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Stratigraphy of the Mesopotamian Plain: A Critical Review

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Abstract

The Mesopotamian Plain is part of the Mesopotamia which extends for vast area bigger than the plain. The Mesopotamian Plain is covered totally by Quaternary sediments among which the fluvial origin is the most prevailing and more specifically the flood plain sediments. The flood plain sediments are Holocene in age, whereas the Pleistocene sediments are restricted to alluvial fan sediments and river terraces. The flood plain sediments cover majority of the Mesopotamian Plain, whereas the alluvial sediments are restricted to the northern eastern, western and southern peripheral parts only. The extreme south-eastern part is covered by the tidal flat and sabkha sediments. Marshes and shallow depressions are also covered by Holocene sediments which are contaminated by Aeolian sediments. However, Aeolian sediments occur in different forms; among them are the sand dunes, sand sheets and Nebkhas. The distal parts of the alluvial fan sediments interfinger with the sheet run off sediments which in turn interfinger with the flood plain sediments. Moreover, the alluvial fan sediments interfinger laterally by other fan sediments or merge laterally together to form Bajada.

Keywords: Fluvial sediments, Pleistocene, Holocene, marshes, Alluvial fan sediments, Aeolian sediments.

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1. Introduction

Mesopotamia is a historical region in West Asia situated within the Tigris–Euphrates river system. In modern days, roughly corresponding to most of Iraq, Kuwait, parts of Northern Saudi Arabia, the eastern parts of Syria, South-eastern Turkey, and regions along the Turkish–Syrian and Iran – Iraq borders (Collon, 2011), see Figure 1.

Mesopotamia, in modern times, has been more generally applied to all the lands between the Euphrates and the Tigris, thereby incorporating not only parts of Syria but also almost all of Iraq and south-eastern Turkey (Foster and Polinger Foster, 2009). The neighbouring steppes to the west of the Euphrates and the western part of the Zagros Mountains are also often included under the wider term Mesopotamia (Canard, 2011, Wilkinson, 2000 and Mathews, 2000). A further distinction is usually made between Upper or Northern Mesopotamia and Lower or Southern Mesopotamia (Miquel et al., 2011). Upper Mesopotamia, also known as the Jazirah (Al-Jazira Plain), is the area between the Euphrates and the Tigris from their sources down to Baghdad (Canard, 2011). Lower Mesopotamia is the area from Baghdad to the Persian Gulf (Miquel, 2011). In modern scientific usage, the term Mesopotamia often also has a chronological connotation. In modern Western historiography of the region, the term "Mesopotamia" is usually used to designate the area from the beginning of time, until the Muslim conquest in the 630s, with the Arabic names Iraq and Jazirah being used to describe the region after that event (Foster and Polinger Foster, 2009 and Bahrani, 1998).

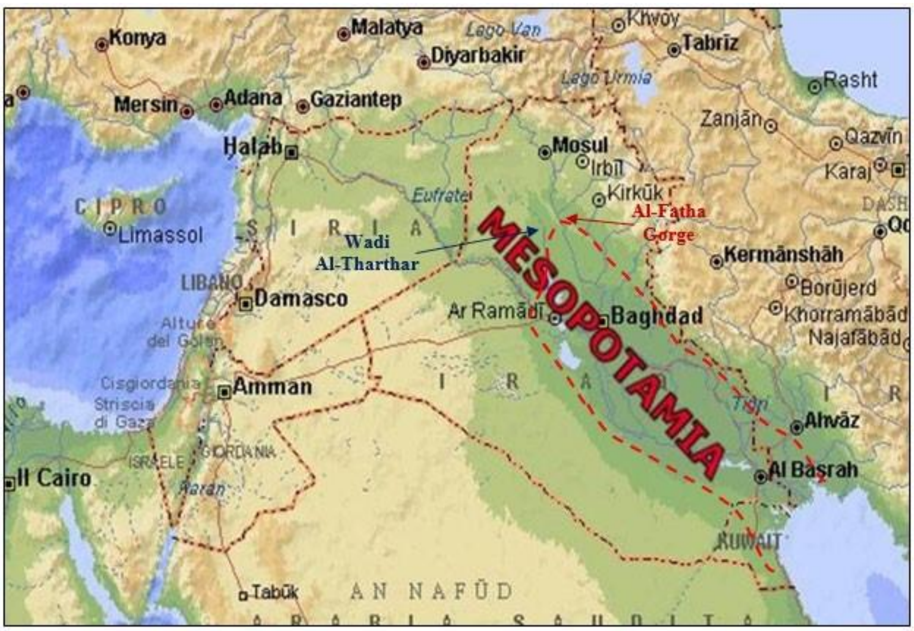

Figure 1: Geographical extension of Mesopotamia showing the Mesopotamian Plain (Approximate limits shown be dashed red line). (Internet data, 2013).

The Mesopotamian Plain; however, is different geographically, geologically and historically from the Mesopotamia. The Mesopotamian Plain represents part of the Mesopotamia, and nowadays it represents the existing plain between the Tigris and Euphrates rivers, which is limited south of Al-Fatha gorge in the north. The alluvial plains along the Iraqi – Iranian borders in the east. From the west (northern part), it is limited by wadi Al-Tharthar and (southern part) the eastern limits of the Western Desert; then extending with the northern limits of the Southern Desert (almost parallel to the Euphrates River); forming the southern limits of the plain. From the southeast, it is limited by the upper reaches of the Arabian Gulf (Figure 1).

The age of the Mesopotamian Plain backs to the Pleistocene (2.558 Ma), and because the alluvial sediments of the plain are not concerned in oil explorations; therefore, very limited data is available from the drilled oil wells, as well from the water wells; since the water wells very rarely encounter the Pleistocene sediments. Moreover, there is a large similarity between the alluvial sediments of the plain and the underlying Pre-Quaternary sediments (Yacoub, 2011); especially, when the Bai Hassan Formation (Pliocene – Pleistocene, mainly conglomerate and claystone) underlies the Mesopotamian Plain sediments.

2. Stratigraphy

Most of the previously carried out works confirm that the Stratigraphy of the Mesopotamian Plain is limited to the Pleistocene Period, among them but not limited to are: Jassim et al. (1984, 1986 and 1990); Yacoub (2011) and Sissakian and Fouad (2012). However, some of the sediments such as Al-Fatha Alluvial Fan, Al-Batin Fan and other alluvial fans located along the eastern limits of the Mesopotamian Plain, and the first stage of terraces of the rivers may have sediments older than the Pleistocene and grade up to Late Pliocene. This assumption is suggested according to the age of the Bai Hassan Formation (Pliocene – Pleistocene); since the rocks of the Bai Hassan Formation are almost equivalent to the oldest sediments of the above-mentioned geological units. The surface of the Mesopotamian Plain; however, is mainly covered by Holocene Period sediments, the most prevailing are the flood plain and sheet run-off sediments. The geological units of the Mesopotamian Plane are presented in Figure 2, and are described mainly based on Yacoub (2011).

In order to facilitate the description of the stratigraphic units of the Mesopotamia Plain, they are divided into three main parts, these are briefed hereinafter.

2.1 Pliocene – Early Pleistocene Rock Units

Three rock units are exposed in the Mesopotamian Plain; these are briefed herein after.

2.1.1 Bai Hassan Formation (Pliocene – Pleistocene)

The Bai Hassan Formation is a synonym of the ex-Upper Bakhtiari Formation (Jassim *et al*.,1984 and Al-Rawi *et al*., 1992). The formation is exposed in the eastern margins of the Mesopotamian Plain, at Mandali, Al-Teeb, Buzurgan and Sheikh Fars vicinities (Figure 2). The Bai Hassan Formation consists of alternation of conglomerate, claystone, pebbly sandstone, and siltstone. The conglomerate consists of gravels with sandy matrix and calcareous and/ or gypsiferous cement materials. The gravels range in size from few millimetres to 20 cm, they are sub-rounded, rounded and well rounded, mainly of carbonates and silicates with subordinate igneous and metamorphic rocks. The exposed thickness of the Bai Hassan Formation is highly variable. Hamza *et al*. (1990) measured 11.5 and 16 m at two localities in northeast of Tikrit city. However, in oil well Buzurgan2 north of Amara city the thickness of the Bai Hassan and the underlying Mukdadiya formations; together does not exceed 243 m (Domas, 1983).

2.1.2 Dibdibba Formation (Pliocene – Pleistocene)

The Dibdibba Formation is exposed in the western margin of the Mesopotamian Plain only in Tar Al-Najaf and covers the whole Karbala – Najaf Plateau. Along the southern margin of the plain, it is exposed in Busaiya and west of Al-Zubair vicinities (Figure 2). The exposed parts of the formation do not exceed few meters in thickness. The total thickness of the formation in the supplementary type section (Oil well Zubair 3) is 354 m. The formation extends towards the Mesopotamia Fluvial Basin, beneath thick Quaternary sediments. The Dibdibba Formation comprises of poorly sorted sand and sandstone; together with gravels. The sand and sandstone are mostly quartz, they consist of quartz grains of monocrystalline and crystalline types, with rear rock fragments and feldspar. The gravels consist mainly of igneous rocks, with rear metamorphic rocks, limestone and chert (Sadik, 1977 in Jassim et al., 1984). The age of the Dibdibba Formation is not ascertained yet (in Iraq), Sissakian and Mohammed (2007) suggested Pliocene – Pleistocene age. It is worth mentioning that the differentiation between the Dibdibba Formation from Al-Batin Alluvial Fan's sediments depends on the type of the cementing material of the sandstone beds. The sandstones of Dibdibba Formation are commonly cemented by calcareous material, whereas gypsiferous cementing materials are prevailing in Al-Batin Alluvial Fan sediments (Yacoub, 2011).

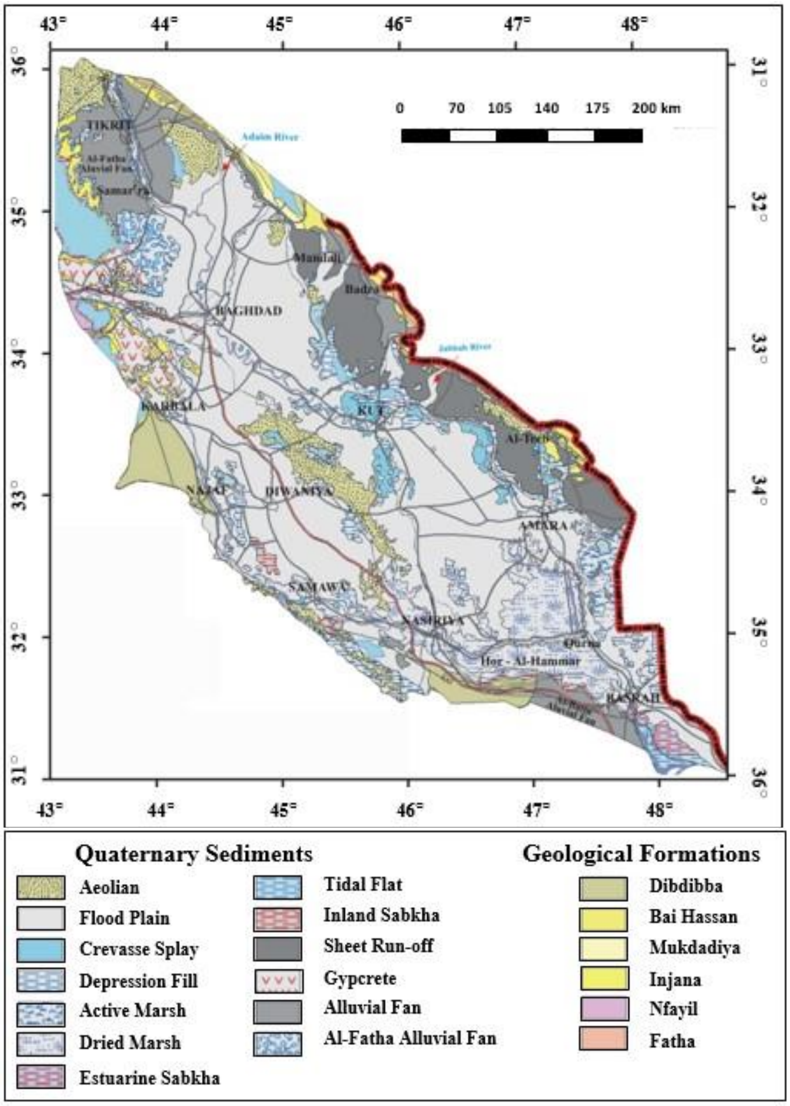

Figure 2: Geological map of the Mesopotamian Plain (After Yacoub, 2011).

2.1.3 Mahmudiya Formation (Pliocene – Pleistocene)

The Mahmudiya Unit was introduced by Domas (1983), it comprises the Plio – Pleistocene sediments of the Mesopotamia Fluvial Basin. Recently, Aqrawi et al. (2006) considered the same unit as Mahmudiya Formation. The formation crops out on the western margin of the plain on the flanks of Iskandariyah mesa, south of Baghdad. Both the upper and the lower contacts of the Mahmudiya Formation are diachronous. The upper contact is with the Pleistocene sediments of the Tigris, Euphrates and foothill Rivers, whereas the lower contact is with the Pliocene fluvial sediments. The Mahmudiya Formation consists of alternation of sand, silt and clay, with thin intercalations of marsh and lake horizons. Prominent differences occur between the sediments of the Mahmudiya Formation and the underlying Pliocene sediments, as the heavy minerals are concerned which are less abundant in the later sediments. The secondary gypsum is one of the most abundant secondary minerals found within the Mahmudiya Formation. Such gypsums occur in the form of veinlets, fibers, disseminated grains and crystals reaching few millimeters. The maximum thickness of the Mahmudiya Formation is 54 m, in a borehole (DB-21) drilled in Hor Al-Dalmaj area, west of Kut city. The thickness decreases to less than 20 m on the western margin of the Mesopotamia Fluvial Basin. In the deeper part of the basin (in Kut vicinity), only the upper (10 – 25) m of the formation has been struck by a borehole at depth around 180 m. Domas (1983), mentioned that the microfossils confirm the Plio – Pleistocene age of the formation, and the Quaternary/ Tertiary boundary lies within the Mahmudiya Formation. The Mahmudiya Formation passes gradually into the upper part of the Bai Hassan Formation at the foothills of Himreen Mountain. The formation is also much correlated with the upper part of Dibdibba Formation, SW of Mesopotamia Plain. Based on the lithology and fossil contents, the Mahmudiya Formation was deposited in fluvial environment with intercalations of fresh water and brackish lacustrine environment. However, the western part of the basin was admixed with the sediments provided from the Inner (Stable) Platform (Yacoub, 2011).

2.2 Pleistocene Sediments

The Pleistocene Period, in the Mesopotamia Plain was characterized by glacial and inter-glacial phases. The climatic oscillations with the Neotectonic activity played an important role in the development of the fluvial sediments in the Mesopotamian Fluvial Basin. The upper contact with the overlying Holocene sediments is diachronous and is not always precisely determined. The same contact could be also recognized when the gravely Pleistocene beds overlain by Holocene fine sediments. Otherwise, the contact becomes uncertain in many parts of the basin. Parts of the Pleistocene sediments are exposed such as huge alluvial fans and river terraces, which occupied the marginal parts of the Mesopotamia Fluvial Basin (Figure 2). However, their subsurface extensions in the deeper parts of the basin form thick sequence of flood plain facies under the Holocene sediments (Yacoub, 2011). Three types of Pleistocene Period sediments are developed in the plain. These are briefed hereinafter.

2.2.1 Sediments of the Mesopotamia Fluvial Basin

The upper parts of this unit have been struck by many drilled shallow boreholes at depths around (15 – 20)m, below the surface. These sediments are spread over the whole flood basin from north of Baghdad to Basra vicinity. These sediments comprise of complicated inter-bedding of pebbly sand and sandy gravels, sands, silts and silty clay, with prevailing sands followed by silts. Thin horizon of marsh sediments, marly limestone and calcareous clays were also found at different depth levels. The pebbly sand and sandy gravel beds are encountered in many boreholes north and northwest of Baghdad, they represent the subsurface extensions of the Euphrates Pleistocene terrace and Al-Fatha Alluvial Fan sediments. The average size of the gravels is (1 – 2)cm, they are composed of chert and quartz, with rare igneous and metamorphic rocks. The gravels disappear south of Baghdad gradually, and the sand beds become fine to medium and rarely coarse grained. The sands are cemented by gypsum or carbonates, forming (3 – 10)cm thick horizons of sandstone. The Euphrates River sediments are richer in altered heavy minerals and monoclinic pyroxene, while the Tigris sediments have more rock fragments, minerals of ziosite – epidote group, hornblende and garnet (Minarikova, 1979). There is an impressive and traceable layer of brown silty which contains large crystals of secondary gypsum (selenite). It has usually a sharp contact with the overlying beds. This has been considered as the top of the Pleistocene sediments, across the whole Mesopotamia Fluvial Basin by Yacoub et al. (1981). The thickness distribution of the Pleistocene sediments across the Mesopotamia Basin ranges from (40 – 50)m in the northeast, (58 – 174)m in the central part and (50 – 110)m in the southern part. The maximum thickness (174 m) is located in Hor Al-Shuwaicha, north of Kut city. The lithological contents and fossil assemblages, and the sedimentary structures of the Pleistocene sediments represent deposition from a fluvial freshwater environment influenced locally by some lacustrine, and slightly brackish conditions (Yacoub, 2011).

2.2.2 Alluvial Fan Sediments

These sediments are the oldest Quaternary sediments within the Mesopotamian Plain (Figure 2). Four alluvial fan systems are developed surrounding the Mesopotamian Plain. They differ in provenance, geological position, sediment grain size, and composition. They are briefed hereinafter and some of them are presented in Figure 3.

2.2.2.1 Northern Alluvial Fan System of the Mesopotamian Plain

Three main individual alluvial fans are developed within this system, besides the fans which merge laterally together to form Bajada along the foothills of Himreen Mountain. The individual fans are described hereinafter.

1-Al-Fatha Alluvial Fan

It is a huge alluvial fan in the northern part of the Mesopotamia Plain. It extends from Fatha where the Tigris River enters the Mesopotamia Plain, to north of Falluja town, in the south. The sediments of this fan are well exposed along the Tigris River and the eastern cliffs of Tharthar Depression (Figures 1 and 3). These sediments; however, may extend southwards under the Holocene sediments reaching up to north of Baghdad City (Jassim, 1981). These sediments are subdivided into two main lithological units by Yacoub et al. (1990). The lower unit is mostly gravels and conglomerate, whereas the upper unit is gypcrete and gypsiferous clastics unit.

The gravels of the lower unit range from fine pebbles to cobbles, and reach 30cm, near the fan apex. The gravels are rounded to sub rounded, composed mainly of chert and limestone with rare igneous and metamorphic rocks. The upper unit consists of gypcrete with gravel, sand, silt, and clay. The thickness of these sediments ranges from (12 – 20)m, but may reach 40m, in Abu Dalaf vicinity. The fan sediments wedge out in the eastern and western directions, towards Shari Salt Marsh and Tharthar Depression, respectively (Figure 4). The thickness of the lower gravely unit is (5 – 15)m, and reaches around 37m, whereas the lower gypcrete unit is (2 – 4)m thick, but occasionally reaches 6m near Abu Dalaf. The age of Al-Fatha Alluvial Fan is considered as Pleistocene. It is more likely that the lower conglomerate unit is of Early – Middle Pleistocene, and the upper gypcrete unit is of Late Pleistocene age. The sediments were deposited in subsiding basin as a huge gravel fan. The sedimentation took place in typical fluvial environments from large braided rivers of very high capacity during Early and Middle Pleistocene. The rivers capacity; however, decreased during Late Pleistocene, represented by the deposition of finer clastics.

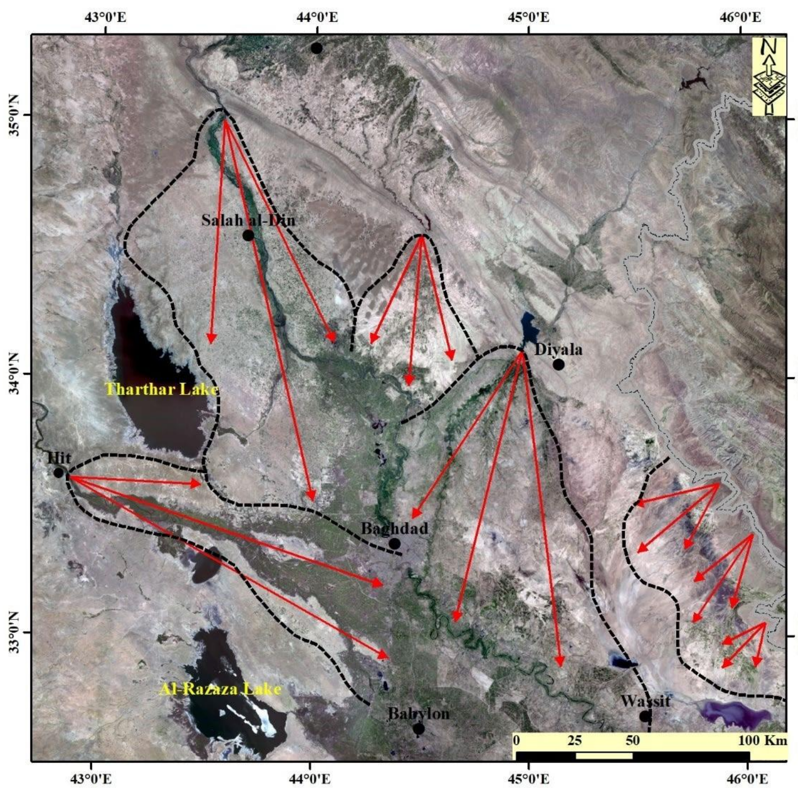

Figure 3: Satellite image of the northern part of the Mesopotamian Plain showing different alluvial fans. 1= Al-Fatha Fan, 2= Al-Adhaim Fan, 3= Diyala Fan, 4= Eastern Fans, 5= Ramadi Fan.

2-Al-Adhaim Alluvial Fan

It is a very large individual alluvial fan (Figure 3) deposited by Al-Adhaim River after leaving Himreen Mountain and reaches almost the Tigris River in the south. On both sides, it interfingers laterally with the sediments of Al-Fatha alluvial fan and Diyala alluvial fan (Figure 3). It has a typical fan shape. The sediments are fine sand and silt with lenses of fine conglomerate. The top cover is either thin gypcrete layer; not more than 1 m in thickness or silty clayey brown soil. The thickness of the fan sediments is not recorded, but the authors believe it ranges from (5 – 15)m.

3-Diyala Alluvial Fan

It is a very large individual alluvial fan (Figure 3) deposited by Diyala River after leaving Himreen Mountain and reaches almost the Tigris River in the south. On both sides, it interfingers laterally with the sediments of Al-Adhaim alluvial fan and sheet run off sediments (Figure 3). It has a typical fan shape. The sediments are fine sand and silt with lenses of fine conglomerate. The top cover is either thin gypcrete layer; not more than 2m in thickness or silty clayey brown soil. The thickness of the fan sediments is not recorded, but the authors believe it ranges from (5 – 25)m.

2.2.2.2 Eastern Alluvial Fan System of the Mesopotamian Plain

This fan system includes all fans that are developed alongside the northeastern and eastern margins of the Mesopotamian Plain (Figure 2). They are well developed as continuous and wide belt of deposits from Mandali to Al-Fak'ka (north of Amara), while their northern extension forms discontinuous and relatively narrow belt, interrupted by slope sediments towards Al-Fatha area. These sediments consist of unsorted and massive gravel beds with sand or mud matrix. However, sharp reduction in grain size occur from the apex in different directions towards the distal fringes. The same variations are noticed between the older and younger stages of these alluvial fans. The grain size of the gravels varies from few millimeters to 30 cm, and larger boulders (Yacoub, 1983). The gravels are sub-rounded to rounded, discoidal, rod like, blade or irregular. They are mainly of carbonates and chert and some igneous and metamorphic rocks. The sands are coarse to medium in size, with gravel admixtures at the apical parts, whereas in the peripheral parts the sands become medium to fine grained, and locally silty or clayey. Secondary gypsum occurs in variable forms and quantities. It is concentrated in the surface layers and occasionally forms gypcrete crust, which is best developed (1 – 2m thick) is in the marginal parts of the alluvial fans. The exposed thickness of the individual alluvial fan, along the banks of the foothill rivers, reaches (5 – 6)m, however, the total thickness may reach 10 m and more. The age of these sediments according to the geological position and the lithology, the age of this unit is considered as Pleistocene. Four stages of Pleistocene alluvial fans are developed along the eastern margin of the Mesopotamia Plain. However, there is a fifth stage representing the recent and sub-recent fan sediments of Holocene age. The first stage (oldest) is deposited at the beginning of Pleistocene, and even earlier (Plio – Pleistocene). The relics of the fan overly the pre-Quaternary bed rocks. The second stage is deposited at the foot of the first stage, it is characterized by desert varnish gravels lag on the surface; its age is Early Pleistocene. The third stage (Middle Pleistocene) is more widespread as compared with the first and second stages, and they are separated by a sharp break, indicating to a period of erosion. The fourth stage represents the last stage, deposited during the Late Pleistocene. This stage is deposited at the peripheral part of the Bajada; and is characterized by finer clastic sediments and smoother surfaces, as compared with the older stages. The fifth stage (youngest) is represented by Holocene wide valley and channel fill sediments forming small fans. All these alluvial fans have been deposited by the foothill streams (rivers) that flow out from Himreen Mountains. The typical alluvial fan environment; is evidenced by the unsorted gravels and boulder sediments that are exposed at the apical parts of the fans. Whereas, the remaining parts of the sediments; reveal fluvial environments. The deposition of successive alluvial fan stages indicates repetition in the sedimentary conditions due to climatic oscillations during the Pleistocene. The sediments of the last stage are deposited by braided rivers and foothill streams from the Himreen Mountain. They are usually loose sandy or gravely sediments restricted within the channel limits that locally form small terraces, indicating to a climatic oscillation during the Holocene.

2.2.2.3 Western Alluvial Fan System of the Mesopotamian Plain

This system is represented by three main alluvial fans; deposited at the peripheral parts of the Western Desert (Figure 2). The sediments of the fans extend under the Holocene sediments of the Mesopotamian Plain. The fans are: **1)** Ramadi Alluvial Fan, **2**) Alluvial Fan of Karbala – Najaf Plateau and **3**) Habbariyah Alluvial Fans. The Euphrates River and the Western Desert valleys which have deposited these fans show no abrupt change in slope and the deposition is a result of the change in channel width and loss of the load volume; as the stream flows out over the fan (Bull, 1975). However, the tectonic effect of the Abu Jir – Euphrates Fault Zone (apart from Ramadi fan) may also has played a role in the development of these fans, which are described hereinafter.

1-Ramadi Alluvial Fan: It is deposited by the Euphrates River after leaving the rocky terrain east of Hit town (Figure 3). It has longitudinal shape not due to the size of the sediments, but due to the nature of the topography. The sediments of the fan are fine sand and silt with lenses of fine to medium conglomerate. The top cover is either thin gypcrete layer; not more than 2 m in thickness or silty clayey brown soil. The thickness of the fan sediments is not recorded, but the authors believe it ranges from (8 – 25)m.

2-Alluvial Fan of Karbala – Najaf Plateau: It has almost similar lithological composition of that of Al-Batin Fan, except the size of the gavels, which is finer (1 – 2cm). The thickness of the sediments varies from (2 – 19.5)m (Al-Khateeb and Hassan, 2005). It is covered by the Dibdibba Formation (Figure 2) and gypcrete; therefore, the age is Early Pleistocene.

3-Alluvial Fan of Hab'bariyah Depression

Sissakian and Abdul Jab'bar (2013) recognized two stages of alluvial fans at Habbariyah Depression (Figure 4) in the Western Desert. They are deposited by many valleys such as Al-Ubaiydh and Tab'bal valleys. They drain the eastern part of the Western Desert into the large and longitudinal Al-Hab'bariyah Depression (Figure 4). The average size of the pebbles ranges from (12 – 20)cm, for the first stage (older) and (0.5 – 3)cm for the second stage. The pebbles are composed mainly of limestone, dolostone and chert. The thickness of the first stage ranges from (5 – 6)m, and may reach (8 – 12)m, whereas the thickness of the second stage ranges from (1 – 5)m (AlMubarak and Amin, 1983). The large pebbles were carried in a matrix of semi-fluid mud; therefore, they have typical fan shape, whereas the finer sizes were carried to more far distances, to form the prone parts. Part of the sediments was also carried and transported by valleys (streams) and deposited as either valley fills sediments or to form depression fill sediments of the Hab'bariyah Depression (Sissakian and Abdul Jb'bar, 2013).

2.2.2.4 Southern Alluvial Fan System of the Mesopotamian Plain

This system is represented by two main alluvial fans; deposited at the peripheral parts of the Western Desert. The sediments of the fans extend under the Holocene sediments of the Mesopotamian Plain. The fans are: **1)** Alluvial Fans of Al-Slaibat Depression and **2**) Al-Batin Alluvial Fan. The desert valleys which have deposited these fans show no abrupt change in slope and the deposition is a result of the change in channel width and loss of the load volume; as the stream flows out over the fan (Bull, 1975). However, the tectonic effect of the Abu Jir – Euphrates Fault Zone may also has played a role in the development of these fans, which are described hereinafter.

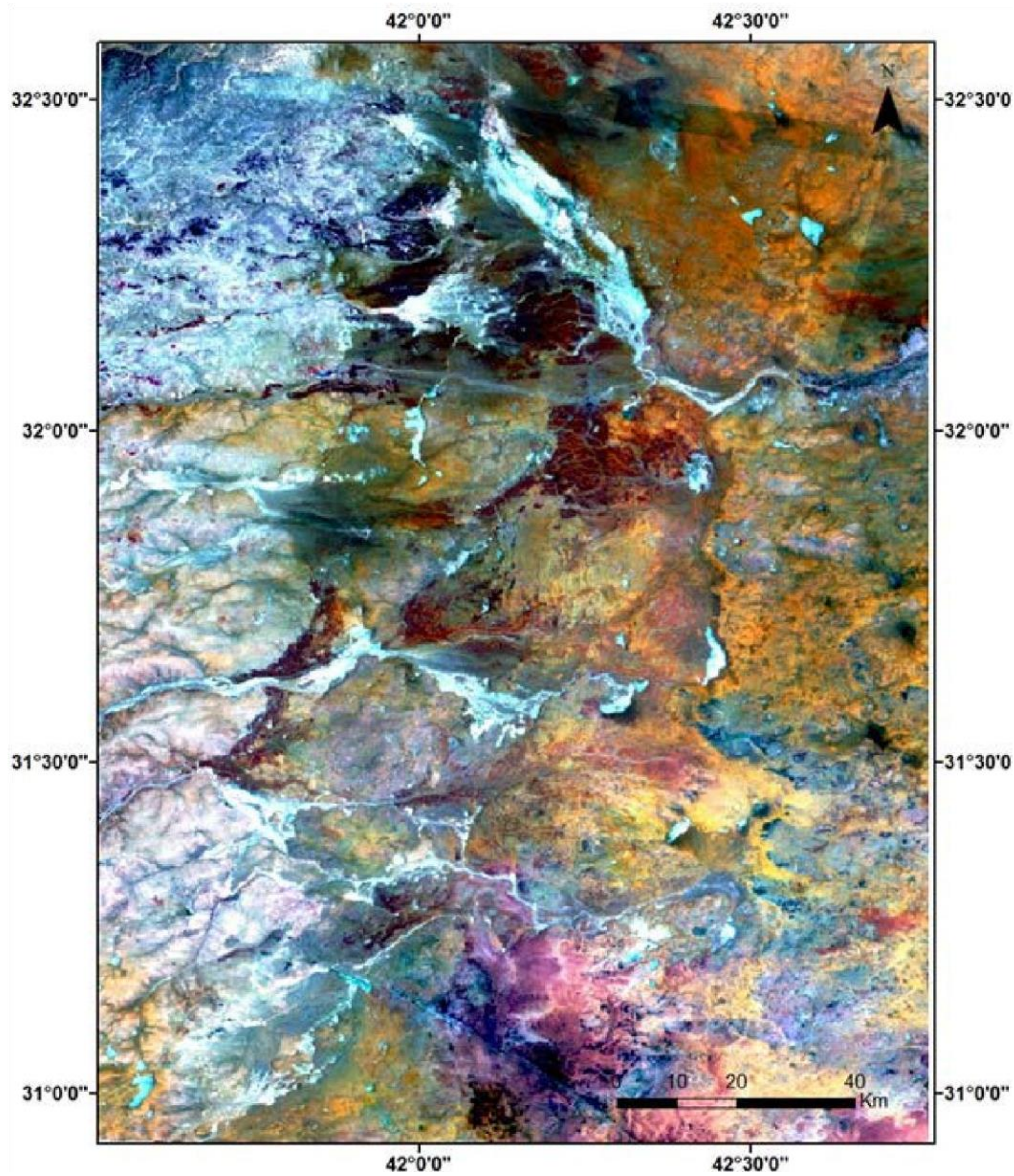

Figure 4: Satellite image of Hab'bariyah alluvial fans (after Sissakian and Abdul Jab'bar, 2013).

1-Alluvial Fans of Al-Slaibat Depression: These are located south of Nasiriya city deposited by different valleys such as Al-Qusiar, Sdair, Ghwair valleys which drain large parts of the Southern Desert into the Al-Slaibat Depression. They comprise of fairly cemented gravels rich in carbonate rock fragments, originated from the exposed rocks in the near surroundings. The age of the fans' sediments is considered as Late Pleistocene, according to their geomorphological position, and because of their limited extension and small catchment area. Many gravel fan shaped bodies and elongated gravel bodies occur, which are in form of small coalescent alluvial fans deposited by the local desert valleys, but then they lost their fan shape due to weathering and erosion (Yacoub, 2011). Zaini and Abdul Jab'bar (2015); have recognized two main stages of fans in those gravel bodies (Figure 5), they divided them into two main groups. The first group includes three alluvial fans called: Al-Hinood, Al-Dheeb and Shali alluvial fans. The alluvial fans of this group are composed of soil because their source is from Dammam Formation (Middle and Upper Members), which are composed of hard carbonate rocks, with several karst features along the valleys, where most of the sediments are dropped in the karst forms. Whereas the second group includes five alluvial fans called: Qusair, Ghwair, Sdair, Khanqa and Abu Ghar alluvial fans. Alluvial fans of this group are composed of rock fragments because their source is from Ghar and Euphrates formation, which are composed of carbonate and clastic rocks.

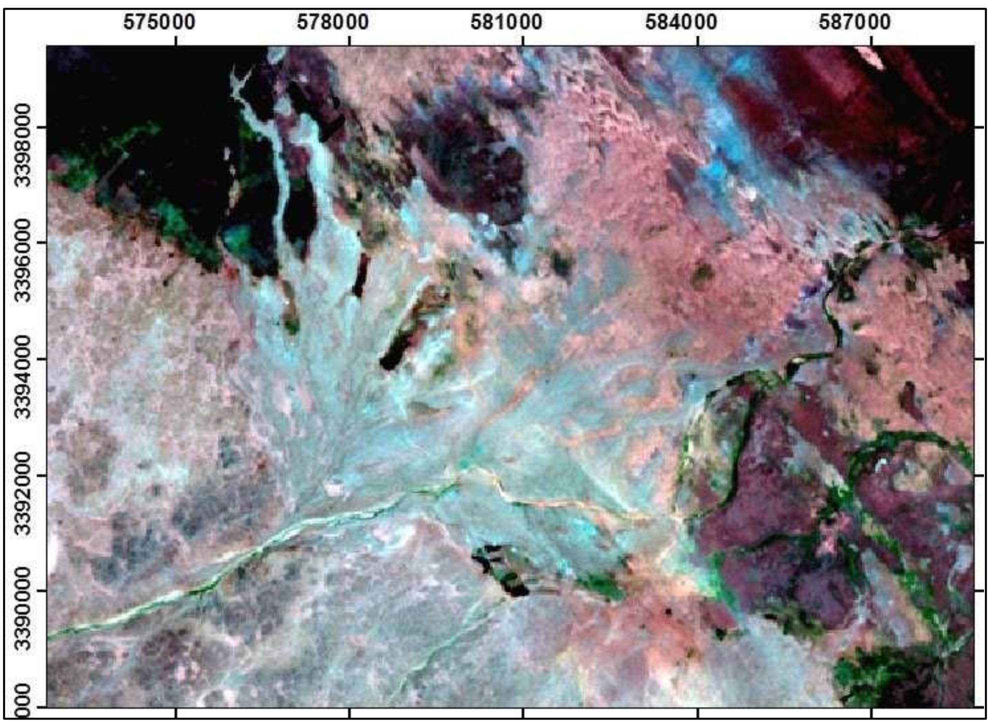

Figure 5: Satellite image of two stages of Qusair Alluvial Fans (after Zaini and Abdul Jab'bar, 2015).

Al-Batin Alluvial Fan: It is an ideal alluvial fan of a desert plateau with distinct four stages. The feeder channel of the fan is wadi (valley) Al-Batin which forms part of the Iraqi – Kuwaiti International borders (Figure 6). It comprises mainly of ill-sorted gravely sand, sandy gravel and gypcrete, with rare silty and sandy clay layers. The sands and gravels are composed mainly of quartz and feldspars, with less limestone pebbles and occasional acidic igneous and volcanic rock fragments. Aqrawi et al. (2006) mentioned the presence of heavy mineral assemblages, mostly of rutile and zircon; in these sediments. The sands are commonly medium to coarse grained. The gravels size varies from coarse gravels (5 – 20cm in size) to fine gravels and pebbles (2 – 5cm in size), around the apex and the peripheral parts of the fan, respectively. The gypcrete and gypsiferous cementing material are fairly common in surface beds. The thickness of highly gypsiferous sand and gypcrete beds ranges between (0.5 – 1.5)m. The coverage area of the fan is about 10842 km^2. The exposed thickness of the fan sediments in west Zubair area, reaches up to 10m (Al-Sharbati and Ma'ala, 1983). The age of the fan sediments is considered as Pleistocene by Al-Sharbati and Ma'ala (1983). The four stages of Wadi Al-Batin (Figure 6) can be correlated with the four alluvial fan stages of the Eastern Mesopotamia Plain Fans System.

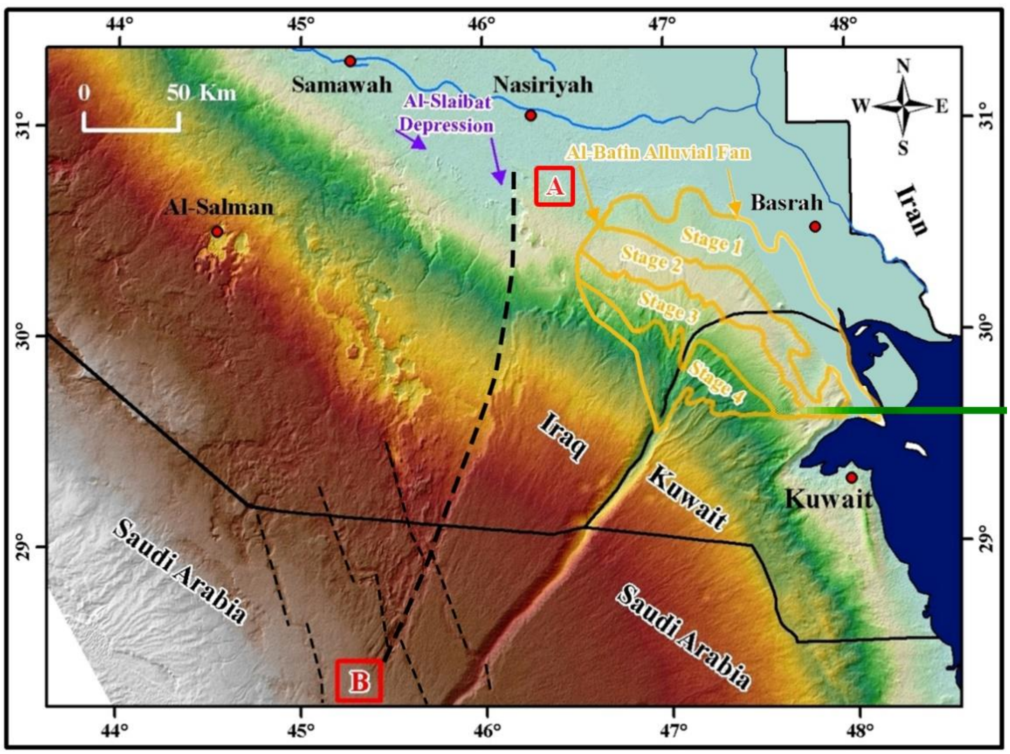

Figure 6: Gradient map of the Global Multi-resolution Terrain Elevation Data 2010 (GMTED2010) 7.5 arc-second spatial resolutions, showing the four stages of Al-Batin alluvial fan (Modified from Sissakian et al., 2014).

2.2.3 River Terraces

The river terraces include: 1) Euphrates River Terraces, which are well developed along the cliffs bordering the river flood plain; from Ramadi to east of Falluja, and further to southeast in Iskandariyah vicinity (Figure 2). 2) River terraces developed in the eastern margin of the Mesopotamia Plain, but limited to the outlets of foothill rivers (wadis). They are preserved on banks of the rivers Diyala, Nafut, Galal Harran, Galal Badra, Chab'bab and Al-Teeb. It is worth to mention that “Galal” means “wadi” or valley. The lithology of the terraces differs at different parts of the Mesopotamian Plain. This is attributed to the exposed rocks in the catchment area, river size and its location inside the plain. The higher level of the Euphrates River terraces consists of highly gypsiferous gravely sand. The gravels have variable shapes and composed mainly of quartz and chert, and their size reaches up to 3 cm. The sand is mostly medium grained and grey in color. The lower terrace level, in Falluja and Iskandariyah vicinities, consist of inter-bedding of sandy gravel, gravely sand and sand with laminated horizons of silty clay. The average size of the gravels ranges between (0.5 – 2)cm, and rarely reaches 5cm. They are essentially composed of quartz and chert with igneous, metamorphic and carbonate rocks. The sands are fine to coarse grained with distinct lamination and cross-bedding. The higher terrace of the Diyala River, comprises of coarser gravels (reach up to 15cm), and composed mainly of carbonates and chert with small amounts of sandstone, igneous and metamorphic rocks. The lower terrace, consists of gravely sand with sandy gravel lenses at the upper part and dominantly sandy gravel at the lower. The thickness of the higher level of terraces of the Euphrates River is about 1 m, which represent remnants preserved on the western bank of Euphrates River. While the thickness of the lower level reaches > 7m, in Falluja vicinity, it reaches 6m, in Iskandariyah vicinity. The Euphrates terraces extend eastwards from the exposure areas under the thick flood plain sediments, where the top of the gravely beds was penetrated by the drillings at depths range between (12 – 20)m. The thickness of the higher level of the terrace of the Diyala River is about 7m, whereas the exposed thickness of the lower level of the terrace is 6 m. The age of the higher level of the terraces of the Euphrates River is Early Pleistocene. It is correlated with the Fatha Alluvial Fan sediments. The age of the lower level is most probably of Middle Pleistocene. The same ages are assumed to the terraces of Diyala River. The terrace sediments were laid down by wide river channels of high current and load capacity. The alternation of gravel and sand with silty clay lenses indicates braided river channels. The deposition took place in wet climate conditions during the Pleistocene. The presence of the stages deduces big climatic oscillation during the Pleistocene and associated with continuous subsidence of the Mesopotamia fluvial basin (Yacoub, 2011).

2.3 Pleistocene – Holocene Sequence

The sedimentary units of this sequence have different origins, such as fluvial, deluvio – fluvial and evaporitic. Three different units are developed; they are mentioned hereinafter.

2.3.1 Sheet Run-off Sediments

These sediments form huge alluvial cones in the distal parts of the alluvial fan sediments in the eastern and northeastern parts of Mesopotamia Plain. They form extensive plain spread between the alluvial fans and the Tigris flood plain. The sediments consist of alternating of sand, silt and silty clay, which graded to each other in both vertical and horizontal directions. The sediments show coarsening upwards from the lower (older) beds towards the apex of the fans. The dominant colors of these sediments are reddish and pinkish brown. Heavy minerals analysis of the sand fraction revealed very high content of opaque minerals with low percentage of amphiboles and pyroxene minerals. The thickness of these sediments ranges from (1 – 15)m. Further, down slope, where there is alternation with Pleistocene foothills and alluvial fan sediments, the unit may become thicker. The sheet run-off sediments are connected originally with the alluvial fans and foothill fluvial system, in addition to the sheet wash activity Down the slopes of the alluvial fans unit, most of the streams and other water courses lose their velocity, due to drop of gradient, consequently, drop down their loads. In such cases, small deltas within sheet run-off unit are developed (Yacoub, 2011).

2.3.2 Slope Sediments

The slope sediments are deposited along the slopes of southwestern limb of Himreen structure. They also were recorded in the western extreme margin of the Mesopotamian Plain facing the Western Desert. In the eastern margin, the slope sediments consist of gypsiferous sand and loam with gravels and rock fragments. The secondary gypsum locally passes to gypcrete. Whereas in the western margin they consist of pebbly coarse-grained sands with thin lenses of brown silty clay, and Aeolian admixture. The thickness reaches (3 – 4)m in the foothills region and (0.5 –2)m in the western margin of the plain. The present surface of these sediments is influenced by sheet and rill erosion in addition to Aeolian activities.

2.3.3 Gypcrete

The gypcrete is often developed on the top of the Pleistocene sediments, such as river terraces and alluvial fans, or mantling the Late Neogene formations, surrounding the Mesopotamia Plain (Figure 2). Gypcrete is highly gypsiferous soil very well compacted and hard, usually (0.3 – 4)m in thickness.

2.4 Holocene Sequence

The majority of the Mesopotamia Plain is covered by Holocene sediments (Figure 2). They represent the uppermost sequence (about 15 – 20m) of the Quaternary sediments of the Mesopotamia Basin. The sediments are characterized by alternation of fluvial, deltaic, lacustrine and estuarine/ marine units. The Holocene started (10000 years ago) after the end of the last pluvial phase of the Pleistocene, which was marked by a considerable warming up of the climate. Nine different lithological units within the Holocene Sequence, they are briefed hereinafter.

2.4.1 Flood Plain Sediments

These sediments are the most widely spread over the Mesopotamian Plane (Figure 2) forming the flood plain sediments of the rivers Euphrates, Tigris, Diyala, Adhaim and foothills streams built up vast flood plains in the Mesopotamia Plain. The sediments of the Mesopotamian Plain consist of interfingering of different lithofacies of different units like: channel belt, natural levees, crevasse splays, normal flood plain and flood basins. Therefore, the Holocene sequence consists of alternation of sand, silt and silty clay, which are vertically and horizontally interfingering by gradual to abrupt boundaries. Marshy horizons exist within the subsurface sequence of the flood sediments. The average thickness of the Holocene flood plain sediments is generally between (15 – 20)m. The equivalent sediments, southeast wards are the deltaic, estuarine and marine sediments of the Hammar Formation, it was first described by Hudson *et al*. (1957).

During early Holocene, the channels of the main rivers started to insist across older Pleistocene sediments on the peripheral parts of the fluvial plain; accordingly, narrow flood plains were developed at their upper reaches. These plains were widened gradually downstream resulting into vast flood plains with gentle surface gradient. According to Aqrawi et al. (2006) the main river channels of the Tigris, Euphrates, Diyala and Adhaim migrated through time within the central parts of the basin. This phenomenon is also confirmed by Yacoub (2011), and Fouad and Sissakian (2011), they attribute that to Neotectonic activities of the subsurface anticlines.

During the late Holocene, the irrigation artificial canal systems have greatly influenced the flood plain sediments and were contaminated by reworked sands and silts. Both ancient and modern river branches of the Tigris and Euphrates Rivers are bifurcated at the lower parts of the plain, forming extensive deltas/ crevasse splays along the northern and western margins of the marshes in the Southern Mesopotamia Plain (Yacoub, 2011).

The flood plains of the main rivers Euphrates, Tigris and Shat Al-Arab are briefly described hereinafter.

1-Euphrates River Flood Plain: It covers the western part of the Mesopotamia Plain and passes gradually as interfingering and/ or overlapping the flood plain sediments of the Tigris River. It consists mainly of silty clay and occasionally contains few pebbles. The silty clay is brown with common massive bedding, and is rich in secondary salts. Some weathered horizons occur too, as indicated by the presence of iron oxides. Marsh deposits also occur indicating the presence of shallow depressions which were filled by these deposits.

2-Tigris River Flood Plain: It covers the central and eastern parts of the Mesopotamia Plain. It consists of muddy sand, fine to medium and even coarse grained. Between Baiji and Samarra towns, pebbles occur too due to the influenced of the adjacent alluvial fan sediments. Southwards, the sediments of the plain are greatly influenced by the sediments provided by Adhaim and Diyala, and foothill Rivers. In the central and southern parts, the silty clay becomes the most abundant in the flood plain. The recent surface sediments show also remarkable influence of irrigation canals, mainly of fine to medium grained sand usually less than one meter thick. Whereas, in the abandoned channels the sand beds reach up to 6 m and exceptionally in the ox-bow lake south of Azizziyah town, the sand reaches more than 13 m. The crevasse splay sediments are well developed and cover extensive areas, in particular of Tigris flood plain from north of Kut to Amara cities. The sediments are composed of fine to medium sand with less silt and mud. They are deposited in many cycles; each cycle represents a major inundation period that took place during Holocene time.

3-Shatt Al-Arab Flood Plain: It consists of silty clay and clayey silt. Whereas, downstream from Basra, Shatt Al-Arab has received and is still receiving its sedimentary load mainly from Karun River with large influence since the sediments change abruptly from silty mud; around Basra into brown muddy sand; downstream from their confluence, in vicinity of Al-Siba town. Natural levees of (1 – 2)km exist along Shatt Al-Arab consist of brown and greyish brown silt and clayey silt. Behind the levees, the flood plain sediments are dominated by clayey silt and silty clay.

2.4.2 Shallow Depression Fill Sediments

These sediments represent the infilled sediments in shallow depressions in the lower parts within the flood plain (Yacoub, 2011). These sediments are variable due to various types of shallow depressions formed by fluvial processes. They differ in dimensions and geomorphic position and in origin as well. These sediments occur in the lowest topographic parts of the flood plain, forming flood basins of the rivers and active stream channels. The main depressions occur between the natural levees of the Tigris River and the distal parts of the alluvial fans east part of the Mesopotamia Plain (e.g. Hor Al-Shuwaicha). They also occur west of the Euphrates

River alongside the western margin of the plain; like Al-Razzazah Depression. Moreover, tens of minor depressions are spread in the Tigris and Euphrates flood plains.

The sediments of the shallow depressions are generally fine silts and clays, with local fine sand inter-layers, greyish brown and greenish grey coloured, with vary-coloured mottling. The high biological activity is a characteristic feature represented by moderate amount of mollusk shells and humificated organic matter. These sediments in the western margin of the Mesopotamia Plain comprise of clayey silt, silty and sandy clayey silt, with thin sand and silty clay intercalations. The main sources of the coarse admixtures is the exposed rocks in the adjacent desert plateau, and windblown sand. These sediments are usually covered by thin salt crust, mainly gypsum forming puffy surface. The thickness of these sediments does not exceed 1 m. However, it ranges from few tens of centimetres to few meters in small and large depressions, respectively. The age of these sediments is doubtlessly recent to sub-recent Holocene, formed contemporaneously with flood plain sediments. Most of the depressions are actually flood basins, which represent fluvial depositional environment of stagnant water accompanied with increase of the biological activity and organic material, as indicated by the grey colour of the sediments. The shallow depressions in the abandoned flood plains are not active; because they are far from the water sources and are highly affected by Aeolian activity. Local marshes could be developed in central parts of some depressions, where enough supply of water is available to keep the growth of marsh vegetation (Yacoub, 2011).

2.4.3 Marsh and Lake Sediments

The modern marshes and lakes represent significant sedimentary environments in the southern part of the Mesopotamian Plain. They cover vast areas (Figure 7) between the fluviatile deltas and the estuarine sabkhas, in the north and west, and Al-Batin Alluvial Fan in the south (Figure 2). The lacustrine complex includes three distinct sub environments. The thickness of the marsh and sub marsh soil does not exceed one meter, in most cases; but locally reaches more than one meter. The age of the modern marsh sediments is late Holocene they were developed after the last retreat of the Holocene sea (2900 ± 550 years B.P., Aqrawi, 1993). He used C14 dating for samples collected from two localities in Hammar and Luqait Lakes and concluded that the age of the upper 35 cm, unit of marsh sediments in Hammar Lake is < 400 year; and the lower part is related to a quite brackish environment subjected to marine influence prior to 3000 years B.P. Relatively, older marsh horizons have also been found intercalated with the Holocene fluvial sediments at different depth intervals in the drilled boreholes, between Amara and Qurna. The present fauna in these sediments represent fresh stagnant water, in shallow aquatic environment. Recently, the aforementioned aquatic environment witnessed many changes due to human activities during 1993 through beginning of 2003. Vast marsh lands have been dried out artificially; accordingly, their floors have exposed to weathering and wind erosion. Consequently, new environmental conditions prevailed accompanied by change in vegetation and land cover. However, large parts of the marshes and lakes have been re-watered and rejuvenated (Yacoub, 2011).

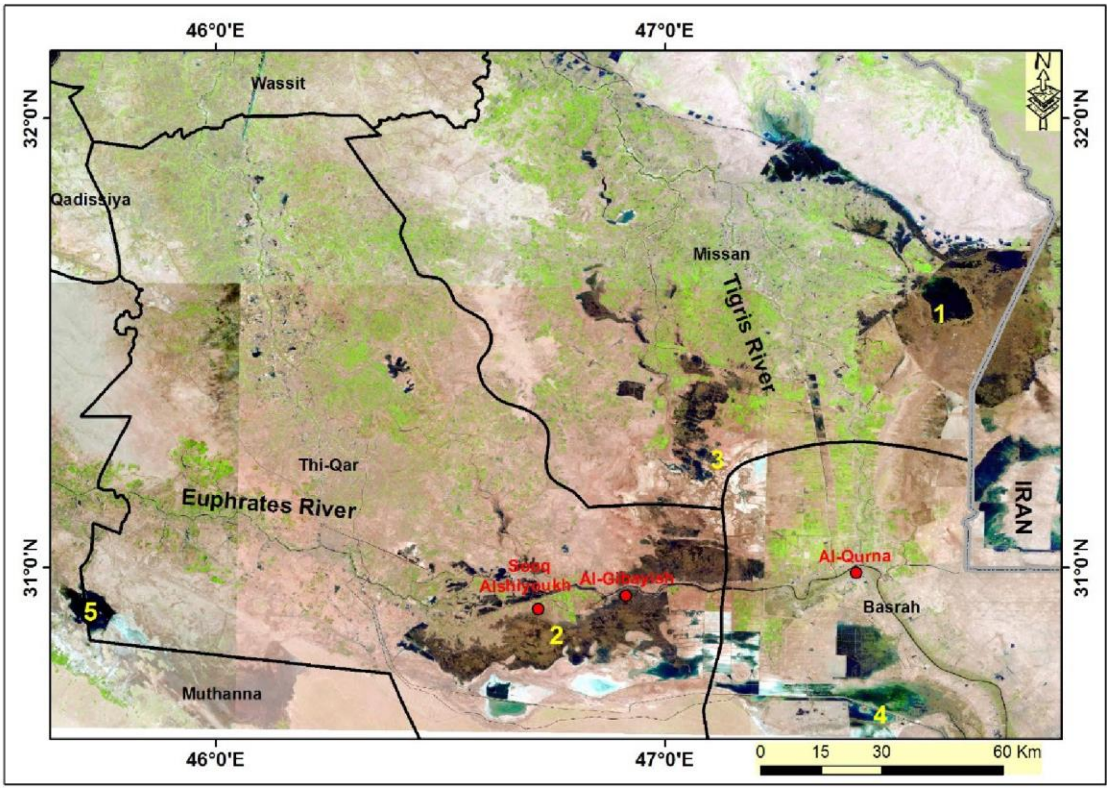

Figure 7: Satellite image of the marshes (2018). 1= Al-Huwaiza, 2= Al-Hammar, 3= northern marshes, 4= Southern marshes, 5= Al-Slaibat Depression.

1-Marsh Sediments: The typical marsh sediments have a dark grey or black horizon (up to 50 cm) at the top it consists of humificated plant debris (peat) and other organic materials mixed with mud. They usually, contain fine lime nodules, amorphous or crystalline gypsum, and mollusk shells. The dark horizon grades rapidly downwards into greenish or blush grey silty clay or mud layer. These sediments are locally intercalated by brown lenses or mottling indicating the influence of fresh sedimentary input of the rivers and irrigation canals (Yacoub et al., 1985).

2-Fresh Water Lake Sediments: These sediments are characterized by light grey to bluish grey, highly calcareous mud, besides, quartz, clay minerals and carbonate fractions. The carbonate fractions decrease towards the fluvial channels and deltaic plain, suggesting that their origin is independent from fluviatile supply (Yacoub et al., 1981). The fibrous clay is regarded as typical characteristic of these lacustrine environment, in the Central Marshes. Several samples from the central parts of Hammar Lake were found to be essentially siliceous. Although the reason for the siliceous sediments is unknown, it is possible that these clay and quartz are relics of paleo Euphrates sediments (Yacoub, 2011).

3-Salt Water Lake Sediments: These sediments are developed in the southern part of Hor Al-Hammar, in Khuraiz Al-Maleh and Horat Al-Luqait salt lakes they are cut-off from the large Hammar Lake by narrow sand barrier of old course of the Euphrates River levees. These lakes are characterized by sandy mud, which are influenced by the outwash of the adjacent Southern Desert sediments and Aeolian admixture.

2.4.4 Inland Sabkha

The main inland sabkhas are restricted to the shallow depressions and playas; especially those located along the western and southern margins of the Mesopotamian Plain (Figure 2). They are also developed between the flood plains of the Tigris River and sheet run-off plain, and between the contact of the latter and alluvial fans. In the vicinity of Hor Al-Dalmaj between the Tigris and Euphrates Rivers, sabkhas occur too. Moreover, inter-dune sabkhas occur in some depressions within the sand dune fields; such as those in west of Adhaim River, northeast of Ba'quba, and south of Samawa. Generally, most of sabkhas are rich in sulphates, mainly gypsum. A good example of sabkhas in the plain is Al-Sanaf (Hor) Salt Marsh. The sabkha consists of vary-coloured fine clastics dominated by reddish brown silty clay with powdered gypsum layers (5 – 10cm thick). The fine crystalline and powdery gypsum may reach more than 1 m in thickness. Their main source is the highly gypsiferous Pleistocene sediments and the exposed pre-Quaternary rocks in Himreen Mountain; transported to the depression by Al-Teeb River and other foothill rivers (wadis), and valleys and streams. The depression is fed also by the irrigation canals from the west and southwest. The thickness of Sabkha sediments is usually less than 0.5m and may reach to more than 1m. The sabkhas stared to develop during the last phase of Holocene and continued to the present day. Sabkhas are typical sediments of arid and semiarid climatic environments, which are characterized by alternating wet and dry seasons. During the former, fine clastics are laid down, whereas the salts have deposited after intensive evaporation during the dry seasons. The shallow groundwater also has played a significant role in supplying access of salts to the surface of sabkhas (Yacoub, 2011).

2.4.5 Estuarine and Marine Sediments

The extremely south-eastern part of the Mesopotamia Plain (Figure 2) represents the coastal region at the head of the Arabian Gulf. It is characterized by three main sedimentary environments. Because the first one is described previously; therefore, it is mentioned here very briefly, whereas the other two environments are described in more details.

1-Fluvial Plain of Shatt Al-Arab and Karun River: It consists of silty clay and clayey silt. Whereas, downstream from Basra, Shatt Al-Arab has received and is still receiving its sedimentary load mainly from Karun River, where the sediments change to brown silty mud.

2-Estuarine Sabkha: This sabkha covers the area between the Shat Al-Arab flood plain and Khor Al-Zubair. It is formed by seawards progradation of the coastline. The sediments are fine textured mud (silt and clay). Sand occurs at the western side only. The sabkha is characterized by great abundance of evaporite minerals, some horizons (2 – 5cm) being deposited as pure gypsum. The thickness is not been recorded, but is believed that the modern sediments could be more than one meter; below the surface. The estuarine sabkhas started to develop after the last regression of the sea in late Holocene, and are continues to the present day. The estuarine sabkha contains scattered marine mollusks and crab remains transported into the sabkha during flooding. This sabkha expresses the combined effect of fluvial and Aeolian sedimentation, with remarkable marine influence. The lamination is resulted from periodic flooding of slightly irregular surface, followed by intensive desiccation.

3-Tidal (mud) Flat: Tidal flat forms a narrow flat coast (1 – 10km), in low sea water level, which extends between Al-Fao, in the east and Um Qasr in the west, and continues farther northwards along the coast of Khor Al-Zubair (Figure 2). The tidal flat consists of fine textured silt and clay, and occasionally sand. The sand is abundant at Khor Al-Zubair coast. The clay reveals the absence of the sand fraction delivered by Karun River. The exposed thickness of these sediments, on the banks of Khor Al-Zubair tidal channels is around (2 – 3)m. The age of these sediments are probably late Holocene and continue to recent time. The sediments of Shatt Al-Arab and the adjacent sediments are of fresh water with little marine influence. The adjacent tidal flats; however, have a scattered marine fauna. In Al-Fao, brackish water mollusks and small oysters occur. The mentioned fauna are also found in Basra vicinity suggesting recent marine influence in these areas. The marine environment of Khor Al-Zubair estuary shows the presence of some ostracod species (Yacoub, 2011).

2.4.6 Subsurface Estuarine/ Marine Sediments

A complete Holocene sequence of sediments is preserved in Amara, Nasiriyah and Basra areas. The contact between the Holocene and Pleistocene sediments is based on a brown silty clay with coarse crystalline gypsum of fluvial origin. These sediments consist of fine to medium grey; alternated with brownish and greenish grey silty clay and clayey silt. Clayey silts and silty clays dominate from Amara to Qurna, whereas south of Qurna the fine sands dominate. At the base of this unit, ancient marsh and lacustrine sediments occur; they were deposited at the early stage of marine transgression. The thickness of these sediments is (5 – 12)m. However, in Zubair oil well No.31, the measured thickness of Hammar Formation is 6.4m. The estimated thickness by MacFayden and Vita-Finzi (1978) is 17.9 m below the sea level in Qurmat Ali, and 5.8m in Amara. The age of these sediments is Holocene, depending on the faunal assemblages. However, Aqrawi (1995 and 2001) using C14 dating determined 8350 ± 230 years B.P., which means Middle Holocene. The analysed sample was collected from borehole located about 25Km west of Basra at depth of about 14.0m, below the surface.

The Holocene sediments are divided into three lithostratigraphic units: **1)** Lower Fluvial Sandy Unit, **2)** Estuarine/ Marine Unit, and **3)** Upper Fluvial – Lacustrine Unit. The units are described hereinafter.

1-Lower Fluvial Sandy Unit: This unit consists of silty sand with gypsum present at its base. This unit began in deposition during the end of Pleistocene and continued until early Holocene (about 9000 B.P.). Aqrawi (2001) has also described the sediments of this unit as the ancient marsh/ lacustrine silty sand unit, which merges laterally into ancient fluvial-plain sediments, in the Southern Mesopotamia Basin.

2-Estuarine/ Marine Unit: This unit was first described by Hudson et al. (1957) they named it as Hammar Formation (includes the lower fluvial unit), in Zubair oil well No.31. The beds were encountered at depth interval (6.1 – 12.5)m, overlying the Dibdibba Formation. The sediments yielded marine fauna of Holocene age. Samples collected from Amara and Qurmat Ali by MacFayden and Vita-Finzi (1978) yielded marine fauna at depth interval (2.7 – 8.5)m, in Amara. They reported a mixture of fresh water and marine sediments. Yacoub et al. (1985) reported estuarine sediments at different levels (the top ranges from 3 to 10m) in borings below ground surface in Amara, Qurna, Nasiriyah and Souq Al-Shiyoukh.

3-Upper Fluvial – Lacustrine Unit: The modern marshes and lakes represent significant sedimentary environments in the southern part of the Mesopotamian Plain. They cover vast areas between the fluviatile deltas and the estuarine sabkhas, in the north and west, and Al-Batin Alluvial Fan in the south (Figure 3).Thus unit includes three types of sediments: **1)** Marsh Sediments, **2)** Fresh After Lake Sediments, and **3**) Salt Water Lake Sediments.

2.4.7 Anthropogenic and Irrigation Canal Sediments

The main effective human activities on these sediments in the Mesopotamia Plain are the irrigation canal system (both ancient and recent), ancient settlements, and artificial tells (hillocks). They are mainly concentrated in the ancient cities and along the main abandoned river courses. The sediments consist of fine clastics of different origins, mixed with brick and pottery fragments. They are either concentrated around tells and along the irrigation canals or disseminated over large areas contaminating the natural pre-existing natural flood plain sediments. The main source of these artefact stones is the destroyed ancient settlements either transported for short distances or accumulated insitu. The ancient settlements and their relics are acting as obstacles around which Aeolian and flood plain sediments accumulated in form of hillocks. The irrigation canal sediments consist of coarse grains, they were built up mainly by silts and fine sands, with less clay fractions reflecting wide oscillation of water flow in the canals. The common colors are brownish and greenish grey; locally are darker bluish grey, due to the influence of humificated organic matter. The thickness of the irrigation canal sediments does not exceed 1 m; but may reach several meters in some archaeological sites. Since the Old Sumerian (2400 – 2000 B.C.) or may be back to Early Dynastic Period (3000 – 2300 B.C.), the irrigation canals were existed in the Mesopotamia Plain on a very primitive stage (Jacobsen and Adams, 1958). The major canal systems were existed with high degree of prosperity during the Sassanian (226 – 636 A.D.) and Abbasid times (636 – 1700 A.D.); the bulk of the preserved ancient canals in the Mesopotamia Plain belong to more recent time interval. Besides that, the modern nets of irrigation canals are wide spread throughout the recent flood plain. The canals brough abnormal coarser sediments with respect to the flood basins, shallow depressions and marshes during high water and flood conditions. The natural morphology and the sedimentary processes in the Mesopotamian Plain were modified by agricultural activities and the effect of the irrigation canals.

2.4.8 Aeolian Sediments

The Aeolian sediments of different forms are characteristic of the arid and semi-arid climatic conditions, which were prevailed during Holocene Epoch. Their influences have increased, especially during the Late Holocene, and recently became more effective (Sissakian et al., 2013). The Aeolian sediments are widely spread in the Mesopotamian Plain; as a thin discontinuous sand sheet, Nabkhas and as large sand dune fields. In the Mesopotamia Plain, three Aeolian fields are developed along the northeastern and southwestern margins and the central part of the plain (Figure 2). They are different in grain size, mineral constituent and source sediments. The thickness of the sand sheets does not exceed one meter with wide extensions. Whereas, the thickness of Barchan fields reaches 5 m, and exceptionally may attain (25 – 30)m, in southwest of Samawa. The bulk of the Aeolian sediments are accumulated during the late Holocene, and may be slightly earlier. Two stages of Aeolian sediments can be observed, the relatively older stage represented by the

fixed Aeolian sediments. These are coated by thin mantle of soil with small native vegetation helped in fixing these friable sediments, whereas the younger stage is the still active one. The sediments of the marginal parts; however, seem relatively older than those deposited in the central part of the plain (Yacoub, 2011). The orientation of the Aeolian fields is usually NW – SE coinciding with the trend of the basin, which is bounded by high topographic terrains having the same directions. The windward slopes of individual Barchans dune indicate that the prevailing wind is N – S and NW – SE. The influences of the wind activities are intensively increased during the last four decades, due to drought environmental conditions, less precipitation and higher temperatures (Sissakian et al., 2013). Accordingly, large rural and agricultural lands of the Mesopotamia Plain were affected; especially, those located adjacent to the sand dune fields, which are creeping quickly to cover large parts of agricultural areas, causing one of the serious desertification problems in the whole Mesopotamian Plain.
The sediments of the three main Aeolian fields are described hereinafter.

1-Aeolian Sediments Along Himreen Range: These are represented in form of large fields west of Adhaim River, south of Mukdadiya town and west of Ali Al-Gharbi town (Figure 2). They consist of fine to medium grained sand, with amount of silt and clay fraction. The dunes are composed mainly of quartz, chert, limestone, and small amounts of heavy minerals; which are derived from the exposed Miocene and Pliocene rocks in Himreen Range and Quaternary sediments.

2-Aeolian Sediments of the Western Margin of the Mesopotamian Plain: These are developed in the western margin and composed of fine to medium grained sand, and small amounts of clay and silt fraction. The sand is composed mainly of quartz, carbonate and small amount of feldspar, and rock fragments. The main source of these sediments is the Neogene and Pleistocene rocks, which are exposed in the Western and Southern Deserts, and along Tar Al-Najaf, besides the local Quaternary sediments.

3-Aeolian Sediments of the Central Part of the Mesopotamian Plain: These are developed between the Tigris and Euphrates Rivers associated with dense anthropogenic sediments. The sediments consist of fine sand, silt and clay; locally rich with mud flakes and mollusk shell fragments. The main sources of the sediments are the flood plain sediments of the Tigris and Euphrates Rivers and related branches, and the ancient irrigation canals.

3. Discussion

The origin and types of the Mesopotamian Plain sediments is well known through many studies, the most detailed and accurate is the one published by Yacoub (2011). Therefore, in the current study only the contact between the sediments of the plain and the underlying Pre-Quaternary sediments and their thickness will be discussed. The youngest geological formations which underlie the sediments of the Mesopotamian Plain are three all of them are Pliocene – Pleistocene in age. The Bai Hassan Formation is exposed in the northern and eastern parts and encountered in the drilled boreholes by Iraq Geological Survey (Yacoub, 2011) in the central and eastern parts of the plain. The Mahmudiya Formation exposed near Iskandiriyah in the western part of the plain, and the Dibdibba Formation in the western and southern parts of the basin. The contact is always gradational and not clear due to: 1) similar type of fluvial sediments, 2) age of the sediments (Plio – Pleistocene) and 3) the contact is indicated from the drilled boreholes through which it is very difficult to distinguish between the sediments of the plain and the underlying sediments. However, in the north-western parts of the plain, the Injana Formation underlies the sediments of the Mesopotamian Plain (Yacoub et al., 1990), it is very clear along the cliff of the Tigris River bank north of Tikrit city; northwards to Baiji town (Sissakian and Fouad, 2012).

The depth of the pre- Mesopotamian Plain sediments is variable within the plain. This is attributed to: 1) the morphology of the basin floor, 2) rate of the sedimentation in the plain (basin), and 3) the rate of the subsidence in the basin. The contact is recorded from the drilled boreholes by Iraq Geological Survey during mid 1980's when the Mesopotamian Plain was mapped in the following depths (Yacoub, 2011): 30 m in the eastern part near Al-Nafit River, 40m near Iskandiriyah town in the western part of the basin, 180 m in Hor Al-Dalmaj; south of Al-Kut city, and 40m near Shat Al-Hilla.

The recorded terraces along the Euphrates River (Yacoub, 2011) near Falluja and Iskandariya towns, most probably are the relics of Ramadi Alluvial Fan (Figure 3). This consumption is attributed to absence of any other terraces along the river downstream from Ramadi city.

4. Conclusions

The Mesopotamian Plain is part of the large Mesopotamia; it is continuously sinking basin filled mainly by alluvial sediments. The flood plain sediments being the most abundant followed by alluvial fan sediments deposited along the rims of the plain and some river terraces. In the extreme south eastern part of the plain, the tidal flat sediment and sabkhas are prevailing. Aeolian sediments like sand dunes, sand sheets and Nebkhas prevail in the central part of the basin. Because the age of the oldest sediments of the plain are of Plio- Pleistocene age which is the same age of the rocks which underlie the plain; like Bai Hassan, Dibdibba and Mahmudiya formations; therefore, the contact between the sediments of the plain and underlying geological formations remains not clear.

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