STRATIGRAPHY OF THE MESOPOTAMIA PLAIN

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ABSTRACT

The current study is a stratigraphic review of the Quaternary sediments of the Mesopotamia Fluvial Basin, which is essentially based on the data obtained from the regional geological survey carried out during 1975 – 1981, by the staff of GEOSURV. Many boreholes were drilled, the acquired data forms essential part of the present study.

The Mesopotamia Fluvial Basin is an integral part of the Zagros Fold – Thrust Belt, which is developed as a result of the last phase of Alpine Orogeny during Pliocene – Early Pleistocene. It represents the area bordered by the uplifted Low Folded Zone, to the east and northeast, and the eastern margin of the Inner (Stable) Platform of the Arabian Shelf, to the west and southwest. At present day, the basin is totally covered by the Quaternary sediments, which are in some margins bounded by limited exposed Tertiary formations that extend beneath the thick Quaternary sediments, within the basin.

Most of the stratigraphy of the Quaternary sediments has not been precisely determined due to the lack of accurate dating. However, relative ages of the main stratigraphic divisions, are suggested depending upon the stratigraphic correlation and their correspondence with global geological events; such as climatic changes. Three main stratigraphic subdivisions are recognized based on their relative ages; namely: Pleistocene, Late Pleistocene – Early Holocene, and Holocene.

The main Pleistocene sediments are represented by river terraces, alluvial fans and fluvial sediments. The Pleistocene – Early Holocene Units include sheet run-off, gypcrete and slope sediments. While the Holocene Units include sediments of different origins, such as fluvial, lacustrine, marine, estuarine, Aeolian and anthropogenic. The Holocene sediments are also found in the modern sedimentary environments of the Mesopotamia Plain.

The presence of Holocene marine sediments (i.e. Hammar Formation) has been confirmed in the Southern Mesopotamia Plain, indicating the influence of marine inundation during early to mid Holocene. Such a marine transgression has reached as far as Amara City, on the eastern side and Nasiriyah City, on the western side, about 200 Km north of the present day northern shoreline of the Arabian Gulf.

طبــاقيــة الســـهل الرســوبي

صباح يوسف يعقوب

المستخلص

الدراسة الحالية هي مراجعة لطباقية السهل الرسوبي النهري التي اعتمدت بالأساس على البيانات التي تم الحصول عليها من خلال المسح الجيولوجي الإقليمي المنفذ من قبل ملاكات الشركة العامة للمسح الجيولوجي والتعدين (جيوسيرف) خلال الفترة من 1977 لغاية 1981.

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نشأ حوض السهل الرسوبي النهري نتيجة لآخر طور من حركة الألباين البانية للجبال (سلسلة زاكروس) خلال نهاية عصر البلايوسين لغاية البلايستوسين المبكر. يمثل هذا الحوض نطاق الهبوط المستمر الذي يحدد بنطاق الطيات الواطئة الصاعد، من الجهة الشرقية والشمالية الشرقية والحافة الشرقية للدرع المستقر من المسطبة العربية، من جهة الغرب والجنوب الغربي. في الوقت الحالي، يغطى الحوض بالكامل بترسبات العصر الرباعي والتي تحاط بتكوينات العصر الثلاثي المتكشفة على أطراف الأنطقة المجاورة، التي تمتد باتجاه الحوض تحت عمود سميك من ترسبات العصر الرباعي.

معظم طباقية رسوبيات العصر الرباعي لم يتم تحديد أعمارها بشكل دقيق لعدم توفر تقنية تحديد العمر الدقيق، في جيوسيرف. مع هذا فان الأعمال النسبية للتقسيمات الطباقية الأساسية تم اقتراحها اعتماداً على الموضع الجيومورفولوجي، نوع الرسوبيات ومضاهاتها الطباقية مع الأحداث الجيولوجية الأرضية، كالتغيرات المناخية خلال العصر الرباعي. وهذه التقسيمات الطباقية الرئيسية هي: البلايستوسين، البلايستوسين المتأخر – الهولوسين المبكر والهولوسين.

تتمثل ترسبات عصر البلايستوسين الأساسية بالمساطب النهرية والمراوح الغرينية والترسبات النهرية قديمة لحوض السهل الرسوبي. أما ترسبات البلايستوسين المتأخر – الهولوسين المبكر تتمثل بصفائح السيول الجارية والجبكريت (الجبس الثانوي) وترسبات المنحدرات. بينما ترسبات الهولوسين تتمثل برسوبيات بيئات مختلفة الأصول: النهرية والبحيرية والبحرية ومناطق مصبات الأنهار، والريحية وأخرى ناتجة عن فعل الإنسان. كما إن هذه الرسوبيات موجودة في البيئات الرسوبية الحديثة والفعالة حالياً في السهل الرسوبي.

إن وجود ترسبات الهولوسين البحرية (تكوين الحمّار) في الجزء الجنوبي من حوض السهل الرسوبي يشير إلى تأثير الطغيان البحري الذي حدث خلال الهولوسين المبكر – المتوسط. وهذا التقدم البحري وصل الى حد مدينة العمارة، من الجانب الشرقي ومدينة الناصرية، من الجانب الغربي، أي وصل الى حوالي 200 كيلومتر باتجاه شمال الساحل الشمالي للخليج العربي الحالي.

INTRODUCTION

The Mesopotamia Fluvial Basin represents the central and southern parts of the major Mesopotamia Foredeep, which is an integral part of the Zagros Fold – Thrust Belt (ZFTB). It is an elongated terrestrial sedimentary basin, lies between the Zagros deformational mountains front and the stable interior of the Arabian Platform (Fouad, 2010). Its southeastern extension is located in Iran, known as Lower Khuzestan Plain, which is not included in the present study (Fig.1). During the Quaternary Period (and even earlier), the basin was continuously receiving sediments, originated from the erosion products of the ZFTB and the Arabian Platform, through active fluvial systems. Thus, the infill sediments of the basin are essentially of fluvial, deltaic, and lacustrine origin. During the Holocene, estuarine, marine and Aeolian sediments were also deposited (Yacoub *et al*., 1985 and Aqrawi, 1993). These sedimentary facies may replace each other, both horizontally and vertically at local scales.

The present paper deals with the stratigraphy of the Quaternary sediments of the Mesopotamia Fluvial Basin, which is based essentially on the data achieved through the regional geological survey that have been conducted by GEOSURV during the period 1975 through 1981. The geological survey of the northern part of the plain was based on the data collected from the exposed sediments along the banks of the Tigris River and Al-Tharthar Lake. Moreover, the discovered sequence in the excavated water wells, which are randomly scattered on Al-Fatha Alluvial Fan (Ibrahim and Sissakian, 1975; Hassan and Al-Jawadi, 1976 and Salim, 1978), in addition to the local detailed geological survey that has been performed for the purpose of the site investigations of Nuclear Power Plant Project in Baiji – Samarra area (Yacoub *et al*., 1991). Whereas, in other areas of the Mesopotamia Plain, few outcrops and profiles are present, which were not sufficient to fulfill the geological mapping task. Thus, to achieve this task, 5643 hand dug pits (1.5 m depth plus 1 m auger hole), 340 shallow boreholes (with average depth of 20 m) and 22 deep boreholes (up to 200 m depth) were drilled, to cover the whole Quaternary succession (Hamza and Domas, 1980; Hamza and Yacoub, 1982; Domas, 1983; Yacoub, 1983 and Yacoub *et al*., 1985).

The data obtained from the aforementioned drillings were partly used in few subsequent detailed research studies, which have been conducted by several workers (Yacoub *et al*.,

1981; Aqrawi, 1993 and 2001; Al-Jumaily, 1994; Al-Jibury, 1997; Aqrawi *et al*., 2006 and Benni, 2009; among others). These studies introduced additional valuable information concerning modern evaluation of the stratigraphy and sedimentology of the Holocene sediments of Mesopotamia Plain, particularly the southern part.

The exposed Pre-Quaternary formations around the Mesopotamia Plain have variable lithology and range in age from Late Eocene to Late Pliocene. The exposed formations along margin of the Western and Southern Deserts are: Dammam (Late Eocene), Euphrates and Ghar (Early Miocene); Nfayil (Middle Miocene); Injana (Late Miocene); Dibdibba (Pliocene – Early Pleistocene). The exposed formations along the foothills of Himreen range on northern and eastern margins of plain are Injana (Late Miocene); Mukdadiya (Late Miocene – Pliocene) and Bai Hassan (Pliocene – Early Pleistocene). These formations are not involved in the present study, except the Dibdibba and Bai Hassan formations. For more details, refer to Sissakian and Mohamed (2007) and Jassim and Al-Jibouri (2009).

The present paper reviews the Stratigraphy of the Quaternary sediments, of the entire Mesopotamia Fluvial Basin from Central to Southern parts, in Iraq.

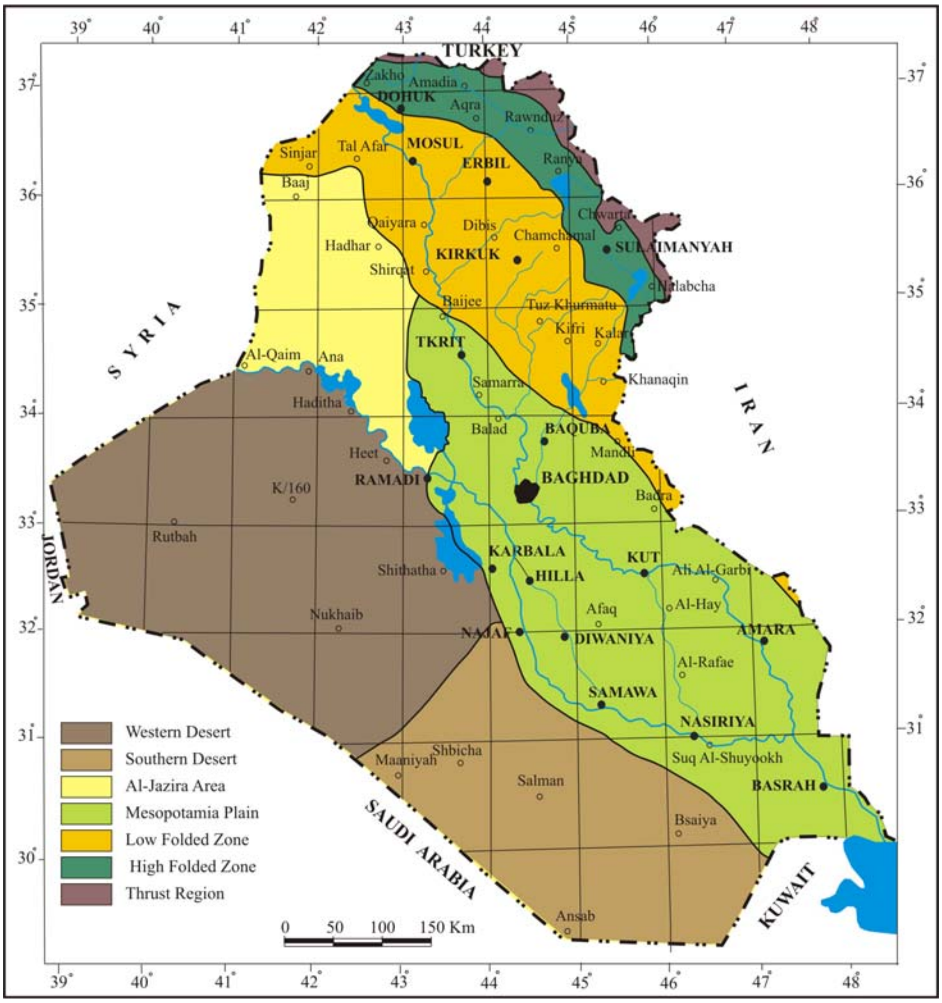

Fig.1: Location map of the Mesopotamia Plain

STRATIGRAPHY

The sediments of the Mesopotamia Plain and near surroundings are divided into three main stratigraphic units, these are mentioned hereinafter.

1. Pliocene – Early Pleistocene Rock Units

This stratigraphic unit includes three rock units, these are.

1.1. Bai Hassan Formation

The name Bai Hassan Formation was introduced by Jassim *et al*. (1984) to replace the Upper Bakhtiari Formation, but was officially announced by Al-Rawi *et al*. (1992). The formation is exposed in many localities on the margins of the Mesopotamia Plain, along the southwestern limb of Himreen structure; in Mandali, Al-Teeb, Buzurgan and Sheikh Fars vicinities (Fig.2).

Lithology: Bai Hassan Formation comprises, generally of alternating beds of conglomerate, pebbly sandstone, siltstone and mudstone. These beds are highly lenticular and show rapid lateral variation. However, the conglomerate is the diagnostic rock type of the formation, which consists of gravels with sandy matrix and calcareous and/ or gypsiferous cement materials. The gravels range in size from few millimeters to 20 cm, but the common size is (4 – 5) cm, in the southwestern limb of Himreen structure. They are subrounded, rounded and well rounded, and generally composed of chert, carbonates, igneous and metamorphic rocks. Lateef (1975) estimated the percentages of these rock types as 51.5%, 33.5%, 9% and 6%, respectively, in Himreen North structure. Yacoub (1983) described the exposed conglomerate beds in Mandali vicinity too. The size of the pebbles and boulders in these beds may reach up to 0.5 m, consisting mainly of carbonate rocks (about 80%) with less amount of chert and/or igneous and metamorphic rocks. Such a lithologic variation could be due to local change in provenance rocks, or these beds may be a part of Bamo Conglomerate (Jassim *et al*., 1984), which is well developed in Khanaqin area, north of the Mesopotamia Plain (Youkhanna and Hradecky, 1978).

Thickness: The exposed thickness of Bai Hassan Formation is highly variable, along the southwestern limb of Himreen structure; mainly due to structural factors (thrust faulting), facial changes and wedging out of the conglomerate beds. Hamza *et al*. (1990) measured 11.5 and 16 m at two localities in northeast of Tikrit city. However, even in other localities, such as along the southwestern limb of Himreen structure the thickness may not exceed 100 m. In addition, southeast ward, in oil well Buzurgan-2 (north of Amara city), the thickness of Bai Hassan and underlying Mukdadiya formations; together does not exceed 243 m (Domas, 1983).

1.2. Dibdibba Formation

The Dibdibba Formation is exposed in the Southern Desert, mainly in Tar Al-Najaf, Busaiya and west of Al-Zubair vicinities (Fig.2). Although it covers extensive areas, the exposed parts are very limited and does not exceed few meters in thickness. The total thickness of this formation is known only from oil wells in SE Iraq. The supplementary type section, of the Dibdibba Formation, was introduced by Owen and Nasr (1958) in Bellen *et al*. (1959) from the Zubair oilfield in oil well Zb-3, with some 354 m thickness. The formation extends towards the Mesopotamia Fluvial Basin, beneath thick Quaternary sediments.

Lithology: The Dibdibba Formation, in the southern and central parts of Iraq comprises of poorly sorted sand and sandstone; together with gravels. The sand and sandstone are mostly quartz, they consist of some 84.2% quartz grains of monocrystalline and crystalline types,

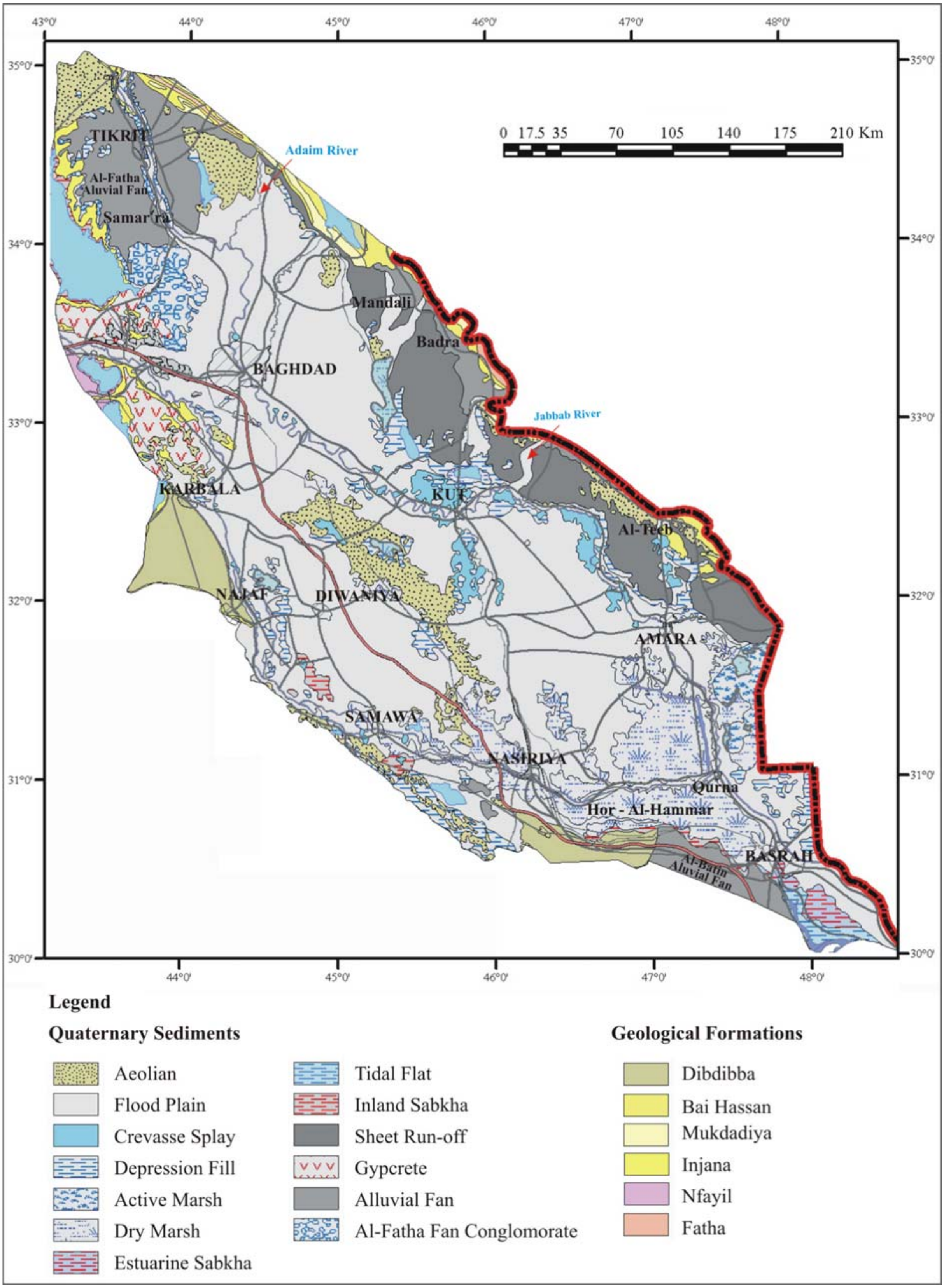

Fig.2: Geological map of the Mesopotamia Plain
(modified from Sissakian, 2000)

with around 8.5% of rock fragments and 7.3% of feldspar. The Dibdibba gravels consist mainly of acidic and intermediate igneous rocks, with smaller amount of metamorphic rocks, limestone and chert (Sadik, 1977 in Jassim *et al*., 1984). Tamar-Agha (1983) described the Dibdibba Formation from two boreholes (namely KH-9 and KH-10), which are located in the Southern Desert, 10 Km north of Busaiya Police Station as "white and pale grey quartoze sandstone, coarse to medium, sometimes pebbly, friable and cemented by fine crystalline calcite. In Tar Al-Najaf, the formation is represented by brown, yellow, white, and grey sandstone and pebbly sandstone (Hassan *et al*., 2002). Jassim and Buday in Jassim and Goff (2006) mentioned that limestone beds occur sporadically throughout the Dibdibba Formation, in water wells, southwest of Busaiya (Fig.1).

Thickness: The thickness of the Dibdibba Formation is (2 – 9) m and 17 m in north and south of Busaiya, and (3 – 8) m in west of Zubair (Al-Sharbati and Ma'ala 1983, and Al-Ani and Ma'ala, 1983, respectively), and (3 – 15.5) m in Tar Al-Najaf (Hassan *et al*., 2002).

Age: The age of the Dibdibba Formation is not ascertained yet (in Iraq), it is assumed to be Late Miocene – Pliocene to Early Pleistocene (Bellen *et al*., 1959). However, Jassim and Buday in Jassim and Goff (2006) claimed post Middle Miocene and Late Miocene – Pliocene age. Al-Sharbati and Ma'ala (1983), Al-Ani and Ma'ala (1983), whereas Sissakian and Mohammed (2007) suggested Pliocene – Pleistocene age, which is adopted by the author.

It is worth mentioning that the differentiation between the Dibdibba Formation from Al-Batin Alluvial Fan 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.

1.3. Mahmudiya Formation

The Mahmudiya Unit was introduced by Domas (1983), it comprises the Plio – Pleistocene sediments of the Mesopotamia Fluvial Basin. It was adopted by GEOSURV geological mapping group of the Mesopotamia Plain. Recently, Aqrawi *et al*. (2006) considered the same unit as Mahmudiya Formation. The formation has been penetrated by many boreholes in the central and southern parts of the plain, where it has been struck at (60 – 100) m depth below the surface. The formation crops out on the western margin of the plain on the flanks of Iskandariyah cut off spur (mesa), south of Baghdad (Fig.3).

Both the upper and the lower contacts of the Mahmudiya Formation are diachronous, since all sediments have generally similar lithology and sedimentary environment. 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 contacts and correlation of subsurface sections are based on the heavy mineral assemblages and their corrosion grade.

Lithology: The Mahmudiya Formation consists of sand, silt and clay; alternating each other, with thin intercalations of marsh and lake horizons, and buried soils. The thickness of individual horizon varies from few tens of centimeters to several meters. The sands and sandstones are grey, brownish grey, and greenish grey, with variable tints; fine to medium grained, occasionally coarse grained, fine pebbles and clay balls may occur. The bedding is massive, laminated, banded by silts and silty clays, or locally cross-bedded. The heavy minerals study revealed some differences in contents within the Mahmudiya Formation, like, the contents of alterites, opaque minerals, and monoclinic pyroxenes, which are higher in the central part of the Mesopotamia Plain than in the western margin. Prominent differences occur between the Mahmudiya Formation and the underlying Pliocene sediments, which are represented by low contents of opaque minerals, serisite – epidote group and garnet; and higher contents of hornblende and pyroxenes in Mahmudiya Formation (Minarikova, 1979).

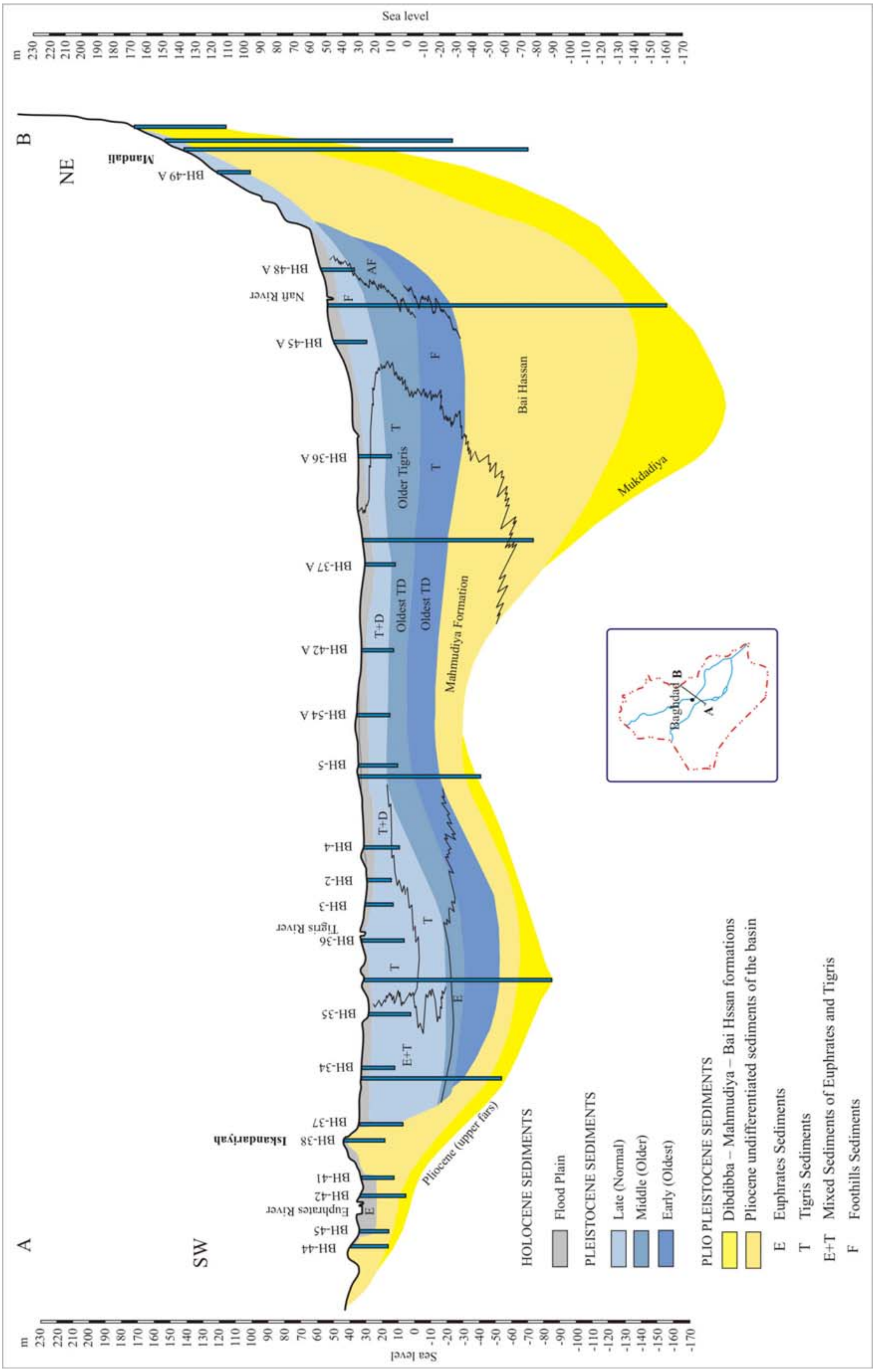

Fig.3: Subsurface Geological cross section between Iskandariyah – Mandali, Northern Mesopotamia Plain (modified after Domas, 1983)

Silts (rarely siltstones) have brownish grey color with different shades. They often form thin horizons inter-bedded with clays and sands, but they make thick layer sequence in the penetrated sediments of the Mahmudiya Formation, at borehole DB-21 in Hor Al-Dalmaj area. Their bedding is massive, banded or laminated due to variation in grain size and colors. The siltstone beds are found cemented by secondary gypsum in the exposure of Iskandariyah cut off spur (Domas, 1983).

Silty clays (partly pure clays) are commonly brown in color, with grayish, greenish or pinkish tints. Whitish and yellowish mottles were noticed on some slightly weathered layers. The beds thickness reaches several meters. The bedding is usually massive, and some of them are banded or laminated. The main mineral constituents of the clays are: carbonates, montmorillonite, chloride, kaolinite, palygorskite and mica.

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 gypsum content in some silty clay beds may reach > 5%.

Thickness: The maximum thickness of the Mahmudiya Formation is 54 m, in borehole DB-21 (from depth 106 – 160 m, below the surface) in Hor Al-Dalmaj area, west of Kut. 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 the deep boreholes DB-8 and DB-9, at depth around 180 m (Fig.4).

Fossils: Some beds of Mahmudiya Formation are rich in microfossils, especially ostracods such as: *Candona* sp., *Cyprinotus* sp., *Ilyocypris* sp., *Darwinula* sp. and *Limnoocythere* sp. Beside those, some typical species for the **Pliocene** and **Quaternary** were recognized by Raji (1983). **Pliocene** ostracods include *Canadona* cf. *balatonica* (Daday), *Darwinula dadayi* Nemes and *Candona* cf. *elegans* Nemes. **Quaternary** ostracods include *Candona* cf. *neglecta* Sars, *Candona* cf. *surki* Hartwig and *Candona* cf. *angulata* Muller. The beds contain fresh water gastropods, *Planorbis* sp., *Lymnaea* sp., *Melania* sp., *Viviparus* sp. and a lot of opercula of brackish to estuarine gastropods *Hydrobidae*.

Age: Domas (1983), mentioned that the microfossils confirm the Plio – Pleistocene age of the formation, and the Quaternary/ Tertiary boundary lies within the Mahmudiya Formation. Therefore, further detailed paleontological and chemostratigraphic studies were recommended to characterize this boundary.

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.

Depositional Environment: Based on the lithology and fossil contents, the Mahmudiya Formation was deposited in fluvial environment with intercalations of fresh water and brackish lacustrine. The sedimentation might be similar to that of the present Mesopotamia Plain, but with water discharge of the rivers has to be much higher (Domas, 1983). However, the western part of the basin was admixed with the sediments provided from the Inner (Stable) Platform.

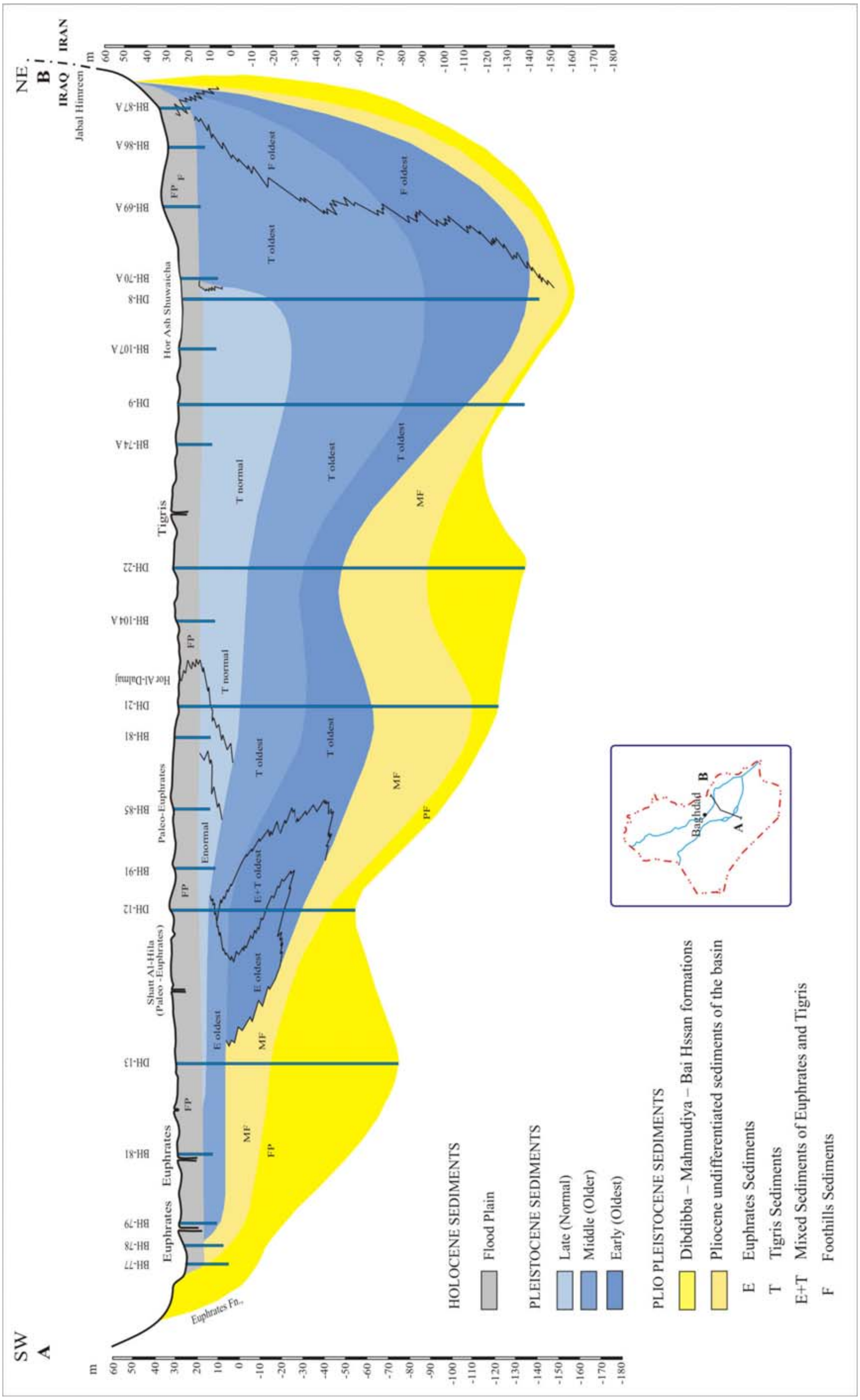

Fig.4: Subsurface Geological cross section, Diwaniya – Jassan, central Mesopotamia Plain (modified after Domas, 1983)

2. Pleistocene Sediments (Rock Units)

The Pleistocene time, in the Mesopotamia Plain was characterized by alternating pluvial and inter-pluvial phases, which correspond to the well-known glacial and inter-glacial phases, globally. These climatic oscillations played an important role, beside the tectonic activities, in the development of the fluvial sedimentation of the Mesopotamian Fluvial Basin.

The upper contact with the overlying Holocene sediments is diachronous and is not always precisely determined; as the Pleistocene fluvial cycles topped by distinctive, slightly weathered brown silty clay or clay layers rich with secondary gypsum crystals, such as in the southern parts of the Mesopotamia Fluvial Basin. The same contact could be also recognized when the gravely Pleistocene beds overlain by Holocene fine sediments, in other areas. 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 (Fig.2). However, their subsurface extensions in the deeper parts of the basin form thick sequence of flood plain facies under the Holocene sediments.

2.1. Pleistocene Sediments of the Mesopotamia Fluvial Basin

The Pleistocene sediments of the Mesopotamia Fluvial Basin were penetrated by most of the drilled deep boreholes, by GEOSURV, which are well distributed in the Mesopotamia Plain. The upper parts of this unit have been struck by the bulk of the drilled shallow boreholes at depths around (15 – 20) m, below the surface (Figs.3, 4 and 5). These sediments are spread over the whole flood basin from north of Baghdad to Basrah vicinity.

Lithology: Pleistocene sediments of the Mesopotamia Fluvial Basin comprise rather complicated inter-bedding of pebbly sand and sandy gravels, sands, silts and silty clay, where the sands are prevailing, 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, which represent the subsurface extensions of the Euphrates Pleistocene terrace and Al-Fatha Alluvial Fan sediments (Figs.2 and 3). The average size of the gravels is (1 – 2) cm, some of them reach up to 5 cm (Hamza and Yacoub, 1982). They are composed mainly of chert and quartz, in addition to igneous and metamorphic rocks. The gravels gradually disappear south of Baghdad, and the sand beds become mostly fine to medium and occasionally coarse grained. The sands are deposited as thin layers inter-bedded with silts and clay; or as thick sand sequence; reaching 40 m, such as at borehole DB-20 in Amara vicinity (Fig.5). The sand beds are commonly fairly compacted; well bedded, laminated and banded, massive beds also were recorded (Yacoub *et al*., 1985). The sands are occasionally cemented by gypsum or carbonates, forming (3 – 10) cm thick horizons of sandstone.

The assemblages of heavy minerals gave clue to differentiate between sediments of the Tigris and Euphrates Rivers. The Euphrates River sediments are richer in altered minerals, and monoclinic pyroxene, while the Tigris sediments have more rock fragments, minerals of ziosite – epidote group, hornblende and garnet (Minarikova, 1979). Such differences could be easily noticed, when comparing the Pleistocene sediments of the western and eastern parts of the Mesopotamia Basin.

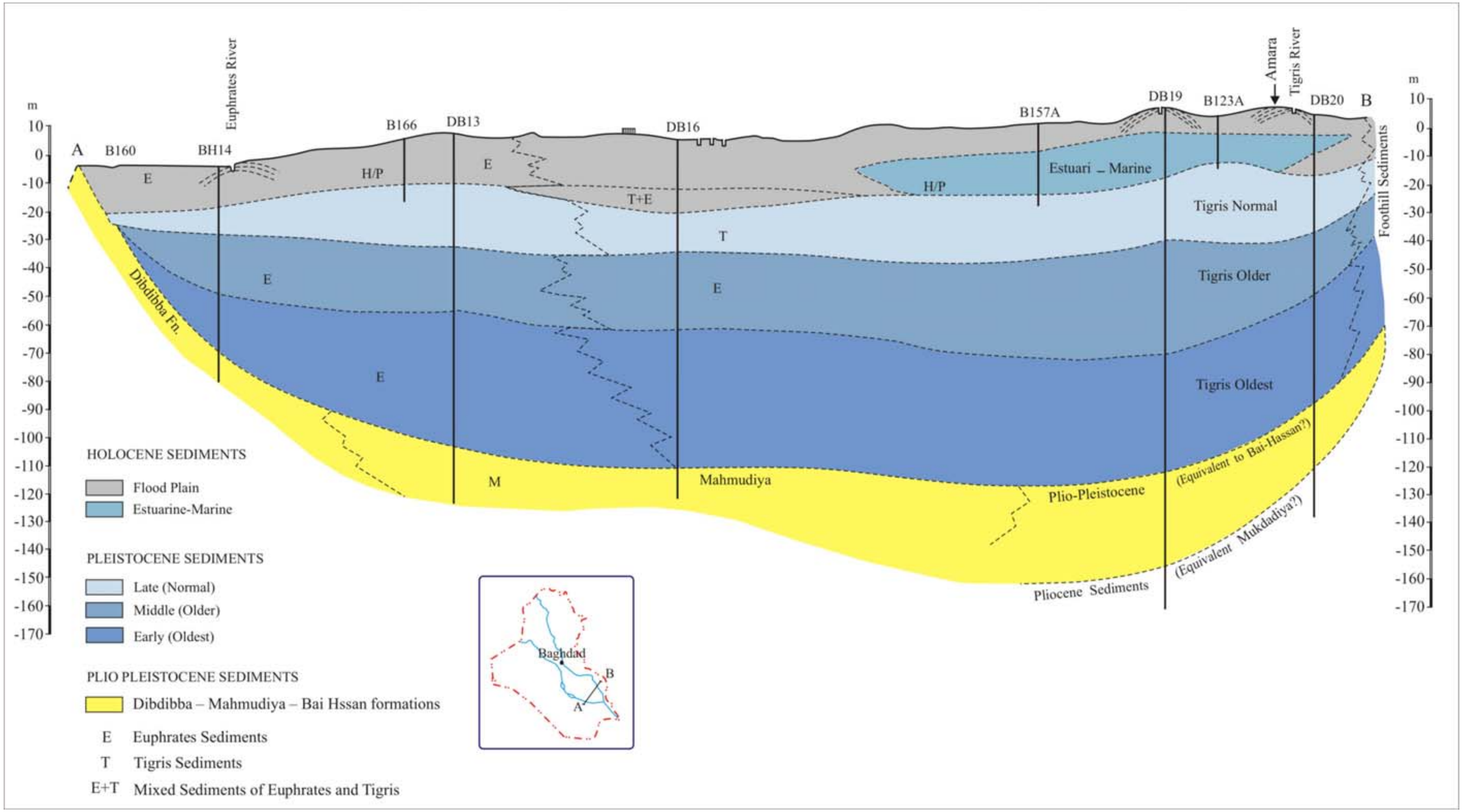

Fig.5: Subsurface Geological cross section, Nasiriyah – Amara, Northern Mesopotamia fluvial basin (after Yacoub *et al*., 1985)

Silts are often clayey, brown with variable shade, greenish and bluish grey colored. They are deposited in layers not exceeding few tens of centimeters, but occasionally may reach 5 m, such as in boreholes DB-15 and DB-16, northeast of Nasiriyah, where the silt and clayey silt become more dominant in the Pleistocene sediments. Clay and silty clays are less abundant in the Pleistocene sediments of the whole Mesopotamia Fluvial Basin, among them, the silty clays are more dominant. They are commonly brown colored with pinkish, reddish or ochre tints, but occasionally are grey and greenish grey. Silty clays are dominantly massively bedded, partly laminated or banded, and fairly compacted.

It is worth mentioning that there is an impressive and traceable layer of brown silty clay (locally passes to highly clayey silt), which contains large crystals of secondary gypsum (selenite). This bed has been penetrated by many shallow and deep boreholes in the Southern Mesopotamia Plain; at depths ranging from (17 – 20) m. 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*. (1985).

The other significant lithologic sequence of the Pleistocene sediments is the dark grey to black marsh sediments, which consist of highly calcareous silts and clays in addition to soil layers. These sediments form (5 – 10) cm thick horizons, intercalated at different depth intervals. However, they may be good indicators of paleo-surfaces and ending of the fluvial cycles, or breaks in sedimentation, and were used for correlation purposes (Figs.3, 4 and 5).

Thickness: 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 sector (Figs.3, 4 and 5, respectively). The maximum thickness (174 m) is penetrated by borehole DB-8, which is located in Hor Al-Shuwaicha, north of Kut (Fig.4).

Fossils: Some of the beds of the Pleistocene sediments are quite rich in microfossils and gastropods, such as ostracods represented by common genera: *Candona* sp., *Cyprinotus* sp., *Ilyocypris* sp., *Darwinula* sp., *Erpetocypris* sp., *Limnocythere* sp. and *Trachycythere* sp. However, one of the most important ostracodes is *Candona*, because they are index fossils for the Pleistocene. *Candona* cf. *neglecta* Sars, also was found to be common in borehole DB-13, at depth (23.7 – 23.8) m; in borehole DB-8 at depth179.5 m; in borehole DB-15 at depth (101.8 – 102.0) m, and in borehole DB-16 at depth (33.0 – 33.35) m (Domas,1983 and Yacoub *et al*., 1985). Also, *Candona* cf. *angulata*, are common in borehole DB-12, at various depths within the interval (51.5 – 56.5) m, and in borehole DB-15 at depth (101.8 – 102) m. Moreover, *Candona* spp., are recognized in borehole DB-13 at depth interval (63.5 – 63.55) m. Also, some beds contain freshwater gastropods, such as *Planorbis valata*, *Melania* sp., *Noritina* sp., *Viviparus* sp. and operculas, and other brackish to estuarine gastropods, such as *Hydrobidae*.

Depositional Environment: The lithological contents and fossil assemblages, as well as the sedimentary structures of the Pleistocene sediments represent dominantly deposition from a fluvial freshwater environment influenced locally by some lacustrine, and slightly brackish conditions.

2.2. Alluvial Fan Sediments

The alluvial fan sediments represent the oldest Quaternary sediments exposed on the surface at different locations within the Mesopotamia Plain (Fig.2). Three alluvial fan systems are developed. They differ in provenance, geological position, sediment grain size, and composition. They are mentioned hereinafter.

▪ **Al-Fatha Alluvial Fan**

It is a huge alluvial fan, occupies the northern part of the Mesopotamia Plain, which extends from Fatha, in the north, where the Tigris River enters the Mesopotamia Plain, to north of Falluja, in the south. The sediments of this fan are well exposed along the Tigris River from Fatha to Samarra, and along eastern cliffs of Tharthar Depression (Fig.2). These fan sediments are also encountered by hundreds of shallow dug water wells (around 10 – 20 m depths) (Yacoub *et al*., 1991). However, these sediments may extend southwards under the Holocene sediments reaching up to north of Baghdad City (Jassim, 1985).

Al-Fatha Alluvial Fan was subdivided into two main lithologic units by Yacoub *et al*. (1991); the lower is mostly gravels and conglomerate unit and the upper is gypcrete and gypsiferous clastics unit. The lower unit comprises sandy gravels grading into well cemented and compacted conglomerate, which are often inter-bedded by sand lenses. The gravels range from fine pebbles to cobbles, occasionally reach boulder size of 30 cm, near the fan apex. However, the dominant size of the gravels ranges between (4 – 8) cm. The gravels are often rounded to sub rounded, unsorted to moderately sorted, and are composed mainly of chert and limestone; in addition to igneous and metamorphic rocks. They are generally massively bedded, but locally planar and cross-bedded. The upper unit consists generally of gypcrete with various fractions of gravel, sand, silt, and clay. It is described as gypsiferous clastics because the percentage of clastics exceeds 50% (Yacoub *et al*., 1991). The average gypsum content within this unit is (50 – 60) %, reaching > 77.2 %, in Abu Dalaf vicinity (about 25 Km north of Samarra) (Fig.2).

Thickness: The average thickness of the Fatha Alluvial Fan sediments ranges from (12 – 20) m, but as maximum thickness; may reach around 40 m, in Abu Dalaf vicinity, where also the deepest part was recorded by GEOSURV’s drillings (Yacoub *et al*., 1991). The fan sediments wedge out in eastern and western directions, towards Shari Salt Marsh and Tharthar Depression (Fig.2), where the thickness of the lower gravely unit is (5 – 15) m, and reaches around 37 m, whereas the lower gypcrete unit is (2 – 4) m thick, but occasionally reaches 6 m.

Age: The age of the 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.

Depositional Environment: The Fatha Alluvial Fan sediments were laid down in continuously subsiding basin, deposited as a huge gravel fan. The sedimentation took place in typical fluvial environments from large braided rivers of very high capacity, which were active during the pluvial phases of Early and Middle Pleistocene. The lateral and vertical variations in grain size of the gravels reflect the changing in stream capacity and loads. The rivers capacity considerably decreased during Late Pleistocene, which is represented by the deposition of finer clastics (sand, silt and mud with less amount of gravels). On the other hand, the gypcrete deposition may reflect intensive evaporation from the surface solutions and ground water rich in Sulphate. The main source of Sulphate could be the Fatha Formation, which is exposed in Himreen and Makhoul Ranges.

▪ **Alluvial Fan System of Eastern Mesopotamia Plain**

This fan system includes all individual fans and Bajada that are developed alongside southwestern flank of Himreen Structure, starting from Al-Fatha vicinity, in central part of Iraq, at the northwestern margin of the Mesopotamia Plain to the north of Amara, in the southeast of the plain (Fig.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.

Lithology: The Eastern Mesopotamia Plain alluvial fan sediments consist of unsorted and massive gravel beds with sand or mud matrix, particularly at the apical parts of each individual fan. Then sharp reduction in grain size occur down-stream, from the apex and in different directions towards the distal fringes. Moreover, lenticular, horizontal and crossed beds are better developed with increasing of the sand. 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, or even larger boulders (Yacoub, 1983). However, the more dominant size is (2 – 5) cm. The gravels are sub-rounded to rounded, discoidal, rod like, blade or irregular. They are mainly of carbonate rocks (limestone), chert and some igneous and metamorphic rocks. The percentage of the carbonate rocks reaches more than 75%, particularly near the apex of the fans, where the coarse gravels and boulders may indicate that the provenance is proximal. Whereas, the percentage of chert increases in the pebbly sized gravels, indicating longer distance of transportation as the provenance is distal. The sands of the alluvial fan sediments are deposited as thin lenticular beds (20 – 80 cm thick); intercalating the gravel beds or as thick beds that reach up to 5 m thick, as in Badra vicinity (Fig.2). 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. The silts and silty clays with sands are the main component in most distal parts of the alluvial fan system. Secondary gypsum occurs in variable forms and quantities. It is commonly concentrated in the surface layers and occasionally forms gypcrete crust. The best development of gypcrete (1 – 2 m thick) is in the marginal parts of the alluvial fans, where the groundwater level becomes close to the surface and around the water springs

Thickness: The total thickness has not been precisely measured, but the exposed thickness of the individual alluvial fan, along the banks of the foothill rivers, reaches (5 – 6) m, such as in Mandali, Zurbatiya, and Badra vicinities (Fig.2).

Age: The age of the alluvial fan sediments has not been precisely determined, due to lack of fossils. However, according to the geological position and the lithology, the age of this unit is considered by Domas (1983) and Yacoub (1983) as Pleistocene.

Four stages of Pleistocene alluvial fans were recognized along the eastern margin of the Mesopotamia Plain by Domas (1983) and Yacoub (1983). Moreover, there is a fifth stage, which represents the recent and sub-recent fan sediments of Holocene age. These stages were differentiated depending on their geomorphic positions, lithologic variations and weathering. The geomorphic criteria seem more applicable, both in field and through aerial photographs interpretation. The 1^{st} stage (oldest) is supposed to be deposited at the beginning of Pleistocene even earlier (Plio / Pleistocene), the relics occupy the higher altitude on the flanks of Himreen structure overlying the pre-Quaternary bed rocks. The 2^{nd} stage is usually deposited at the foot of the 1^{st} stage, it is well developed in Zurbatiya vicinity, and is characterized by desert varnish gravels lag on the surface; its age is considered as Early Pleistocene. The 3^{rd} stage (Middle Pleistocene) is a widespread; with respect to 1^{st} and 2^{nd} stages, and they are separated by a sharp break, indicating to a period of erosion. The 4^{th} stage represents the last stage, deposited during the Late Pleistocene. This stage is deposited at the peripheral part of the Bajada; and it is characterized by finer clastic sediments, better fluvial layering, and smoother surfaces, as compared with older stages. The 5^{th} stage (youngest) also can be added, which is represented by Holocene wide valley and channel fill sediments, which form small fans.

Depositional Environment: All the alluvial fans, in the eastern margin of the Mesopotamia Plain have been deposited by the foothill streams (rivers) that flow out from Himreen Mountains. The classic alluvial fan environment; is evidenced by the unsorted gravels and boulder sediments that are exposed at the apical parts of the fans. Whereas, the rest of their

bulk sediments; reveal fluvial environments. The later is clearly evidenced by better sorting and layering of the sediments; far from the apex of the fans. These sedimentary conditions were repeated in accordance with the main oscillations of the Pleistocene climate, which led to the deposition of successive alluvial fan stages. The sediments of the last stage are deposited by braided rivers and other foothill streams from the Himreen Mountain, either periodically or ephemerally. 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.

- **Alluvial Fan System of the Western Mesopotamia Plain**

This system is represented by three main alluvial fans; deposited at the peripheral parts of the Western Desert, which extend into the margin of the Mesopotamia Plain under the Holocene sediments. They include; the **Alluvial Fan of Karbala – Najaf Plateau, Al-Batin Alluvial Fan** and **Al-Qusair Alluvial Fan.** The geomorphic conditions of the valleys forming these fans differ than the previously mentioned alluvial fans. The desert valleys 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 rule in the development of these fans. The three alluvial fans are described hereinafter.

– **Al-Batin Alluvial Fan:** It is one of the ideal cases of alluvial fans of a desert plateau. It comprises essentially of ill-sorted gravely sand, sandy gravel and gypcrete, with subordinate layers and lenses of silty and sandy clay. 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) also 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 form thin lenses, lenticular beds, reach up to 2 m in thickness, or randomly scattered within the sand beds. The size of the gravels varies from coarse gravels (5 – 20 cm in size), around the apex of the fan in the main channel of Wadi Al-Batin, to fine gravels and pebbles (2 – 5 cm in size), in the peripheral parts of the fans. Planar bedding, cross-bedding and gravel lag are common fluvial sedimentary structures in this fan system. The gypcrete and gypsiferous cementing material are fairly common in surface beds. The thickness of highly gypsiferous sand and gypcrete beds varies in average between (0.5 – 1.5) m.

– **Alluvial Fan of Karbala – Najaf Plateau:** It has almost similar lithologic composition of that of Al-Batin Fan, except the size of the gavels, which is finer (1 – 2 cm) in the former (Al-Khateeb and Hassan, 2005).

– **Alluvial Fan of Wadi Al-Qusair:** It is located south of Nasiriyah and differs from the aforementioned fans, in geomorphic position, lithologic composition and source rocks. It comprises mainly of fairly cemented gravels rich in carbonate rock fragments, originated from the exposed rocks in the near surroundings (see other details in Yacoub, 2011).

Thickness: The exposed thickness of Al-Batin Alluvial Fan sediments, in the sand pits and quarries, in West Zubair area, reaches up to 10 m (Al-Sharbati and Ma'ala, 1983). The thickness of Karbala-Najaf Alluvial Fan varies from (2 – 19.5) m (Al-Khateeb and Hassan, 2005) they considered it as Dibdibba Formation of Pliocene – Pleistocene age.

Age: The age of Wadi Al-Batin Alluvial Fan was considered as Pleistocene by Al-Sharbati and Ma'ala (1983). The geological mapping conducted by Al-Sharbati and Ma'ala (1983) recognized four stages of Wadi Al-Batin, depending on their geomorphic positions. Stratigraphically, these stages could be correlated with the alluvial fan stages of the alluvial fans of the Eastern Mesopotamia Plain (for more details see Yacoub, 2011). The age of

Al-Qusair Alluvial Fan sediments is considered, in the present study; as Late Pleistocene, according to their geomorphological position, on extreme peripheral part of the Southern Desert and because of its limited extension and small catchment area, when compared with the aforementioned fans. Stratigraphically, it is most likely correlated with the fourth stage of Al-Batin Alluvial Fan. Other correlatable gravel bodies with Al-Qusair Alluvial Fan are the elongated gravel bodies, in its southeastern vicinity, which is considered by Yacoub (2011), as small coalescent alluvial fans deposited by the local desert valleys, but then they lost their fan shape due to weathering and erosion.

Depositional Environment: The desert alluvial fans represent fluvial sedimentation took place during the pluvial phases of the Pleistocene, which led to the deposition of wide spread fans, in different position on the peripheral parts of the Southern Desert. In case of Wadi Al-Batin Alluvial Fan, the pluvial periods were interrupted by inter-pluvial phases, which progressively led to the development of four stages of alluvial fans. The gradual fining of the grain size distribution; by time may obviously indicate decreasing in streams capacities and climatic changes during the Pleistocene. The provenance of the alluvial fans is the exposed sediments in the Southern Desert and may extend further to Arabian Shield, in the southwest.

2.3. River Terraces

The Pleistocene terraces include the 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 (Figs.2 and 6). River terraces are also developed in the eastern margin of the Mesopotamia Plain, but with limited areas restricted to the outlets of foothill rivers, at their emergences from Himreen Range. They are preserved on banks of the rivers Diyala, Nafut, Galal Harran, Galal Badra, Chab'bab, Al-Teeb, and Khar Khar (Fig.2).

Lithology: The higher level of the Euphrates River terraces, which are preserved at the top of the cliffs on the right bank of the river valley, consist of highly gypsiferous gravely sand. The gravels have variable shapes, rounded to sub-rounded, composed predominantly 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, comprises inter-bedding of sandy gravel, gravely sand and sand, but laminated horizons of silty clay also occur, locally. The average size of the gravels ranges between (0.5 – 2) cm, and rarely reaches 5 cm. They are essentially composed of quartz and chert, but igneous, metamorphic and carbonate rocks also occur. The sands are grey and greyish brown, fine to coarse grained with distinct lamination and cross-bedding. The terraces of the Diyala River are different from those of the Euphrates River. The higher terrace of the Diyala River, comprises of much coarser gravels (reach up to 15 cm), and composed mainly of carbonates and chert with subsidiary amount of sandstone, igneous and metamorphic rocks; with sandy and mud matrix, massively bedded, and highly gypiferous (Hamza and Domas, 1980). The lower terrace, consists of gravely sand with sandy gravel lenses at the upper part and dominantly sandy gravel at the lower. It seems, that this gravely bed extends below the recent river course, forming valley terrace.

Thickness: The thickness of the higher level of terraces of the Euphrates River is about 1 m, which may represent only a remnants of terraces preserved on the western bank of Euphrates River. While the thickness of the lower level reaches > 7 m, in Falluja vicinity (Hamza and Yacoub, 1982), maximally it reaches 6 m, in Iskandariyah vicinity (Domas, 1983). The terraces extend eastwards from the exposure of Falluja area, 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 (Figs.3 and 4). The thickness of the higher level of the terrace of the Diyala River is about 7 m, whereas the exposed thickness of the lower level of the terrace is 6 m (Hamza and Domas, 1980).

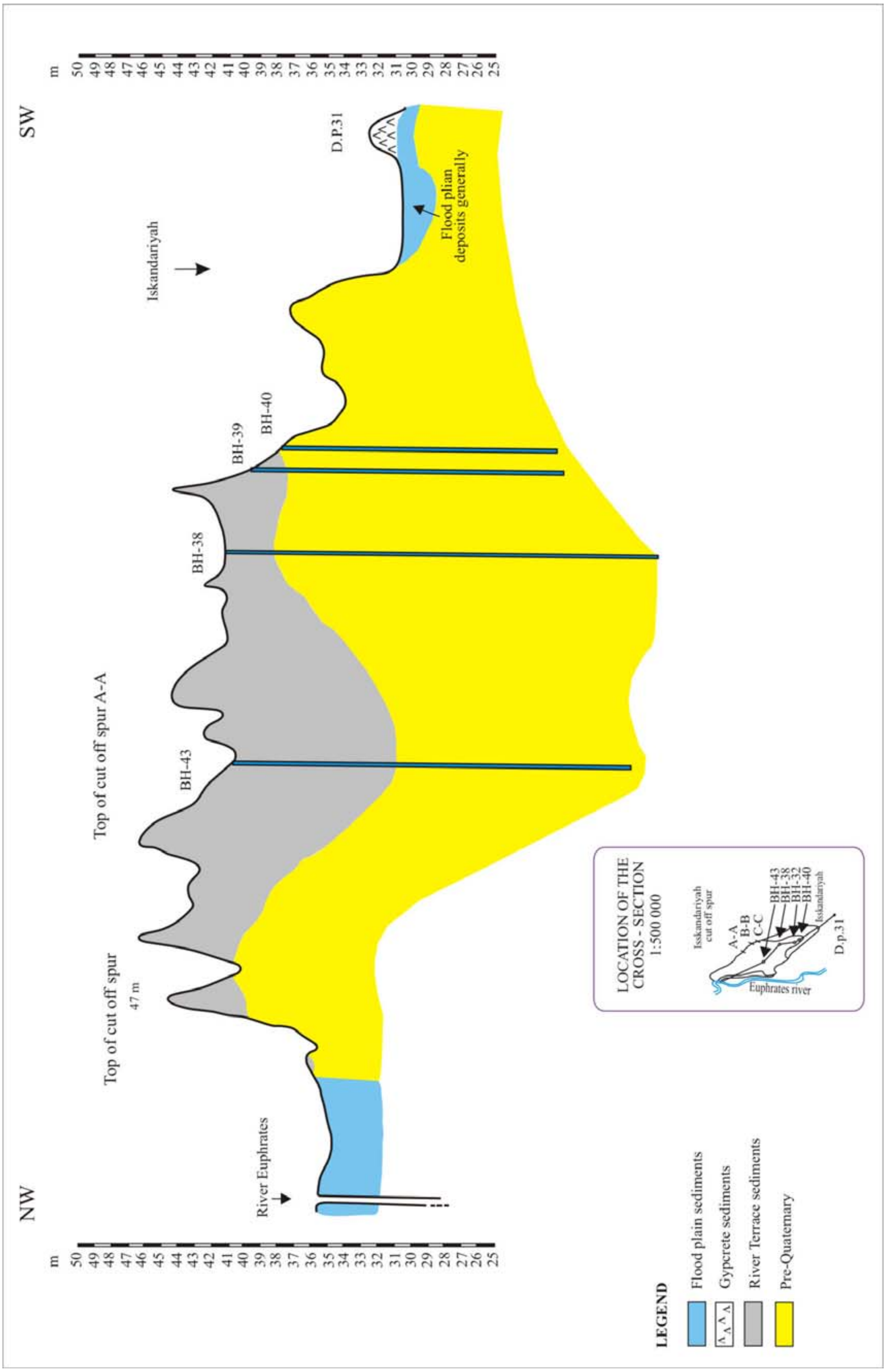

Fig.6: Euphrates River terraces in Iskandariyah vicinity (south of Baghdad)
(modified after Domas, 1983)

Age: The higher level of the terraces of the Euphrates River, which overlies unconformably the pre-Quaternary sediments (supposed to be Injana Formation), more likely is of Early Pleistocene age. It is correlated with the Fatha Alluvial Fan sediments. The top of the higher level of the terraces is about 23 m, above the normal water level of the Euphrates River. The age of the lower level (the younger stage), is most probably of Middle Pleistocene. The top of this stage is about 10 m; above the mean water level of the river. This gap in the elevations between the two stages is attributed to inter-pluvial period, during which erosion processes were prevailing, after the deposition of the older stage.
Depositional Environment: The Euphrates fluvial terrace sediments were laid down by wide river channels of high current and load capacity. The alternation of gravel and sand with local silty clay lenses evidences for braided river channels and/ or for anastomozing stream. The deposition took place in wet climate conditions during the Pleistocene. The presence of river terrace stages deduces big climatic oscillation during the Pleistocene and may be associated with continuous subsidence of the Mesopotamia fluvial basin.

3. Pleistocene – Holocene Sequence

This sequence started to be developed during the Late Pleistocene and continued through the Holocene; hence "Pleistocene – Holocene" age was suggested for the sequence by Yacoub and Barwari (2002). The sedimentary units of this sequence have different origins, such as fluvial, deluvio – fluvial and evaporatic. Three different units are developed, they are mentioned hereinafter.

3.1. Sheet Run-off Sediments

These sediments represent the distal parts of the alluvial fan sediments of the eastern and northeastern parts of Mesopotamia Plain, forming some huge alluvial cones, which are well visible on the satellite images. The cones form extensive plain spread between the alluvial fans and the Tigris flood plain.
Lithology: The sheet run-off sediments consist essentially of alternating layers of sand, silt and silty clay that commonly graded to each others in both vertical and horizontal directions. Layers of pure clay or silt are rare and if exist then does not exceed few centimeters in thickness, whereas individual sand layers reaches up to 50 cm. However, the unit is composed essentially of sand, clayey silt or silty clay; reaching several meters in thickness. The grain size distribution of sheet run-off sediments, generally shows coarsening upwards from the lower (older) beds and towards the apex of the fans. The dominant colors of the sheet run-off sediments are reddish and pinkish brown, which can be used in the field for differentiating them from the adjacent grayish colored flood plain and shallow depression sediments. The sediments are commonly laminated and banded, but the superficial layers are often massive with impressive bioturbation marked by plant root veins and earth warm burrows. Heavy minerals analysis of the sand fraction revealed very high content of opaque minerals with low percentage of amphiboles and pyroxene minerals.

The content of the secondary gypsum and other soluble salts is rather high, the average percentage of TSS ranges from (5 – 10) %, while the SO_3 ranges from (3 – 5) %. The gypsum occurs either as disseminated crystals or concentrated in the form of thin horizons; indicating to the buried sabkhas.
Thickness: The thickness of the sheet run-off sediments starts from few meters, alongside the contact with the alluvial fans and it may reach (14 – 15) m. Further, down slope, where there is alternation with Pleistocene foothills and alluvial fan sediments, the unit may become thicker (Fig.3). The superficial parts of the sheet run-off sediments are still active at present-day.

Depositional Environment: 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. During heavy rainstorms, the flooded shallow water courses are connected with each other forming wide sheet floods. In many cases, these sheets join again forming single channel down slope and the whole process might be repeated. The last sheet run-off deltas end at stagnant water environment; in shallow depressions.

3.2. Slope Sediments

The slope sediments are usually deposited along the foothill slopes, overlying the bed rocks, along the southwestern limb of Himreen structure. They are deposited by gravity on low gradient slopes, thus the term "deluvio – fluvial" was used by Yacoub (1983) and Domas (1983) for these sediments. Slope sediments also were recorded in the extreme margin of the Western Desert forming very narrow strips, not exceeding 2 Km in width.

Lithology: The slope sediments of the eastern margin of the Mesopotamia Plain consist generally of gypsiferous sand and loam with gravels and rock fragments. The secondary gypsum is more concentrated in the superficial layers and locally passes to gypcrete. The sediments in the western margin consist of pebbly coarse grained sands with thin lenses of brown silty clay, and Aeolian admixture.

Thickness: The slope sediments reaches (3 – 4) m in the foothills region and (0.5 – 2) m in the western margin of the plain.

Depositional Environment: The slope sediments were deposited on the foots of structural limbs and hill slopes, because of gravity and fluvial transportation.. In the case of slope sediments alongside Himreen Range, the main source rocks are Bai Hassan, Mukdadiya, and Injana formations, in addition to the older alluvial fans. Whereas in the western side of the Mesopotamia Plain, the main sources are alluvial fans, Dibdibba, Injana, Nfayil, Euphrates, and Dammam formations. The presence of secondary gypsum is a result of evaporation of interstitial water, after or during the deposition of these sediments. The present surface of these sediments is influenced by sheet and rill erosion in addition to Aeolian activities.

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 (Fig.2). Other details are given in the Fatha Alluvial Fan (Paragraph 2.2, p. 58 – 62)

4. Holocene Sequence

The Holocene sediments cover the major part of the Mesopotamia Plain (Fig.2). They form the upper sequence (about 15 – 20 m) of the Quaternary sediments of the Mesopotamia Basin. The Holocene sequence is characterized by alternation of fluvial, deltaic, lacustrine and estuarine/ marine units. At present day, they are represented on the surface by almost similar modern sedimentary environments.

The Holocene started after the end of the last pluvial phase of the Pleistocene, which marked a considerable warming up of the climate. The climatic changes accompanied by waning of rivers capacity, which deduced by the general fining of Holocene sediments, as compared with those of underlying Pleistocene, particularly in the southern reaches.

4.1. Flood Plain Sediments

The rivers Euphrates, Tigris, Diyala, Adhaim and foothills streams built up vast flood plains in the Mesopotamia Plain. Most of these rivers and secondary channels are levee builders, with occasional distinct bedded sediments. The major flood plain of the Tigris and Euphrates Rivers and their distributaries occur in the central and southern parts of the plain, which have been terminated in form of four non-marine (lacustrine) deltas forming the northern and western margins of the marshes between, Amara and Nasiriyah.

It is worth to mention that the flood plains were intensively used by human, since the ancient times and continued to the present time. The irrigation projects that have been constructed during last forty decades have played a significant role in controlling the distribution of rivers and channels flow. Nevertheless, some areas are totally controlled by human activities that became out of the reach of the floods.

Lithology: The typical depositional model of the Mesopotamia Plain sediments involves complicated interfingering lithofacies of channel belt, natural levees, crevasse splays, normal flood plain and flood basins. Consequently, the Holocene sequence comprises of interfingering of fine to medium grained sand of channel belt (including point bars and ox-bow lakes), fine sand with less amount of clayey silt and silty clay of levees and crevasses, and silty clay and clay of the flood basin. This alternation of sand, silt and silty clay, are vertically differentiated by gradual to abrupt boundaries. The thickness of the individual beds is greatly variable, from few centimeters to few meters.

The soluble salt content in the flood plain sediments oscillates around 1%, but locally reaches 5%, and the content of carbonates is around 30%. Secondary gypsum occurs in fine crystalline form, whereas the organic material is moderate, especially in fine sediments. However, marshy horizons are encountered frequently within subsurface sequence of the flood sediments. Slightly weathered horizons also where noticed at different depth intervals. Marshy and weathered horizons represent old surfaces, which are used in stratigraphic correlation.

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

– **Euphrates Flood Plain:** It covers the western part of the Mesopotamia Plain; it is bounded from the west by the Tertiary rocks of the Western Desert, whereas from the east it passes gradually as interfingering and overlapping the flood plain sediments of the Tigris River. It consists predominantly of silty clay, but loamy sand and sandy loam are also recorded frequently. The sands are grey and brown colored, usually massive, fine grained, and contain few pebbles that are probably derived from the fluvial terrace deposits, in Iskandariyah. However, the exposed rocks in the desert also provide rock fragments that might be deposited directly in the flood plain. Silts were found in the boreholes, below ground surface in maximum depth of 4 m, they become massive or laminated, with occasional existence of clay balls. The silty clay is generally brown with common massive bedding, and is rich in secondary salts; mainly carbonate nodules and gypsum as powder or in fine crystalline form.

The sediments of the Euphrates flood plain include weathered horizons, which are indicated by the presence of iron oxides and affected by biological activity. The horizons represent dry period during sedimentation. Marsh deposits also occur frequently that indicate the presence of shallow depressions because of environmental changes during the deposition of the flood plain sediments.

– **Tigris Flood Plain:** It covers the central and eastern parts of the Mesopotamia Plain. It is characterized by muddy sand, fine to medium and even coarse grained; locally pebbly in the upper reaches of the basin, between Baiji and Samarra towns. It is influenced by the adjacent exposed alluvial fan sediments. Further to the south, the sediments of the Tigris River are

greatly influenced by the sediments provided from its main tributaries; Adhaim and Diyala, and foothill Rivers. In the central and southern parts of the Mesopotamian Plain, the silty clay becomes the most common sediments of the flood plain, which thus represents 50% of the total sediments; there the flood plain shows considerable alternation of varied textured sediments. The recent surface sediments show also remarkable influence of irrigation canals (Munir in Jassim *et al*., 1984). The sand is fine to medium grained, massive and variably colored; usually is inter-bedded with thin finer sediments as silty clay; and is deposited in form of beds usually less than one meter thick. Whereas, in the abandoned channels the sand beds reach up to 6 m and exceptionally reach more than 13 m, e.g. in the ox-bow lake south of Azizziyah town (Domas, 1983). The ox-bow lakes include relatively abundant mollusk shells, but they are commonly occurring in silty clay horizons.

The crevasse splay sediments are well developed and cover extensive areas, in particular, of Tigris flood plain from north of Kut to Amara (Yacoub, 2010). They are laid down by local overbank flow; during inundation seasons. Their sediments are usually coarse textured and composed of fine to medium sand with finer lamination of silt and mud. They are deposited in many cycles being separated by weathered soil horizons, each cycle represents a major inundation period that took place during Holocene time.

– **Shatt Al-Arab Flood Plain:** It is characterized essentially by silty clay and clayey silt being most predominant in the recent and sub-recent sediments. Whereas, downstream from Basrah, Shatt Al-Arab has received and is still receiving its sedimentary load mainly from Karun River. The influence of Karun River's input is clearly observed in the modern sediments of Shatt Al-Arab, where they change abruptly from silty mud; around Basrah into brown muddy sand; downstream from their confluence, in vicinity of Al-Siba town (Yacoub *et al*., 1981).

Shatt Al-Arab also built wide (1 – 2 Km) natural levees of brown and grayish brown silt and clayey silt. The flood plain sediments behind the natural levees are dominated by clayey silt and silty clay. The soluble salts content in theses sediments varies from (< 2 – 7.5) %, and is influenced by the adjacent estuarine Sabkha. The sediments are also characterized by relatively high carbonate fraction (up to 45%), when compared with the Euphrates and Tigris Rivers flood plain sediments, which is around (25 – 30) % (Domas, 1983 and Yacoub *et al*., 1985). The carbonate fraction includes up to 10% dolomite, which might be provided from the marshes and lakes; in addition to that provided by tidal action from sea (Yacoub *et al*., 1981).

Thickness: 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, which was first described by Hudson *et al*. (1957); further details are given in article (4.5).

Fauna: The fauna in the flood plain sediments are mostly mollusks, in addition to some micro fauna. However, they vary depending on the rivers, which have supplied them. The Tigris River flood plain's sandy sediments, in Amara vicinity contain mostly *Cubicula* and reworked Tertiary and Quaternary forams, whereas the finer fraction includes; *Planorbis, Bellamy Neritina, Cyprideis* and ostracods. These assemblages indicate only freshwater environment; and cannot be used for age determination.

Depositional Environment: During early Holocene, the main rivers started to insist their channels across older Pleistocene sediments on the peripheral parts of the fluvial plain, forming narrow flood plains at their upper reaches, which were widened gradually downstream resulting into vast flood plains with gentle surface gradient. The sedimentary environments of the flood plain differ according to the micro-morphological position and climatic changes, during the Holocene. These are determined in subsurface by vertical and

horizontal lithofacial changes and repeated sedimentary cycles, in the Holocene; using sequence correlations. The sand isoliths map of Holocene sediments, which was published by Aqrawi *et al*. (2006) revealed that the main river channels of the Tigris, Euphrates, Diyala and Adhaim migrated through time within the central parts of the basin. This phenomenon was also confirmed in the recent and sub-recent sediments by the presence of abandoned river channels, which are clearly visible on the aerial photographs and satellite images of the Mesopotamia Plain (Yacoub, 2010). The flood plain sediments comprise slightly weathered horizons with some biological activity, which are preserved at different stratigraphic levels within the Holocene sequence, indicating that the sedimentation was interrupted by short breaks in some places and continued in others, throughout the Holocene.

During the late Holocene, the flood plain sediments were greatly influenced by irrigation artificial canal systems and were contaminated generally with reworked sands and silts, which were transported by irrigation water. Both ancient and modern river branches of the Tigris and Euphrates Rivers are densely bifurcated at the lower stretches of the plain, forming extensive deltas/ crevasse splays along the northern and western margins of the marshes in Southern Mesopotamia Plain.

4.2. Shallow Depression Fill Sediments

The term depression fill sediments was suggested during mapping of the Mesopotamia Plain (GEOSURV), for depositional environment in topographically lower parts within the flood plain. The Mesopotamia Plain includes various types of shallow depressions, because of fluvial processes. They differ in dimensions and geomorphic position and in origin as well.

The shallow depression fill sediments occur in the lowest topographic parts of the flood plain, forming flood basins of the rivers and active stream channels. The major depressions occur between the natural levees of the Tigris River and the distal parts of the alluvial fans in the eastern 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. However, minor depressions are widely spread in the Tigris and Euphrates flood plains.

Lithology: The sediments of the shallow depressions of the main rivers and their distributaries, as well as of Hor Al-Shuwaicha are generally fine silts and clays, with local fine sand inter-layers. They may show thin laminations due to of color or textural difference. They are often grayish brown and greenish grey colored, with vary-colored mottling. The characteristic feature of the shallow depression sediments is relatively the high biological activity, which is represented by moderate amount of mollusk shells and humificated organic matter. The salts accumulated as thin films or laminations surface or as disseminated crystals within the sediments. The TSS content usually ranges between (2 – 5) %, but in some places is much higher, for example in Hor Al-Shuwaicha reaches more than 17%, in the upper 0.5 m depth (Domas, 1983).

The sediments of the shallow depressions of the western margin of the Mesopotamia Plain comprise relatively coarser texture, as compared with the aforementioned depressions. They comprise clayey silt, silty and sandy clayey silt, with thin sand and silty clay intercalations. The main sources of the coarse admixtures in the shallow depressions are the out wash of the exposed rocks in the adjacent desert plateau, and windblown sand. These sediments are often covered by thin salt crust, mainly gypsum, which makes the surface puffy (wrinkly).

Thickness: The thickness of typical shallow depression sediments may not exceed 1 m. However, it ranges from few tens of centimeters to few meters in small and large depressions, respectively.

Age: The age of surface depression fill sediments is doubtlessly recent to sub-recent Holocene, formed contemporaneously with flood plain sediments. They are also recognized at different stratigraphic levels in the subsurface layer sequence of the Holocene sediments.

Depositional Environment: Most of the depressions are actually flood basins, which represent fluvial or fluvio – lacustrine depositional environment. The grey color of the depression fill sediments indicates stagnant water environment, which is accompanied with increase of the biological activity and organic material. The upper horizon; sometimes is weathered and locally represents fossil soil (Aqrawi *et al*., 2006). The shallow depressions in the abandoned flood plains may be not active any more; due to their geomorphic position, far from the water sources and they 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.

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 between the fluviatile deltas and the estuarine sabkhas, in the north and west, and Al-Batin Alluvial Fan in the south (Fig.2). The lacustrine complex includes three distinct subenvironments (Yacoub *et al*., 1985).

– **Marsh Sediments:** The typical marsh sediments have a dark grey or black horizon (up to 50 cm) at the top, which consists essentially of humificated plant debris (peat) and other organic materials mixed with mud; often contains fine lime nodules, amorphous or crystalline gypsum, and mollusk shells. Invariably, this dark horizon grades rapidly downwards into greenish or blush grey silty clay or mud layer. The marsh and sub-marsh sediments are locally intercalated by brown lenses or mottling, which indicates influence of fresh sedimentary input of the rivers and irrigation canals; the brown colored mud increases towards the margins of the marshes (Yacoub *et al*., 1981).

– **Fresh Water Lake Sediments:** They are characterized by light grey to bluish grey, highly calcareous mud, with thin dark grey lamina or mottling. Beside, quartz and clay minerals, the carbonates form, generally the dominant mineral constituents of the lake sediments. The carbonates attain highest concentration (about 55%) in Zichri and Baghdad Lakes, which are located in the Central Marshes, west of the Tigris River. The carbonate fractions tend to decrease progressively towards the fluvial channels and deltaic plain, suggesting that its origin is independent from fluviatile supply (Yacoub *et al*., 1981). The clay minerals in the lake sediments are similar to those in river deltas and flood plains. However, significant number of samples, in addition to common clay mineral suite (chlorite, illite, kaolinite smectite) also contain attapulgite in minor quantities. This fibrous clay may be regarded as typical characteristic of these lacustrine environment, in the Central Marshes. In spite of the overall importance of the carbonate fraction within the lacustrine sediments, several samples from the central parts of Hammar Lake (recently, it is mostly dried) 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.

– **Salt Water Lake Sediments:** They are developed in the southern part of Hor Al-Hammar, in Khuraiz Al-Maleh and Horat Al-Luqait salt lakes, which were 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, the sand fraction increases towards their southern shore being influenced by the outwash of the adjacent Southern Desert sediments and Aeolian admixture. The presence of powdery gypsum grains is around 20% within the sediments with possible traces of dolomite, this also express the highly restricted nature of these lake environments.

Thickness: The thickness of the marsh and sub-marsh soil may not exceed one meter, in most cases; but locally reaches more than one meter.

Age: The age of the modern marsh sediments is late Holocene, which were developed after the last retreat of the Holocene sea (2900 ± 550 years B.P., Aqrawi, 1993), depending on C^{14} dating of sediments collected from two localities in Hammar and Luqait Lakes. He also concluded that the age of the upper 35 cm, unit of marsh sediments in Hammar Lake is < 400 year; and the lower part, shelly unit of the studied section 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 (Fig.7).

Fauna and Depositional Environment: The mollusk fauna recorded in **marsh sediment** are dominated by relatively large gastropods: *Viviparus* and to lesser degree by *Planorbis* sp., *Lymnaea, Unio* and *Milanodes* (fresh water mollusks). Raji (1983) recognized the following ostracods within the marsh sediments of Holocene sequence; obtained by drillings in the area between Euphrates and Tigris Rivers: *Candona* sp., *Ilyocypris* sp., *Darwinula* sp., *Cyprinotus* sp., *Cypridopsis* sp., and *Limnocythere* sp., these fauna represent fresh stagnant water, in shallow aquatic environment.

The abundant fauna of **brackish water marsh sediments** are: *Hydrobia* sp., *Melania* sp., *Planorbis* sp.and *Cyprideis* sp., in addition to rarely preserved fauna as; *Lymnaea* sp., *Melanopsis* sp., *Cyridopsis* sp., *Darwinula* sp., and *Candona* cf. *neglecta* SARS. Some of the mentioned faunas represent a wide salinity range, but the general faunal assemblage shows the deposition in shallow – brackish water environment.

It is worth to mention that the Euphrates and the Tigris Rivers lose most of their sedimentary load in the deltaic fans at the northern and western margins of the marsh and lacustrine complex. Consequently, the suspended loads supplied by the two rivers were very low. Aqrawi (1995) calculated the rate of the sedimentation in Hor Al-Hammar, as 0.4 mm/ year, during the late stage of Holocene. It is also clear that the Aeolian supply to the marshes is very significant; the presence of annual dust storms has obvious sedimentological implications on the sediments of the marshes. Aeolian effects were confirmed by the micro-morphology of the quartz grains from lake sediments (Yacoub *et al*., 1981).

Recently, the aforementioned aquatic environment witnessed many changes due to man activities during the last three decades. Vast marsh lands have been dried out artificially during 1993 through beginning of 2003, and their floors exposed to the surface weathering and wind erosion. Consequently, new environmental conditions were prevailed accompanied by change in vegetation and land cover. However, 50% of the marshes and lakes have been re-watered and rejuvenated (Abdul-Jabbar, 2008 and Al-Ma'amar *et al*., 2008).

4.4. Inland Sabkha

The main sabkhas are restricted to the shallow depressions and playas; particularly those situated along the western and southern margins of the Mesopotamia Plain. Playas and salt marshes also are developed between the Tigris flood plain and sheet run-off plain, as well as between the contact of the alluvial fans and sheet run-off plain. Other sabkhas are in the vicinity of Hor Al-Dalmaj, in the central part of the plain, between the Tigris and Euphrates Rivers. In addition to inter-dune sabkhas, which have smaller extensions and developed in some depressions within the sand dune fields; such as those in west of Adhaim River, northeast of Ba'quba, and south of Samawa (Fig.2).

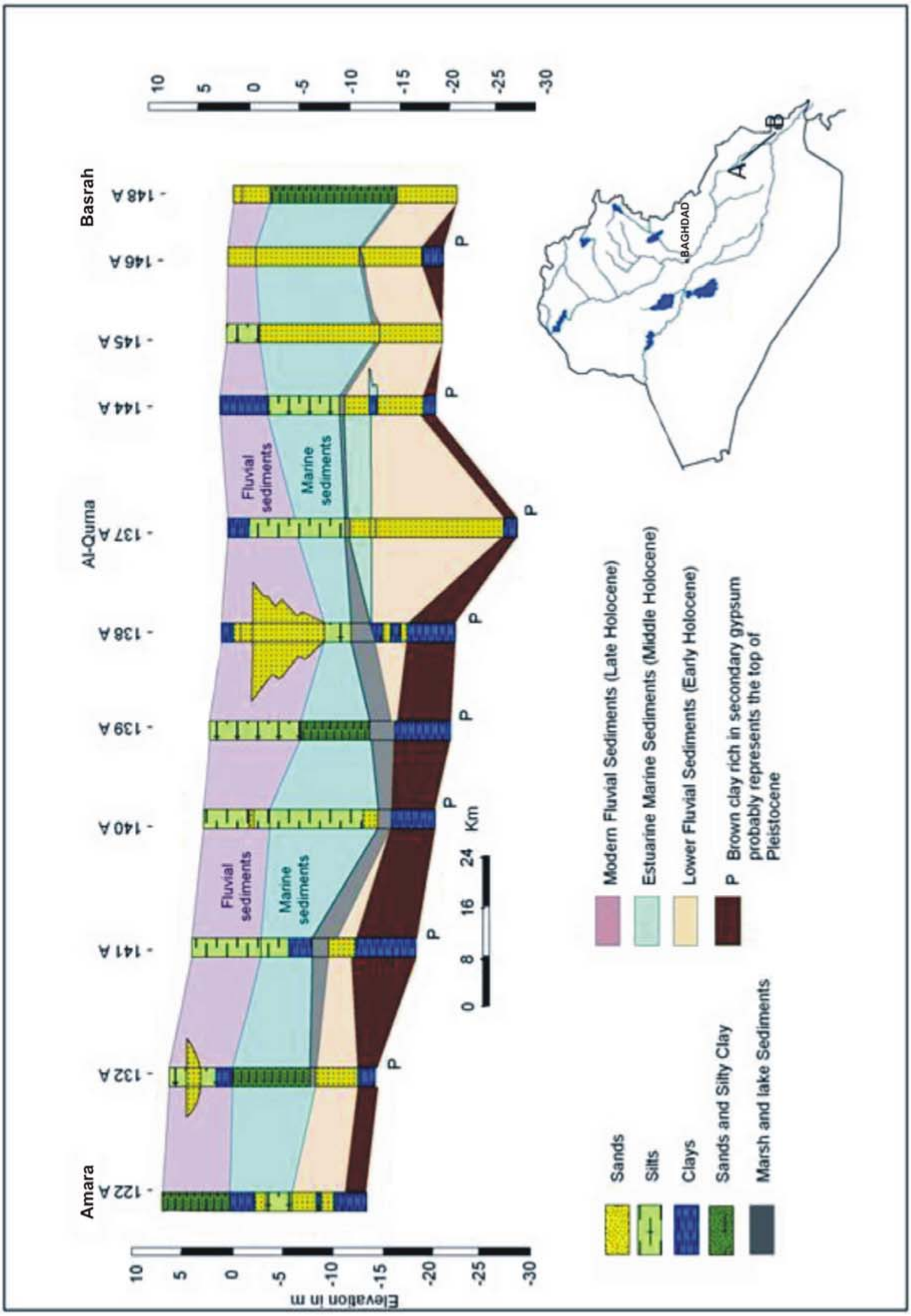

Fig.7: Subsurface profile from Amara – Basrah, shows the Holocene stratigraphic units, in the southern part of Mesopotamian fluvial basin (modified after Munir, in Jassim *et al.*, 1984)

Most of sabkhas are resulted after intensive evaporation of salty water accumulated on the surface or rise to the surface from shallow underground water in some depressions, e.g. Hor Al-Sanaf (north of Amara). Extensive sabkhas are developed in the vicinity of Hor Al-Dalmaj, west of Kut as a result of evaporation of salty water collected by the drainage and irrigation canal systems. The western and southern sabkhas are rather complex, being influenced by Aeolian activities, thus the sediments have more sandy fraction.

Lithology: Generally, most of the aforementioned sabkhas are rich in sulfates, mainly gypsum, with fewer amounts of chloride salts. Al-Sanaf (Hor) Salt Marsh is a good example of sabkhas in the Mesopotamia Plain. It is characterized by alternation of vary-colored fine clastics dominated by reddish brown silty clay and clayey silt with intercalations of powdered gypsum layers. The thickness of the individual layer ranges between (5 – 10) cm. The fine crystalline and powdery gypsum, locally becomes predominant and reaches > 1 m in thickness. The gypsum content in Al-Sanaf (Hor) Salt Marsh sediments is about (65 – 75) %. The main source of the gypsum and other salts is the highly gypsiferous Pleistocene sediments and exposed pre-Quaternary rocks in Himreen Mountain; they brought to the depression mainly by Al-Teeb and Khar Khar Rivers from the north and northeast. The depression is fed also by the irrigation canals from the west and southwest.

Thickness: Sabkha sediments are usually concentrated in the upper layers of the depression fill sediments, they usually are less then 0.5 m, but occasionally may reach more than 1 m.

Age: The surface sabkhas stared to develop during the last phase of Holocene and continued to the present day. Older sabkhas are not frequently preserved in the subsurface sedimentary sequence of Holocene; it may be due to dissolving of the salt layers by groundwater. However, layers rich with gypsum crystals were recorded in some boreholes, particularly in the western margin of the Mesopotamia Plain.

Depositional Environment: Sabkhas are typical sediments of arid and semiarid climatic environments, which are characterized by alternating wet and dray seasons. During the wet seasons (flood season) fine clastics are laid down, whereas the salts have deposited after intensive evaporation during the dry seasons. The shallow groundwater also played an important role in supplying access of salts to the surface of sabkhas.

4.5. Estuarine and Marine Sediments

The extremely southeastern part of the Mesopotamia Plain represents the coastal region at the head of the Arabian Gulf. It is characterized by three main sedimentary environments: **1)** Fluvial Shatt Al-Arab with Karun River, which have been described in previous article (4.1, p.67), **2)** Estuarine sabkha, and **3)** Marine tidal flat (Fig.8). The last two are described hereinafter.

- **Estuarine Sabkhas**

The estuarine sabkhas characterize the area between the Shat Al-Arab flood plain and Khor Al-Zubair. Most probably, it is formed by seawards progradation of the coastline.

Lithology: Estuarine sabkha is mostly of fine texture, mud (silt and clay), generally predominating over the sand fraction. Sand occurs at the western side, being supplied from the desert high land. It is characterized by great abundance of evaporite minerals, some horizons (2 – 5 cm) being deposited as pure gypsum; some times finely laminated, these laminations may be related to thin algal mats; reflecting marine influence. The total soluble salts in the sediments reach 15%, as measured at the top soil from clay samples. Carbonate content attains 45%; including 10% dolomite (Yacoub *et al*., 1981).

Thickness: The thickness has not been recorded, because the groundwater is very near to the surface, therefore the digging of the pits was almost impossible. However, the author believes that the modern sediments could be more than one meter; below the surface.
Age: The estuarine sabkhas started to develop after the last regression of the sea in late Holocene time and continues to the present day.
Fauna and Sedimentary Environment: The estuarine sabkha contains scattered marine mollusks (notably *Cerithiadae*, *Cingulate*, and *Neritina*) and crab remains transported into the sabkha during flooding. The estuary sabkha expresses the combined effect of fluvial and Aeolian sedimentation, with remarkable marine influence, where the associated brines delivered primarily from the sea water. The characteristic (somewhat wavy appearance) of the lamination is probably resulted from periodic flooding of slightly irregular surface, followed by intensive desiccation.

- **Tidal (mud) Flat**

Tidal flat occurs only as a narrow flat coast, about (1 – 10) Km wide, in low sea water level conditions, 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.
Lithology: The tidal flat is characterized by fine textured sediments, usually silt and clay, and occasionally sand. The sand is abundant at Khor Al-Zubair coast, due to influence of the reworked sediments of the Dibdibba Formation. The clay, in general reveals the absence of sand fraction delivered by Karun River; this suggested the inexpressive recent influence of the river on the sediments in the estuary area. However, electronic microscopic study of quartz grains from silt and clay in Khor Al-Zubair shows a very distinctive morphology of marine water, and many grains show the indication of Aeolian transportation (Yacoub *et al*., 1981).
Thickness: The exposed thickness of the tidal flat sediments, on the banks of Khor Al-Zubair tidal channels is around (2 – 3) m.
Age: The surface and near surface tidal flat sediments are probably late Holocene and continue to recent time.
Fauna and Depositional Environment: The Shatt Al-Arab and the adjacent sediments of tidal flat are essentially fresh water with little marine influence, in spite of their remarkable tidal effect. The adjacent tidal flats however, have a scattered marine fauna represented by crab and *Periothalamus* (Fig.8). In Al-Fao, brackish water mollusks were found including gastropods with predominant *Cerithiadae* and *Neritina*, in addition to small oysters. The mentioned fauna are also found in Basrah vicinity; this suggested recent marine influence in these areas. The marine environment of Khor Al-Zubair estuary shows the presence of some ostracod species as *Cyprideis* and gastropods as *Pirenella* and *Melanopsis*.

4.6. Subsurface Estuarine/ Marine Sediments

The subsurface Holocene sediments of the southern part of the Mesopotamia Basin are studied well during regional geological mapping (Yacoub *et al*., 1985). A complete sequence of sediments through the Holocene has been found preserved in Amara, Nasiriyah and Basrah areas (Figs.6 and 7). Below the base of the sequence, there is a fluviatile brown silty clay with coarse crystalline gypsum, this clay was suggested to be deposited in dry climate at the end of the Pleistocene, and all the overlying sequence deposited during the Holocene.

The Holocene sediments can be divided into three stratigraphic units: **1)** Lower Fluvial Sandy Unit, **2)** Estuarine/ Marine Unit, and **3)** Upper Fluvial – Lacustrine Unit. The upper unit includes the late Holocene and the modern sedimentary environments, which is described in article (4.3), whereas the first two units are described hereinafter.

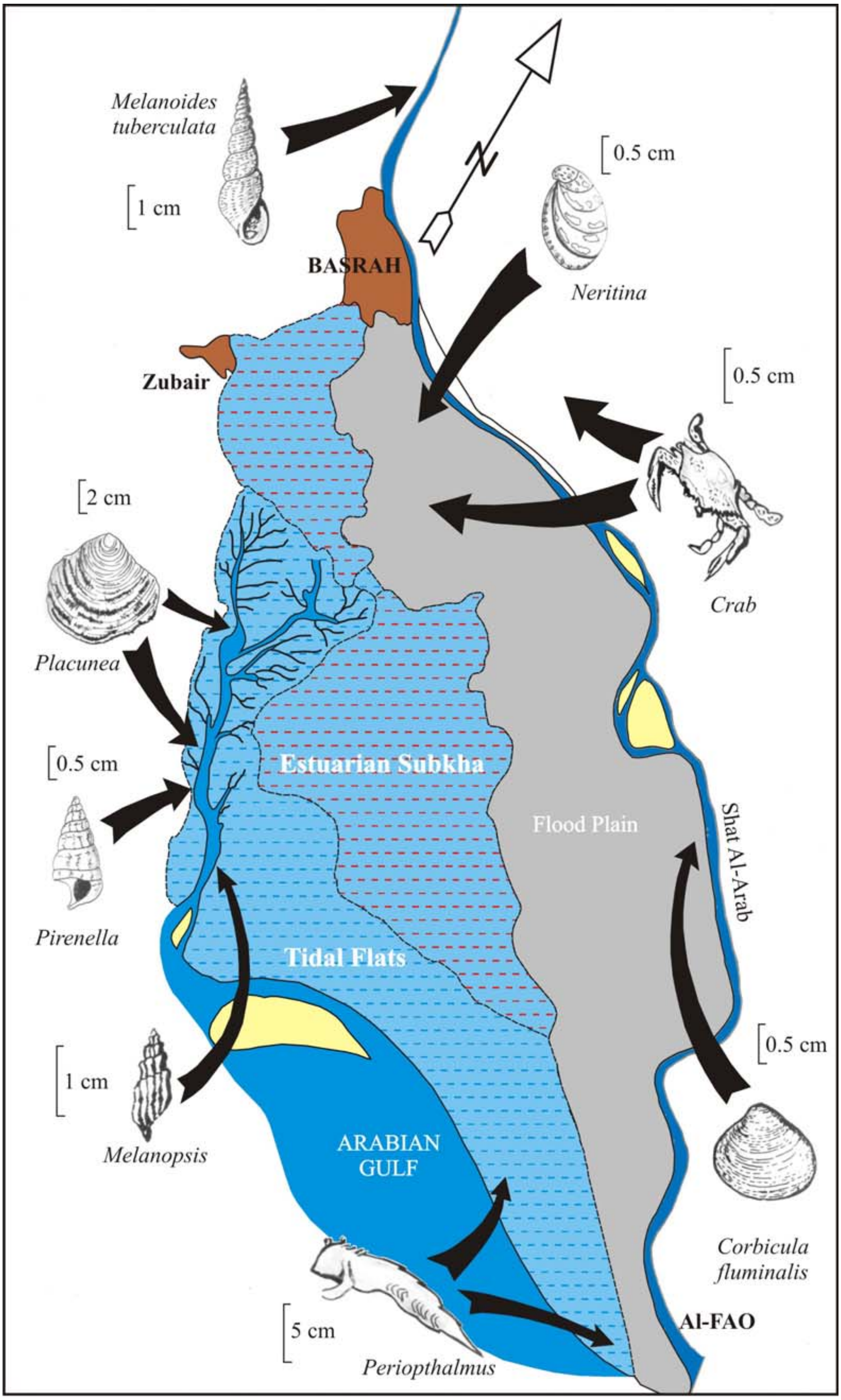

Fig.8: Geological map of the costal region with distribution of some faunal assemblages in different sedimentary environment (modified after Munir, in Yacoub *et al*., 1985)

– **Lower Fluvial Unit:** It comprises mainly of silty sand sediments and has weakly developed gypsum at its base. The deposition of this unit, in river flood plains began during the end of Pleistocene and persisted until early Holocene (about 9000 B.P., Munir in Jassim *et al*., 1984). The fluvial sand shows increase in thickness toward south from Qurna to Basrah, which reflects relative high rate of sedimentation, in this part of the basin, during the deposition of this sand. Aqrawi (2001) has also described the early Holocene sediments as the ancient marsh/ lacustrine silty sand unit, usually merges laterally into thick ancient fluvial-plain sediments, in the Southern Mesopotamia Basin. However, the sediments were highly admixed with coarse sandy deposits of playa and Aeolian sources in the Southern Desert margins, and with older reworked sands of Zagros Foothills, to the northeast of the Mesopotamia Plain.

– **Estuarine/ Marine Sediments:** These were first described by Hudson *et al*. (1957), and named as **Hammar Formation** (includes the lower fluvial unit), in Zubair oil well No.31, at Latitude 30° 31' 00" and Longitude 47° 36' 34". The beds were encountered at depth interval (6.1 – 12.5) m, overlying the Dibdibba Formation. The sediments yielded marine mollusk fauna of Holocene age, and numerous foraminifera, crab and echinoid fragments as well. Mac Fayden and Vita-Finzi (1978) collected samples from Amara and Qurmat Ali, the Qurmat Ali sequence yielded marine fauna, which is from (2.4 – 21.3) m, below sea level and at depth interval (2.7 – 8.5) m, in Amara. They reported a mixture of fresh water and marine sediments, according to the presence of estuarine and marine fauna. The regional geological mapping of the Mesopotamia Plain (Yacoub *et al*., 1985) reported estuarine sediments at different levels (the top ranges from 3 to 10 m) in borings below ground surface in Amara, Qurna, Nasiriyah and Souq Al-Shiyoukh.

Lithology: The estuarine/ marine sediments comprise of fine to medium grey sand, with thin lamina of silty clay and clayey silt; 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. Aqrawi (2001) subdivided the brackish-marine unit into four coarsening-up subunits. At the base of this unit, ancient marsh and lacustrine sediments were distinguished; they were deposited at the early stage of marine transgression. This unit is characterized by a transgression surface; rich in shelly sediments and by authigenetic brackish-water dolomite (Aqrawi, 2001).

Thickness: The thickness of the estuarine/ marine sediments is (5 – 12) m, as recorded in the shallow boreholes of the geological mapping (Fig.7). However, in Zubair oil well No.31, the measured thickness of Hammar Formation by Hudson *et al*. (1957) is 6.4 m. The estimated thickness after Mac Fayden and Vita-Finzi (1978) is 17.9 m (from 2.4 to 21.3 m, below the sea level) in Qurmat Ali, and 5.8 m (from 2.7 to 8.5 m below sea level) in Amara.

Age: The estuarine/ marine sediments are of Holocene age, depending on the faunal assemblages. However, Aqrawi (1995 and 2001), determined the age more precisely as Middle Holocene depending on the C^{14} dating. The analyzed samples showed that the oldest one is (8350 ± 230 years B.P.); the sample was collected from borehole located about 25 Km west of Basrah at depth interval (14.0 – 14.2) m, below the surface.

Fauna and Depositional Environment: South of Qurna, the estuarine/ marine sediments, as described in deep borehole No.17 at Latitude 30° 45' 50" and Longitude 47° 34' 01", show a sequence of fine to medium grained, grey sand with thin clay inter-beds. This sequence yields marine fauna at depth interval (5.3 – 18.0) m. The following fauna were determined (Salman in Jassim *et al*., 1984), Foraminifera: *Quinqueloculina confuse* REUSS, *Q. akneriana* D' ORBIGNY, *Q. arenosa* TERMEQUEM, *Q. pygmaea* REUSS, *Q. mauricesis*, HOWD, *Q. limplexa* TERMEQUEM, *Q. parvula* SCHLUMBERGER, *Q. gibbosa* HUSSEY, *Spiroculina* sp., *Triloculina* sp., *Ammonia beccarii* LINNE; Ostracods: *Cyprideis* sp., *Cytheretta* sp., *Candona* sp., *Cyprinotus* sp., *Corbicula* sp., *Tellina* sp., *Barbatia* sp.,

Spondylus sp., *Glycymeris* sp., *Venus* sp., *Pitar* sp., and *Brachidontes* sp. According to Karim, oral communication in Jassim *et al*. (1984), the abundance of well preserved foraminifera species, as *Quinqueloculina* and *Triloculina*, and the common occurrence of calcareous *Ammonia* in depth between (16.5 and 17.75) m, indicate hyper saline shallow marine environment. At depth interval (7.9 – 13.8) m, the presence of many broken shells of *Osterea* and rare occurrence of foraminifera in oxidized form, indicates an active marine environment of very shallow depth. In deep borehole BH-19, located at Latitude 31° 46' 10" and Longitude 47° 01' 23", which is located 14 Km southwest of Amara, marine fauna were also recorded (Salman, oral communications in Jassim *et al*., 1984), in grey sand and silt at depth from (9 – 19.5) m. The fauna are: Foraminifera: *Quinqueloculina akneriana* D' ORBIGNY, *Q. laevigata* D' ORBIGNY, *Nonion* sp., *Ammonia beccarii tepida* CUSHMAN, *Ammonia beccarii globula* CLOM, *Triloculina inornata* D' ORBIGNY, *Spiroculina concave* PETRI, *Elphidium articulatium* (D' ORBIGNY) CUSHMAN, *Elphidium incertum* WILLIAMSON; Ostracods: *Cyprideis* sp., *Ereptocypris* sp., *Cytheretta* sp., *Darwinella* sp., *Stenocypris* sp., Pelecypods: *Tellina* sp., *Corbicula* sp., *Ostrea* sp., *Pecten* sp., *Pitar* sp., *Venus* sp., *Abra* sp., *Spondylus* sp., *Anadara* sp., Gastropods: *Torinia* sp., *Cerithium* sp., *Lymnaea* sp., *Turritella* sp., *Pirenlla* sp., *Hydrobia*, *Caecum*, *Melania*, *Planorbis*, *Valvata* and also *Charaphite* and *Bucella* sp., (Karim oral communication in Jassim *et al*., 1984). The presence of aforementioned fauna, suggest that the location was nearer towards the inner shelf than lagoon, and quite warm marine environment.

In Nasiriyah and Souq Al-Shiyoukh area, Raji (1983) recorded the following marine fauna, in a sequence of grey and green clayey silt, and sandy clayey silt, which was struck by many shallow boreholes: Foraminifera: *Ammonia beccarii parkinsoniana* D'ORBIGNY, *Rotalia punctatogranosa* SEGUENZA, *Rotalia umbonata* LEORY, *Elphidium clavatum* CUSHMAN, *Buccella frigida* CUSHMAN and *Nonion* sp., Ostracods: *Cytherella* sp. *and Cyprideis* sp., Molluscs: *Abra* sp., *Pirenella* sp., *Bulimus tentaculatus* (LINNE), *Bellemya* cf. *bengalensis* LAMARCK, *Eulimella* sp., and *Amnicola cjecta* MOUSSON. These faunal assemblages indicate a very shallow marine environment. The marine sediments, recorded by the geological mapping were considered to be coinciding with Hammar Formation (Munir in Jassim *et al*., 1984). The aforementioned evidences for estuarine marine sediments confirm that the southern part of the Mesopotamia Plain was highly influenced by Holocene marine inundation, and the sea reached as far as Amara and Nasiriyah. The rise of the sea level started at early Mid-Holocene (about 9000 years B.P.) and reached its optimum around late Holocene (4000 years B.P.) (Aqrawi, 1995). Then a major sea regression occurred and subsequently modern marsh and lake complex were developed. Yacoub *et al*. (1981) noticed estuarine fauna including oysters and gastropods with oolitic limestone; along the southern shores of Hammar Lake, situated at or near the surface. Their presence clearly indicates recent changes in environments. Similarly, the presence of numerous crab remains and marine mollusks on the surface of sabkha, northwest of Basrah also indicates rapid evolution of this area. Aqrawi (1993) concluded that the effect of the sea level fluctuation may have been ended nearly 3000 years B.P. The Paleogeography of the marshes area has changed from brackish lagoon and intertidal flats into inland lake and marshes, in the modern environment.

4.7. Anthropogenic and Irrigation Canal Sediments

The irrigation canal system (both ancient and recent), ancient settlements and artificial tells (hillocks), represent the main effective man's activities on to natural sedimentation of the fluvial regime in the Mesopotamia Plain. They are often concentrated in the ancient civilized centers (ancient cities) and along the main abandoned river courses. They have outstanding reliefs on the almost flat-lying surface of the plain.

Lithology: The anthropogenic sediments consist, generally of fine clastics of different origin, mixed with brick and pottery fragments or other artifacts; 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 artifact stones is the destroyed ancient settlements either transported for short distances or accumulated insitu. The ancient settlements and their relics also act as obstacles around which Aeolian and flood plain sediments accumulated in form of hillocks. The irrigation canal sediments consist relatively of coarse grains, as compared with the surrounding flood plain sediments, they were built up commonly by silts and fine sands, with subordinate clay fractions, which reflect the condition of frequent wide oscillation of water flow in the canals. The common colors are brownish and greenish grey with slight yellowish tints; locally are darker bluish grey, due to the influence of humificated organic matter. They are either deposited in massive beds or laminated and banded layer; cross-bedding have also been noticed (Yacoub *et al*., 1985).
Thickness: The thickness of the irrigation canal sediments may often not exceed 1 m; but they may reach several meters in some archeological sites.
Age: 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 later time interval. Besides that, the modern nets of irrigation canals are wide spread throughout the recent flood plain.
Depositional Environments: The irrigation canals carry the sedimentary loads far from main rivers and spread them over large areas of flood plain (even during normal water level conditions). They brought rather abnormal coarser sediments with respect to the flood basins, shallow depressions and marshes during high water and flood conditions. This case is frequently evidenced on the margins of the flood plain, where most of the canals are terminating. These all together with related agricultural activities played significant role in modifying the natural morphology, as well as the sedimentary processes in the Mesopotamia Plain.

4.8. Aeolian Sediments

The Aeolian activities characterize the arid and semi-arid climatic conditions, which were prevailed during Holocene Epoch, in the Mesopotamia Plain. Their influences progressively increased, particularly during the Late Holocene, and they became more effective in the modern environments. The Aeolian activities are widely spread in the modern environment of the Mesopotamia Plain; as a thin discontinuous sand sheet, or as very small accumulations, but the most extensive Aeolian sediments are concentrated in large fields.

The main Aeolian fields are developed in three geomorphic positions in the Mesopotamia Plain: along the northeastern and southwestern margins and the central part of the plain (Fig.2). They are different in grain size, mineral constituent and source sediments. The sediments of the most extensive Aeolian fields are described hereinafter.
Lithology: The lithology of each sand dune field is described separately, hereinafter**.**
Aeolian Sediments Along Himreen Range are concentrated in large fields; west of Adhiam River, south of Mukdadiya and west of Ali Al-Gharbi. They generally consist of fine to medium grained sand, with few amount of silt and clay fraction. Occasionally, coarse sand fraction was recorded within the Aeolian sediments of dry foothill valleys. The sand grains are composed mainly of quartz, chert, limestone, and few amount of heavy minerals; the main

source of these sediments is the exposed Miocene and Pliocene rocks in Himreen Range and Quaternary sediments.

Aeolian Sediments of the Western Margin of the Mesopotamia Plain comprise mainly of fine to medium grained sand, with few coarse admixtures, and subordinate amount of clay and silt fraction. The sand is composed essentially of quartz, carbonate and less amount of feldspar, and rock fragments. The percentage of quartz grains often exceeds 50% and the carbonates reach up to 27.5%, in Samawa area (Al-Ani, 1979). The main source of Aeolian sand in this area is the Late Neogene and Pleistocene rocks, which are exposed in the Southern Desert, and along Tar Al-Najaf, besides the local Quaternary sediments.

Aeolian Sediments of the Central Part of the Mesopotamia Plain are developed between the Tigris and Euphrates Rivers, overlying the pre-existed abandoned flood plain sediments. They are associated with dense anthropogenic sediments, which are well preserved in this area. The sediments of this field comprise essentially of fine sand, silt and clay; locally rich with mud flakes and mollusk shell fragments, which are deflated from the surrounding dry marshes and lake sediments. The main sources of the sediments; of this field are the flood plain sediments of the Tigris and Euphrates Rivers and related branches, and the ancient irrigation canals, as well.

Most of the Aeolian sediments are deposited in massive bedding, however, horizontal and cross bedding were noticed in some profiles; surface ripple marks are well developed and very frequently visible sedimentary structures in Aeolian fields.

Thickness: The deflated sand sheets may not exceed one meter in thickness, but they often have wide extensions. The thickness of the Aeolian sediments, generally in Barchan fields reaches 5 m, but exceptionally they attain (25 – 30) m, in southwest of Samawa.

Age: The author believes that the bulk of the Aeolian sediments are accumulated during the late Holocene, however they could be started slightly earlier, but during late Holocene more arid conditions were prevailing. Two stages of Aeolian sediments were observed in the field, the relatively older stage is the fixed Aeolian sediments, which are usually coated by thin mantle of weakly cemented soil with small native vegetation helped in fixing these friable sediments. The younger stage is the still active one. The sediments of the marginal parts seem relatively older than those deposited in the central part of the plain.

Depositional Environments: The orientation of the sand dune fields is usually NW – SE that coincides with the general trend of the basin, which is bounded by topographically high terrains trending in the same directions. The windward slopes of individual Barchans dune are always facing the wind direction, which indicate that the prevailing wind is the N – S and NW – SE.

It is worth to mention that the influences of the wind activities are intensively increased during the last three decades, as a result of drought environmental conditions, which affected on large rural and agricultural lands of the Mesopotamia Plain, particularly those areas located adjacent to the sand dune fields. The sand dunes are creeping relatively, quickly to cover large parts of agricultural areas, causing one of serious desertification problems. Therefore, this problem has to be taken into consideration in the future studies and different geological and environmental surveys.

DISCUSSION AND CONCLUSIONS

- Most of the previous works adopted the age of the Bai Hassan Formation as Pliocene – Pleistocene, which means that the age of the formation extends through the whole Pleistocene Epoch. The author believes that the Pleistocene Epoch is represented in the Mesopotamia Plain by the well developed cycles or stages of alluvial fans, river terraces and the thick sequence of Pleistocene fluvial sediments of the Mesopotamia Basin. Because, the

Bai Hassan Formation is involved by the last intensive phase of Zagros Orogenic movements, which is evidenced clearly by the tilted strata of the formation on the southwestern limb of Himreen structure and elsewhere. Whereas, the overlying Pleistocene sequence, in the same area is almost horizontal. Therefore, we believe that the age of the formation is most like Pliocene – Early Pleistocene or might be Pliocene – Plio/ Pleistocene.

- The contact between the Quaternary sediments and the underlying Late Tertiary rocks (in the deeper parts of the basin) has not been precisely determined due to lack of index fossils and precise dating. However, this contact may be recognized on the marginal parts of the Mesopotamia Basin, where there are considerable lithologic differences between the two Mega-sequences, or the presence of erosional and/ or angular unconformity.
- During the Quaternary Period, the rate of sedimentation was greatly influenced by the climatic conditions, which played an important role in development of the fluvial sediments throughout the Mesopotamia Basin.
- The sequence stratigraphic framework of the Quaternary sediments of the Mesopotamia Basin has not been precisely established due to the lack of detailed paleontological and chemostratigraphic studies, in Iraq.
- The ages of the main stratigraphic subdivisions were suggested (previously) depending upon the stratigraphic position and geomorphic location, type of sediments and their correlation with global geological events or climatic changes, during Quaternary Period. No amendment of ages had been carried out, yet.
- The main proposed stratigraphic subdivisions (or main sequences) are: Pleistocene, Late Pleistocene – early Holocene, and Holocene.
- During Pleistocene, the Mesopotamia Plain was characterized by alternating of pluvial and inter-pluvial phases, which could correspond, globally to the well known glacial and inter glacial phases; such as those of Europe. These climatic changes have led to the deposition of successive fluvial cycles through out the Quaternary Period.
- The Pleistocene fluvial sediments of the Mesopotamia Basin were differentiated and subdivided, based on the heavy mineral assemblages and their characters (e.g. corrosion), particularly in sandy layers.
- The alluvial fans represent the oldest Quaternary (i.e. Pleistocene) sediments; and include three alluvial fan systems namely, Al-Fatha Alluvial Fan, Alluvial Fan System of Eastern Mesopotamia Plain, and Alluvial Fan System of the West and Southwestern Mesopotamia Plain.
- The Pleistocene – Holocene Sequence is deposited during Late Pleistocene and continued into early Holocene. The sequence includes sheet run-off, gypcrete and slope sediments units.
- The Holocene started after the end of the last pluvial phase of the Pleistocene, which had marked a considerable warming up in climate, particularly in the mid Holocene. The Holocene sediments are around (15 – 20) m thick in the Mesopotamia Basin. They include many units, such as flood plain, deltaic, lacustrine and marsh, sabkha, estuarine/ marine, Aeolian, and anthropogenic sediments. All of them are also represented in the modern sedimentary environments of the Southern Mesopotamia Plain.
- The rivers Euphrates, Tigris, Shatt Al-Arab, Diyala, Adhaim and foothills streams have built up vast flood plains throughout the Mesopotamia Plain, where enormous amount of fluvial sedimentation took place. The Mesopotamian Plain sediments involve complicated interfingering lithofacies of channel belt, natural levees, crevasse splays, normal flood plain and flood basins.

- The major flood plains of the Tigris and Euphrates Rivers and their distributaries occupy most of the central and southern parts of the Mesopotamia Plain.
- The marshes and lakes complex is a special modern sedimentary environment of the Southern Mesopotamia Plain, within which the deltaic system continues to function. The lacustrine environment includes three major sub-environments, these are marshes, freshwater lake and saline lake. The marsh and lake (i.e. Ahwar) sediments are generally characterized by fine texture, light grey with dark grey to black organic-rich mud (i.e. silt and clays), with high carbonate contents (up to 55% $CaCO_3$), as they are rich in mollusks and ostracods.
- The southeastern coastal area, which is the lower reaches of the Mesopotamia Plain, is characterized by three main sedimentary environments: Flood plain of Shatt Al-Arab (with input from the Karun River), Estuarine sabkha and Tidal mudflat.
- The subsurface Holocene sequence is subdivided into three main stratigraphic units; the lower two units are considered to be the Hammar Formation; whereas the upper unit is represented by the modern fluvial – lacustrine sediments.
- The Aeolian activities prevailed during the arid and semi-arid climatic conditions, which were introduced to the Mesopotamia Plain during mid-Holocene.
- Three Aeolian fields were developed in the Mesopotamia Plain along the northeastern and southwestern margins, and the central part. They are namely; Aeolian sediments along Himreen Range, Aeolian sediments of the western margin of the Mesopotamia Plain and the Aeolian sediments of the central part of the Mesopotamia Plain. They differ in grain size, mineral content, and provenance.
- It is worth mentioning that the sand dunes are creeping quickly to cover vast parts of agricultural areas, particularly at the southwestern margins of the Mesopotamia Plain, causing desertification of the fertile soils. Therefore, this problem has to be highlighted in the future geological and environmental studies, in order to suggest the best solutions and recommendations, for their retardation.

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