983 a and b).

Fossils: The fossils found in the Lower Member are: *Ammonia beccarii* LINNE, *Peneroplis farsensis, Quinqueloculina* sp., *Rotalia* sp, *Cytheropteron* sp. and *Ammonia beccari parkinsoniana* (D'ORBIGNY), gastropods, pelecypods, echinoid spins and plates. While the fossils of the Upper Member are: *Quinqueloculina* sp., *Elphidium* sp., *Peneroplis* sp., *Textularia* sp., *Pyrgo* sp., *Cytherella* sp., and calcareous algae, bryozoa, shark teeth, and recrystallized fossils (Salman, 1984 and shaker, 1984).

Age: The age of Nfayil Formation, depending on the fossils content, is Middle Miocene which is equivalent to Fat'ha Formation (Sissakian *et al*., 1997 and Sissakian and Mohammed, 2007).

Depositional Environment: The Nfayil Formation was deposited in shallow marine environment with normal salinity. The upper part of the Upper Member may indicate near shore environment with some deltaic influence as indicated by the type of clastics (fining upwards and reddish brown color) of the upper most part of the formation (Sissakian *et al*., 1997).

Lower Contact: The Nfayil Formation is underlain conformably by Euphrates Formation; the contact is based on the base of green marl, over the recrystallized limestone of the Euphrates Formation (Al-Mubarak and Amin, 1983). In Busaiya vicinity a horizon of basal conglomerate or pebbly sandstone was described by Al-Ani and Ma'ala, 1983b. The thickness of the conglomerate horizon is (0.3 – 0.7) m, most probably it represents a local break or special development in the basin of the deposition (Sissakian, 1999).

2.2. Pliocene – Pleistocene

The Southern Desert, during Pliocene – Pleistocene was still uplifted area, due to collision of the Arabian Plate with the Neo-Tethys terrains. Therefore, continental, fluvial deposits prevailed over the considered area. The Pliocene Epoch is represented by two formations as follows:

2.2.1. Dibdibba Formation (Pliocene – Pleistocene)

Type Locality: The type locality of the Dibdibba Formation is in Birjisiya, south of Basrah, it is defined by the following coordinates (Mcfayden, 1938 in Bellen *et al*., 1959):

Longitude 47º 38' 00" E
Latitude 30º 22' 00" N

A supplementary type section was introduced by Owen and Nasr (1958), in Bellen *et al*. (1959) from Zubair Oil Well 3, with thicker development (305 m thick).

Exposure Areas: The Dibdibba Formation is exposed between Busaiya and Iraqi – Kuwait and Saudi Arabian borders. The formation is exposed at the eastern area of Wadi Abu Ghar and form extensive flat and slightly wavy terrain, in Busaiya vicinity and west of Zubair area (Al-Sharbati and Ma'ala, 1983a and b). In southwest of Busaiya area, it occupies a huge uvala karst and doline karst features which are common in the area (Al-Sharbati and Ma'ala, 1983a and Al-Ani and Ma'ala, 1983b) (Fig.2).

Lithology: Dibdibba Formation, in the type locality, is composed of poorly sorted sand, sandstone and gravels of igneous rock (Macfadyen, in Bellen *et al.*, 1959). Sadik (1977 in Jassim *et al*., 1984) indicated that, the Dibdibba Formation in the southern and central parts of Iraq is composed of sand, sandstone and gravels, poorly sorted. The sands and sandstones are composed of 84.2% quartz of monocrystalline and crystalline grains, with 8.5% of rock fragments and 7.3% of feldspar. The Dibdibba gravels consist mainly of acidic and intermediate igneous rocks (granite, granodiorite, rhyolite, andesite), quartz with smaller amount of sandstones, metamorphic rocks, limestone and chert. In north Busaiya, Al-Ani and Ma'ala (1983b) described the Dibdibba Formation from composite section as "conglomeratic sandstone, partly cemented by calcareous material, followed by interbedding of sandstone, and gravely sandstone. The sandstone is massive, yellowish grey, whitish grey and partly consolidated. The gravels are of quartz and igneous rocks. In south Busaiya, the Dibdibba Formation is composed of gravely sandstone, grey and brownish grey, consolidated. The sandstone is fine to coarse grained, cemented by calcareous and gypsiferous materials at the upper part, the gravels are rounded to subrounded, variable in size and composed mainly of quartz and igneous rock fragments (Al-Sharbati and Ma'ala, 1983a). Tamer-Agha (1984), described the formation from two boreholes (Butaiya and Richi) located 10 Km north of Butaiya police station as "white and pale grey quartzose sandstone, coarse to medium, some

times pebbly, friable and cemented by fine crystalline calcite". In Al-Richi borehole, the formation is divided into two units. The **Lower Unit** (48 m thick) consists of sandstone, yellowish brown some times clayey with some pink gravel. The **Upper Unit** (33 m thick) it has similar lithology but with less clay and generally is more gravely.

Thickness: The thickness of the Dibdibba Formation is variable; it is 354 m in Zubair Oil Well 3, in Kidder Al-Mai well 58 m, in Jraishan well 90 m, in Rumaila 354 m and Tuba 273 m, and in Ratawi well 140 m (Jassim *et al*., 1984). On surface exposures, it is (2 – 9) m in north Busaiya, 17 m in south Busaiya and (3 – 8) m in Zubair area (Al-Sharbati and Ma'ala, 1983a; Al-Ani and Ma'ala, 1983b).

Fossils: No fossils were found in Dibdibba Formation in southwest of Busaiya (Al-Sharbati and Ma'ala, 1984). In north of Busaiya, some un-identified vertebrate remains, chara, ostracods and *Planorbis* sp., were recorded (Al-Ani and Ma'ala, 1984b**).**

Age: The age of the Dibdibba Formation is not ascertained yet, it is assumed to be Late Miocene – Pliocene to early Pleistocene (Bellen *et al*, 1959), Jassim *et al*., 1984 and Jassim and Buday in Jassim and Goff, 2006 claimed? Upper Miocene – Pliocene age. The age is suggested as Pliocene – Pleistocene by Al-Ani and Ma'ala, (1983b); Al-Sharbati and Ma'ala (1984a) and Sissakian and Mohammed (2007). Tamer-Agha (1984), suggested Upper Miocene for the Dibdibba Formation in Butaiya area.

Remark: The authors did not accept the late Miocene for the Dibdibba Formation and agree with the Pliocene – Pleistocene, due to its interfingering with Zahra Formation as mentioned later.

Depositional Environment: Sadik (1977 in Jassim *et al*., 1984) suggested the environment of the Dibdibba Formation to be fluviatile based on the grain size analysis, shape and size of the gravels and the sedimentary structure. According to Jassim *et al.* (1984), Dibdibba Formation represents fluvial sedimentation in extensive sheet probably as large old alluvial fans. From thickness studies, it seems that at least two such fans may be considered. Salman (1984), assumed a fresh water environment to the formation according to its fossil contents. Jassim and Buday in Jassim and Goff (2006) suggested that the formation was deposited in a fresh water environment, becoming deltaic some times.

Lower Contact: The Dibdibba Formation overlies unconformably different units of the Dammam and Ghar formations in Busaiya area (Al-Sharbati and Ma'ala, 1983a).

2.2.3. Zahra Formation (Pliocene – Pleistocene)

Type Locality: The name Zahra Formation was introduced by Williamson (1941) in Bellen *et al.* (1959) from the type locality in Faidhat Al-Zahra west of Busaiya. It is defined by the following coordinates:

Longitude 45º 27' 54" E
Latitude 30º 13' 12" N

Exposure Areas: The Zahra Formation occurs in the Southern Desert in Faidhat Al-Shifalahiya, Ghanimi, Faidat Al-Radhaim, Chabd, Galaib Shawiya, Faidhat Al-Zahra and Al-Maanniya (Al-Sharbati and Ma'ala, 1983a and 1983b, Al-Ani and Ma'ala 1983b and Al-Khateeb, 2008). Jassim *et al.* (1984) mentioned that the distribution of the Zahra Formation is extensive in the Southern Desert, especially between Al-Salman and Busaiya areas. It is always present in some topographically lower areas than the surrounding older rocks.

Lithology: Generally, the formation consists of white and red limestone, locally sandy, red and purple sandy marls, calcareous sands (Bellen *et al.*, 1959 and Buday, 1980). Al-Mubarak and Amin (1983) mentioned that the Zahra Formation in the Southern Desert is composed of (1 – 3) cycles, except in west and south of Tar Al-Leefiyiah; there it consists of 6 cycles.

Generally, each cycle is composed of either alternation of a claystone, and limestone or alternation of claystone, sandstone, and limestone. The claystone beds (thickness of each bed is 4 – 5 m and reaches up to 8 m in the western part of Tar Al-Leefiyiah area) are red to reddish brown and dark brown occasionally greenish grey at upper part, soft, conchoidally fractured. The sandstone beds (thickness of individual bed ranges between 1– 4 m) are light brown to yellowish brown, partly friable, massive, medium to coarse grained, cemented by calcareous and gypsious materials. The limestone beds (the thickness is between 0.5 – 4 m, occasionally reaches up to 10 m, in western part of Tar Al-Leefiyiah area) are white to whitish grey and pink, hard to very hard, bedded, undulated, highly jointed, highly recrystallized, rich with burrows, partly sandy and fossiliferous. Al-Ani and Ma'ala, (1983a) and Al-Sharbati and Ma'ala (1983b), described the formation in south of Samawa and southwest of Busaiya, respectively, as one cycle only, as follows: The **lower part** is composed of reddish brown massive sandy claystone. The clastic increase, in thickness towards south, It is locally intrbedded with two horizons (up to 0.5 m thickness of each) of pinkish to reddish grey, fine crystalline limestone, with lenses of calcareous sandstone. The **upper part** is composed of massive (up to 1.5 m thick) pinkish to reddish grey, recrystallized, burrowed limestone. Al-Haza'a (1996) studied the type section of Zahra Formation, and divided it into two units as follows: **Clastic Unit,** it is consists of (0.2 – 1.7) m of claystone, reddish brown, conchoidally fractured massive, partly sandy. Overlain by (2 – 7.5) m of yellowish white sandstone; friable to moderate hard with quartz and rock fragment become sometimes gravelly in the base. **Calcareous Unit**, it consist of (1– 8) m of light pink or bluish grey, massive, hard, splintery limestone with borrows.

Thickness: The thickness of the Zahra Formation in the type locality is 30 m (Bellen *et al*., 1959). The exposed thickness in South of Samawa is (3.50 – 14.5) m (Al-Ani and Ma'ala, 1983a), in north of Busaiya is (2.5 – 4.0) m, in South of Busaiya is 1.0 m, in southwest of Busaiya is (4 – 25.7) m and in Zubair area is (1.20 – 1.70) m (Al-Sharbati and Ma'ala, 1983a and b), in Tar Al-Leefiyiah is 45 m (Al-Mubarak and Amin, 1983). Salman (1993) stated that the thickness of the formation in the type locality is about (26 – 31) m, Al-Haza'a (1996) mentioned that the thickness of the Clastic Unit of the formation ranges from (0.2 – 7.5) m, while the thickness of the Calcareous Unit ranges from (1 – 8) m.

Fossils: Bellen *et al*. (1959) and Salman (1993) recognized the following fossils from the type locality: *Chara* sp. *Melanoides tuberculation* MUELLER, *Planorbis* sp., *Viviparous* sp., tubular holes probably of reed stalks. While, Salman (1984) recorded the following fossils from Samawa area: *Planorbis* sp., charaphytes, pelecypods and gastropods. Al-Sharbati and Ma'ala, (1983a), mentioned the following fossils: charaphytes, *Planorbis* sp., ostracods and shell fragments.

Age: The age of Zahra Formation is claimed to be probably Late Miocene – Pliocene (Thompson, 1957 in Bellen *et al*., 1959); Late Miocene or younger is claimed by Bellen *et al.* (1959). Al-Mubarak and Amin (1983) claimed at least Pliocene age for the Zahra Formation, in the Southern Desert indicating by its occurrence in the central parts of the closed karsts depressions and it is accumulated after the karstification of the gypsum. Al-Ani and Ma'ala (1983) and Al-Sharbati and Ma'ala (1983a and b), reported that the Zahra Formation may represent a lateral facies of Dibdibba Formation, so they have the same age (Pliocene – Pleistocene). Al-Ani and Ma'ala (1983b), suggested Pliocene – Pleistocene age in the north of Busaiya, according to its stratigraphic position because it overlies the Fat'ha Formation and passes laterally into Dibdibba Formation. Jassim *et al.* (1984) denoted that the presence of a tongue of limestone similar to those of Zahra Formation in Dibdibba Formation suggests that the two formations are laterally equivalent at least in parts. However, Salman (1993) claimed

Pliocene – Pleistocene age according to its lateral relation with Dibdibba Formation. Jassim and Buday in Jassim and Goff (2006) claimed Late Miocene – Pliocene age.

Remark: The authors believe that the age of the Zahra Formation is Pliocene – Pleistocene.

Depositional Environment: The Zahra Formation according to Bellen *et al*. (1959) is of fresh water environment, the fossils evidence confirm their opinion. Al-Mubarak and Amin (1983) indicated that the formation is deposited in fresh water fluviatile environment. From paleogeographical points of view, the Zahra Formation may have been deposited in water logged marshy area, at the margin of the floodplains of the Dibdibba Formation (Jassim *et al*., 1984). Salman (1993) mentioned that the formation seems to be deposited in fresh water lacustrine conditions. The Zahra Formation is considered by Jassim and Buday in Jassim and Goff (2006) as fluvio – lacustrine and karst fills facies, due to the presence of reed stalks.

Lower Contact: The Zahra Formation overlies Dammam Formation with an abrupt change from carbonate to reddish brown claystone. It also overlies the Euphrates and Ghar formations and the contact is characterized by the presences of light brown calcareous sandstone (Al-Mubarak and Amin, 1983). Jassim *et al*. (1984) mentioned that the formation laid on Umm Er Radhuma, Dammam, Ghar, Euphrates and Fat'ha formations unconformably.

3. Quaternary Sediments

The Southern Desert is generally flat with hilly terrain. The Quaternary sediments are limited in extension. Many types of sediments were developed in different parts of the Southern Desert, such as:

– **Terraces (Pleistocene)**

The terraces are present on both banks of main valleys in the Southern Desert, such as Al-Khir, Hussab, Al-Farij, Al-Daawahi and Al-Karaz (Al-Mubarak and Amin, 1983). Two levels of terraces were also found in north of Busaiya area and also in Wadi Abu-Ghar and Wadi Sdair. They are composed of gravels with sand, silt and gypcrete. The gravels of all valleys are of sedimentary rocks, except that of Wadi Al-Khir contains some igneous rocks. The pebbles are rounded to subrounded and range from few millimeters up to 5 cm in diameter. Occasionally reach up to 15 cm. in Wadi Al-Khir (Al-Ani and Ma'ala, 1983a and b and Al-Sharbati and Ma'ala, 1983a and b).

– **Gypcrete (Pleistocene)**

The gypcret is developed in the Southern Desert, in south of Samawa, north of Busaiya, south and southwest of Busaiya and Zubair areas, and form a cap rock over the Dibdibba Formation. The gypcrete indicates deposition in an arid climate. The thickness ranges from (0.5 – 1.0) m.

– **Alluvial Fan Sediments** (**Pleistocene)**

The deposits are composed of gravels (different sizes and shapes) of carbonate rocks mixed with sands and gypcrete. The most important and biggest alluvial fan in the Southern Desert is Al-Batin Fan. Wadi Al-Batin is an ideal condition for fan formation, typical for desert areas. It shows no abrupt change in slope. Therefore, deposition was as a result of change in channel width and loose in volume as stream flows over the fan (Bull, 1973 and Jassim *et al*., 1984). The cone of the fan is limited by Hor Al-Hammer along its northern margin and Khor Al-Zubair along the southwest. Al-Batin Fan sediments are asymmetrical shaped and has radial channel distribution from the apex. They are composed of unconsolidated sand and gravel, which are mainly derived from Pliocene and Pleistocene strata that occur in the northern part of Saudi Arabia. The Fan sediments are underlain by Miocene and Pliocene – Pleistocene formations; Dibdibba Formation in particular (Jassim *et al.*, 1984). Al-Sharbati and Ma'ala (1983a) divided the fan sediments into four stages. In

this subdivision, a distinctive gradational fining, in gravel size and an increase in sand percentage is recorded towards the periphery. The sediments are composed essentially of gravelly sand, sandy gravel (composed of quartz and feldspar) and gypcrete with subordinate layers and lenses of silty and sandy clay. The size of the gravels reaches up to 20 cm, the clastics are poorly sorted and generally rounded exhibit common sedimentary structures with dominant cross bedding and channel lag sediments.

– Valley Fill Sediments (Holocene)

The main valleys are filled by different sediments, which are highly variable in the composition, size and thickness. The floor of the deep valleys are narrow and filled by gravel and rock fragments, the gravels are rounded ranging in size up to (15 – 20) cm. Sandy and clayey materials also occur in these valleys, which cause the cementation of the gravels. Many valleys are shallow and they are filled by silty and clayey materials with some sand grains and small pebbles due to the small amount of water flowing through them. The thickness varies from few cm to 1m.

– Depression Fill Sediments (Holocene)

They form flat areas, which are known as "Playa or Faidhah". They are rounded, elongated and oval in shape. The sediments are mainly of clay and silt rich in SO_4. The thickness is (0.5 – 1.5) m.

– Wind Blown Sands (Holocene)

These are developed as sand dunes or longitudinal pattern of sand sheet. There are two types of sand dunes. First, the fixed sand dunes, which are characterized by loose, fine to medium grained quartz, with lamination and cross bedded in all directions, and it is light brown in color. Second, active sand dunes, which are loose, fine to very fine grained quartz and clayey materials; without any sedimentary structure, grey to greenish grey in color. The sand sheets are composed of loose, medium to coarse grained quartz and igneous rocks, well rounded grains and locally mixed with gypcrete sediments.

4. Jabal Sanam Rock Unit

Jabal Sanam is an isolated hill; 100 m high and 2 Km in diameter, located about 5 Km west of Safwan town on the Basrah – Kuwait highway. Vertically dipping sandstone beds of Didibba Formation (Pliocene – Pleistocene) are exposed as visible to about 5 Km around the hill. The main body of Jabal Sanam consists of variably dipping cross cutting slope sediments containing a mixture of rocks, passing into a gently inclined pediment that radiates and extends a few kilometers from Jabal Sanam. Rafts of black algal dolomite, anhydrite and altered dolerites were observed in the quarries set in the chaotic accumulation of the Jabal Sanam. Similar black algal dolomite layers are found in the salt domes of southwest Iran. Two dolerite samples studied by Buday and Jassim (1987) by K-Ar method revealed 570 ± 10 Ma and 580 ± 10 Ma dating, respectively. The negative gravity residuals associated with the structure strongly suggests that it is underlain by Infracambrain salt and formed the Sanam salt plug (Jassim and Buday in Jassim and Goff, 2006).

CONCLUSIONS

From reviewing the presented data, which deals with the stratigraphy of the Iraqi Southern Desert, the following can be concluded:

- The large lithological and thickness differences in the members of the Dammam Formation could be attributed to structural effects.
- The Wagsa Unit of the Early Ypresian age is interfingering with the Rus Formation in Kibritiya sinkhole, and in Umm Al-Hashim Borehole (KH 2), the Late Ypresian age is represented by interfingering of the Rus Formation with the Shbicha – Lower Huweimi Unit

of the Dammam Formation. According to this relation, the Rus Formation is equivalent to the Early Eocene units of the Dammam Formation in the Southern Desert.

- No Oligocene rocks are exposed in the Southern Desert due to the uplifting of the Salman Zone and the Euphrates and Zubair Subzone of the Mesopotamian Zone in Oligocene time.
- In Al-Busaiya vicinity, the Euphrates Formation is interfingering with the Ghar Formation in a very complicated exposure pattern, therefore it is mapped together as Euphrates – Ghar Formation.
- The authors believe that the Upper Unit of the Euphrates Formation described by Al-Mubarak and Amin (1983) belongs to Nfayil Formation due to the similarity in lithology with the latter.
- The regional geological surveys in the Southern Desert, described the exposures of Fat'ha Formation without any beds of anhydrite or gypsum. Therefore, they belong to Nfayil Formation.
- The authors did not accept the Late Miocene age for the Dibdibba Formation and agree with the supposed Pliocene – Pleistocene age, due to its interfingering with Zahra Formation.
- The Quaternary sediments are thin and of limited extension.
- Al-Batin Fan is the biggest alluvial fan in the Southern Desert, which was formed as a result of change in channel width and loose in volume as stream flows over the fan.
- Jabal Sanam is thought to be a salt plug of 100 m high in a flat terrain.

REFERENCES

Al-Ani, M.Q. and Ma'ala, K.A., 1983a. Report on the regional geological mapping of south Samawa area. GEOSURV, int. rep. no. 1348.

Al-Ani, M.Q. and Ma'ala, K.A., 1983b. Report on the regional geological mapping of north of Busaiya area. GEOSURV, int. rep. no. 1349.

Al-Khateeb, A.A.G., 2008. Series of geological reports on the exposed geological formations in Iraq "Zahra Formation". GEOSURV, int. rep. no. 3067.

Al-Hashimi, H.A.J., 1972. Foraminiferida of the Dammam Formation (Eocene) in Iraq. Unpub. Ph.D. Thesis, London University.

Al-Hashimi, H.A.J., 1974. The sedimentary facies and depositional environment of the Eocene Dammam and Rus Formations. Jour. Geol. Soc. Iraq, Vol. VI, p. 1 – 18.

Al-Hashimi, H.A.J. and Amer, R.M., 1977. Stratigraphy and paleontology of the sub-surface rocks of Samawa area. Jour. Geol. Soc. Iraq, Special Issue, p. 1 – 39.

Al-Hashimi, H.A.J. and Amer, R.M., 1985. Tertiary Microfacies of Iraq. GEOSURV, Baghdad, 56pp.

Al-Haza'a, S., 1996. Sedimentological and geochemical study of Zahra Formation, (Pliocene – Pleistocene) in the Southern and Western Deserts of Iraq. Unpub. M.Sc. Thesis, Baghdad University.

Al-Mubarak, M.A. and Amin, R.M., 1983. Report on the regional geological mapping of the eastern part of the Western Desert and western part of the Southern Desert. GEOSURV, int. rep. no. 1380.

Al-Sharbati, F. and Ma'ala, K., 1983a. Report on the regional geological mapping of southwest Busaiya area. GEOSURV, int. rep. no. 1346.

Al-Sharbati, F. and Ma'ala, K., 1983b. Report on the regional geological mapping of west of Zubair area. GEOSURV, int. rep. no. 1345.

Al-Naqib, K.M., 1967. Geology of the Arabian Peninsula, Southeastern Iraq. U.S.G.S. professional paper No. 560-G, 54pp.

Amer, R.M., 1976. Biostratigraphy and paleontology of subsurface rocks of Al-Nasriya, Shekhiya, Shawiya and Samawa area. GEOSURV, int. rep. no. 714.

Abdul Munium, A., 1983. Biostratigraphy of Lower Eocene – Upper Miocene of west Samawa area, Iraq. GEOSURV, int. rep. no. 1326.

Abdul Munium, A., 1984. Micropaleontological study and biostratigraphy of west Nukhaib area .GEOSURV, int. rep. no. 1325.

Bellen, R.C., Dunnington, H.V., Wetzel, R. and Morton, D., 1959. Lexique Stratigraphic International. Asia, Fasc. 10a, Iraq, Paris.

Buday, T., 1980. The Regional Geology of Iraq, Vol. I, Stratigraphy and Paleogeography. Kassab, I., and Jassim, S.Z. (Eds.). GEOSURV, Baghdad, 445pp.

Bull, W.B., 1973. Geomorphology of segmented alluvial fans in Western Franco Country, Calif., U.S.G.S. professional paper No. 352-E.

Ditmar, V., 1972. Geological conditions and hydrocarbon prospect of the Republic of Iraq. Vol.11, South Iraq. Techno export report, OEC Lib., Baghdad.

Jassim, S.Z., Karim, S.A., Basi, M.A., Al-Mubarak, M.A. and Munir, J., 1984. Final report on the regional geological survey of Iraq. Vol.3 "Stratigraphy ". GEOSURV, int. rep. no. 1447.

Jassim, S.Z. and Goff, J., 2006. Geology of Iraq. Dolin, Prague, 341pp.

Mahmood, E., 1983. Biostratigraphic and Paleontological study of Shbicha area. Iraq. GEOSURV, int. rep. no. 1228.

Mahmood, E., 1984. Biostratigraphic study of three subsurface sections from block (1, 2, 3), Southern Desert, Iraq. GEOSURV, int. rep. no. 1389.

Owen, R.M.S. and Nasr, S.N., 1958. The stratigraphy of the Kuwait – Basrah area. In: Weeks, G.L. (Ed.). Habitat of Oil Symposium. A.A.P.G., Tulsa.

Raji, W. and Said, V.V., 1984. Primary study on paleontology of Dammam and Zahra Formations in south Samawa area. GEOSURV, int. rep. no. 1387.

Salman, B., 1984. Biostratigraphy and paleoecology of north Busaiya area. GEOSURV, int. rep.no.1390.

Salman, B., 1993. Revision of the Zahra Formation. GEOSURV, int. rep. no. 2199.

Shaker, S., 1983. Biostratigraphic study of the south Najaf area. GEOSURV, int. rep. no. 1322.

Shaker, S., 1984. Biostratigraphic study of south Salman area. GEOSURV, int. rep. no.1344.

Sissakian, V.K., Mahdi, A.I., Amin, R.M. and Salman, B., 1997. The Nfayil Formation, a new lithostratigraphic unit in the Western Desert of Iraq. Iraqi Geol. Jour., Vol. 30, No.1, p. 61 – 65.

Sissakian, V.K., 1999. Series of geological reports on the exposed formations in Iraq "The Nfayil Formation". GEOSURV, int. rep. no. 2496.

Sissakian, V.K., 2000. Geological Map of Iraq, 3rd edit., scale 1: 1 000 000, GEOSURV, Baghdad, Iraq.

Sissakian, V.K. and Abdul Jabbar, M.F., 2001. Series of geological reports on the exposed geological formations in Iraq "The Dammam Formation". GEOSURV, int. rep. no. 2622.

Sissakian, V.K. and Mohammed, B.S., 2007. Geology of Iraqi Western Desert (Stratigraphy). Iraqi Bulletin Geol. Min., Special Issue, p. 51 – 124.

Tamar-Agha, M.Y., 1984. Final report on geology of the Southern Desert (Blocks 1, 2 and 3). GEOSURV, int. rep. no. 1424.

Yacoub, S.Y. and Hamid, A.T., 2001. Series of geological reports on the exposed geological formations in Iraq. "The Umm Er Radhuma Formation". GEOSURV, int. rep. no. 2743.

Yousif, W., 1981. Biostratigraphy and paleoecology of south Nukhaib area. GEOSURV, int. rep. no. 1269.