GEOMORPHOLOGY OF AL-JAZIRA AREA

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ABSTRACT

This study deals with defining of landforms, morphogenetic processes and climatic fluctuations during the continental phases through the Tertiary and Quaternary periods, based on the available data obtained from the geological studies of the Iraqi Jazira Area. The study shows that the present surface of Al-Jazira Area is ascribed to a rejuvenated plateau within the Mesopotamian Depression Province, which originated from influence of destruction and construction processes during two continental phases. The first phase, which started after the sea regression in Oligocene, had produced older plateau, it is characterized by prevailing of denudation processes in humid semiarid climate. The second phase, which started during the initial influence of the last Alpine movements in Late Miocene, gave rise to younger plateau. It is characterized by climatic fluctuations (between wet – arid and semiarid), prevailing of denudation – deposition – chemical weathering and periodical activity of vertical movements, which contributed in development of twenty seven landform assemblages, attributed to seven morphogenetic units of variable origins. The younger plateau witnessed intensive denudation processes and evolution of two peneplains, salt marshes, karsts and surface drainage system.

The study regarded that Tharthar and Chagh Chagh rivers were ancient tributaries of the Euphrates River during Pleistocene – Holocene, which were dried later on, due to neotectonic activities in Sinjar mountain and climatic changes. The developments of ancient rivers, as well as genesis of Tharthar Depression, salt marshes, halcrete and calcrete have been discussed. Moreover, a new geomorphological map for the Iraqi Jazira Area is constructed depending on this study.

جيومورفولوجية منطقة الجزيرة

خلدون عباس معله

المستخلص

تناولت هذه الدراسة تحديد التضاريس الأرضية والعمليات الجيومورفولوجية والتغيرات المناخية التي رافقت الأطوار القارية في العصرين الثلاثي والرباعي، اعتمادا على المعطيات المتاحة من الدراسات الجيومورفولوجية لمنطقة الجزيرة العراقية. بينت الدراسة إن السطح الحالي لمنطقة الجزيرة ينسب الى الهضبة المتجددة ضمن مقاطعة منخفض وادي الرافدين التي نشأت من تأثير عمليات الهدم والبناء خلال طورين قاريين. بدأ الطور الأول بعد تراجع البحر في عصر الأوليكوسين وتكوين الهضبة الأقدم، وتميز هذا الطور بسيادة العمليات التعروية في مناخ شبه جاف ورطب والتي أنتجت نوعين من التضاريس الأرضية تنتمي الى وحدة جيومورفولوجية واحدة. أما الطور الثاني فقد بدأ خلال التأثير الأولي لآخر الحركات الالبية في عصر المايوسين المتأخر وكون الهضبة الأحدث، تميز هذا الطور بالتذبذب المناخي (بين مطير وجاف وشبه جاف) وسيادة العمليات التعروية – الترسيبية – الكيميائية والحركات العمودية التي أنتجت تجمع سبعة وعشرون نوعا من التضاريس الأرضية تنتمي إلى سبع وحدات جيومورفولوجية ذات أصول مختلفة. كما شهد الطور الثاني عمليات تعرية شديدة كونت سهلين تعرويين، وتطور مستنقعات السباخ الملحية والكارست ونظام التصريف السطحي.

واعتبرت الدراسة ان نهري الثرثار وجغجغ هما رافدين قديمين لنهر الفرات خلال عصري البلايستوسين – الهولوسين، ولكنهما جفا في نهاية الهولوسين بسبب النشاط الحركي الحديث في جبل سنجار والتغيرات المناخية. كما ناقشت هذه الدراسة تطور الأنهار القديمة وأصل منخفض الثرثار ومنخفضات السباخ الملحية والقشرة الملحية والقشرة الكلسية، وأعدت أيضا خريطة جيومورفولوجية جديدة لمنطقة الجزيرة العراقية اعتمادا على النتائج المستنبطة من هذه الدراسة.

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INTRODUCTION

Generally, Al-Jazira Area is the extension of the northern part of the Mesopotamia Depression Province; it occupies about 29270 Km^2 located in the northwestern part of the Iraqi territory, between Euphrates and Tigris Rivers. It extends from the northern bank of the Euphrates River, in the south, to the foot slope of Sinjar – Sheikh Ibrahim mountains (the line between Sinjar – Tel Afar towns), in the north. From the west and east, it is bordered by Iraqi – Syrian boundary and Tharthar Valley, respectively (Fig.1).

Al-Jazira Area is built up by sedimentary rocks of carbonate, evaporate and clastic facies. Their ages range between Late Oligocene and Late Miocene with different Quaternary sediments.

This study is concerned with the characteristics of the landforms, morphogenetic processes and the influence of ancient climatic fluctuations during the continental phases of the Oligocene and Miocene – Quaternary Periods. A new geomorphological map of the Iraqi Jazira Area is acquired during this study.

PREVIOUS STUDIES

There are many previous studies concerning Al-Jazira Area, but most of them dealt with the geology and few geomorphological features. The most conspicuous studies, which are related to the geomorphology, are that of Hamza (1997) and Sissakian (2000). The former compiled the geomorphological map of Iraq, scale 1: 1000 000 and divided the area into five genetic units; while the latter compiled five geomorphological units which partly considered as potential landforms for hazards. While Zuwaid (1988), Sissakian and Hafidh (1993 and 1995) and Hassan and Hassan (1994) studied smaller sectors in form of compiled geological quadrangles, scale 1: 250 000 that represent the area. Accordingly, five geomorphological units were recognized in the area; but without referring to the ages and continental phases.

GENERAL MORPHOLOGY

Al-Jazira Area, which is slopes towards south, is characterized by step-like topographic nature. The lowest and highest elevations (a.s.l.) are 50 m (south of Tharthar Lake) and 400 m (southwest of Sinjar – Tel Afar area), respectively. The nature of the topography reflects the type of the exposed rock units, thicknesses and intensity of denudational processes. Generally, the main different topographical levels could be recognized in two plains (Fig.2):

- **Ba'aj Plain**

It is flat terrain, slopes gently towards south and dissected by shallow valleys; located in the north. The plain starts from south of Sinjar – Tel Afar cities with elevation 400 m (a.s.l.) and terminates by erosional scarp cliff that extends from Bawara – Snaisla to Tel Abta, with elevation (320 – 225) m (a.s.l.). It represents the youngest rock unit (Injana Formation).

- **Hadhr Plain**

It is flat and gently rolling terrain, sloping gently towards south and interrupted by main valleys, salt marshes and sinkholes. The plain starts from the last cliff of Injana Formation (in the north) to the incision slope of Euphrates Valley. It represents the Middle Miocene rock unit (Fat'ha Formation), and terminates by Euphrates River, which is a canyon-like in some parts of its course; representing the Early Miocene rock unit (Euphrates Formation).

- **Incision of Euphrates Valley**

It is a slope of the northern side of the Euphrates Valley towards south; it is interrupted by rills, galleys and sand dunes, representing the oldest exposed rock unit (Anah and Euphrates formations)

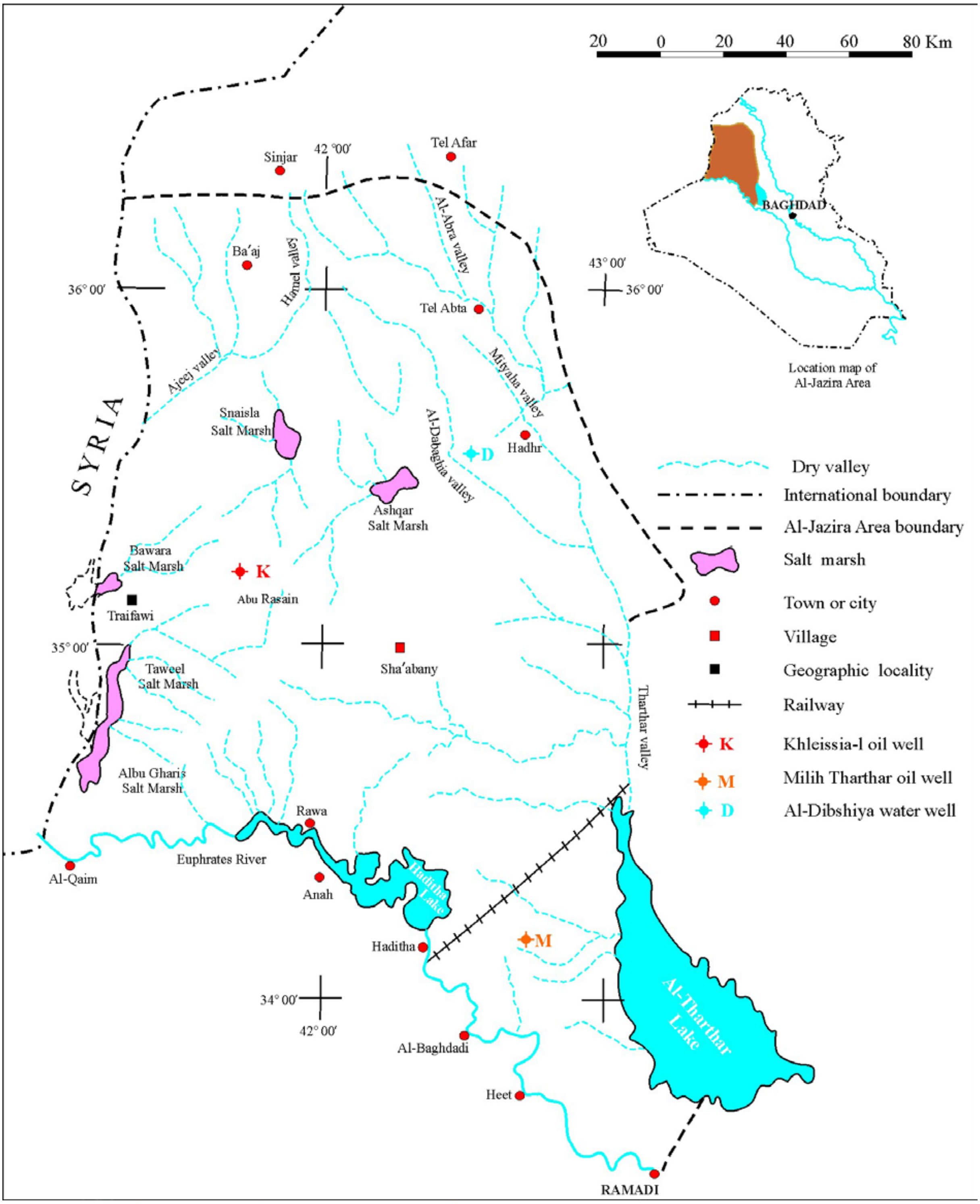


Fig.1: Location map of Al-Jazira Area

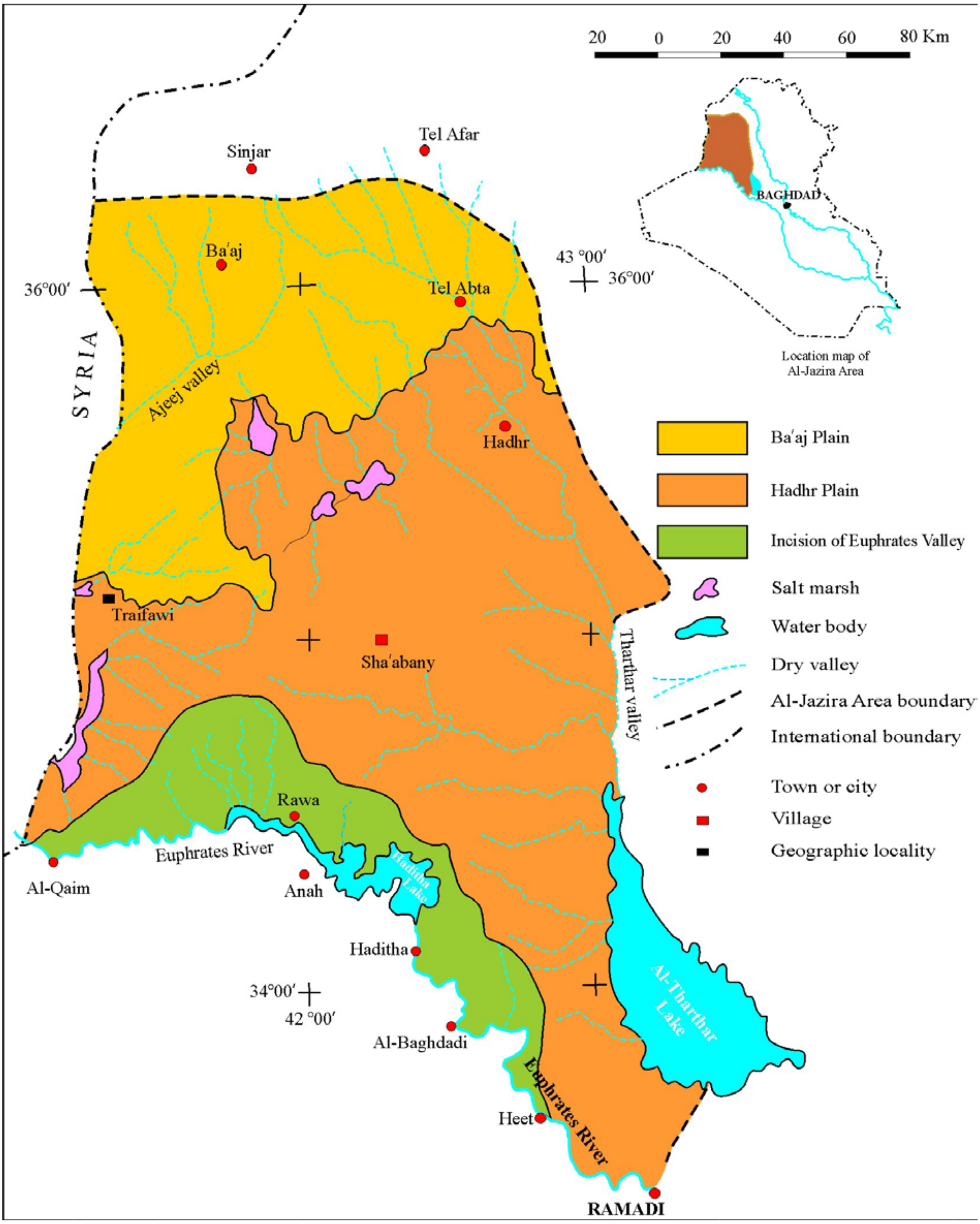
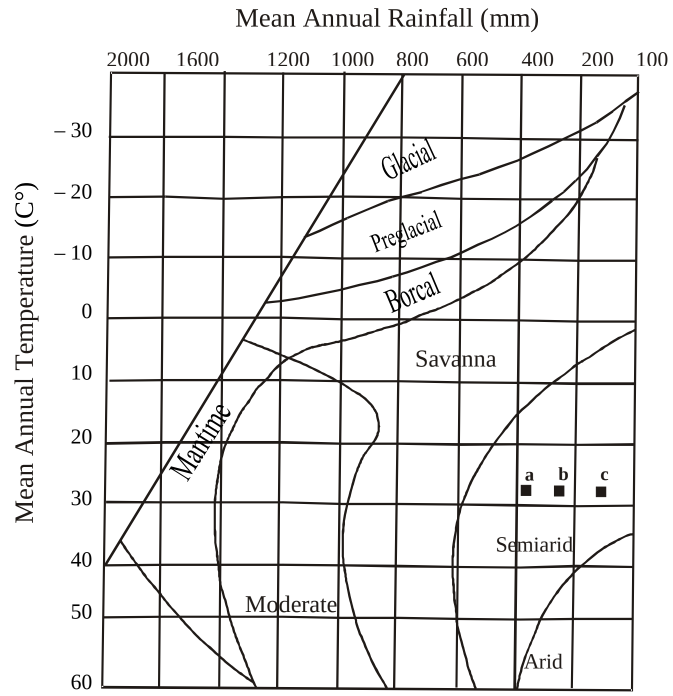


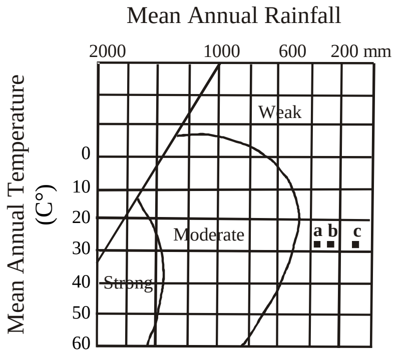
Fig.2: Map showing the topographic parts of Al-Jazira Area

THE PRESENT CLIMATE

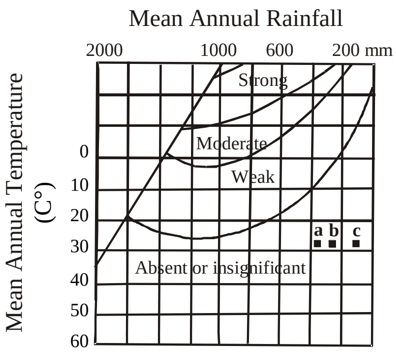
According to the data recorded by the Iraqi Meteorological Organization (1941 – 2000), the present climate is characterized by mean annual temperature of (30 – 33)° C, mean annual amount of evaporation (3000 – 3200) mm, mean annual rainfall, which occurs in winter months, is 150 mm (in the south), (200 – 300) mm (in the center) then increases gradually to 400 mm (in the north). The potential of evaporation in the area is several times more than the average rainfall. According to the diagrams of Peltiers (1950), the area is under the influence of semiarid climatic condition (Fig.3A). Therefore, the present climate leads to form several localities of sand dunes, and in different parts Nebkhas and halcrete accumulations. But, the influence of the climate on the chemical and mechanical weathering of rocks is weak and insignificant, respectively (Fig.3B and C).



A) Location of the climatic parameters in Al-Jazira Area



B) Intensity of chemical weathering (decomposition)



C) Intensity of mechanical weathering (disintegration)

a) Climatic parameters of the southern part. **b)** Climatic parameters of the central part. **c)** Climatic parameters of the northern part.

Fig.3: Rainfall/ temperature diagrams of Peltiers (1950)

GEOLOGICAL SETTING

The denudational processes led to exposure of a sequence of Miocene rock units, which are deposited in shallow marine, lagoonal and continental environments, represented by Euphrates, Fat'ha and Injana formations, respectively (Fig.4). They are briefly described hereinafter:

▪ **The Early Miocene**

This rock unit, which is exposed only along the incision slope of the Euphrates River, is expressed by carbonate facies of the **Euphrates Formation;** it is divided into two members:

─**Lower Member** comprises of: **a)** Basal conglomerate, consists mainly of limestone pebbles of Anah Formation with thickness of (1.5 – 8) m. **b)** Shelly limestone, well bedded and locally dolomitic. **c)** Chalky limestone, massive, dolomitic with two horizons of oolitic limestone; at the lower and upper parts, marl and marly limestone horizons occur.

─**Upper Member** consists of intraformational breccia of limestone and dolomitic limestone with lenses of green marl; the whole succession is highly deformed and brecciated, the deformation increases upward without controlled direction (Al-Mubarak, 1971; Tyracek and Younan, 1975; Hamza, 1975; Al-Jumaily, 1976; Jassim *et al*., 1984 and Sissakian and Hafidh, 1993 and 1994). The Early Miocene rock unit is underlain unconformably by the Oligocene rock unit **(Anah Formation)** (Al-Mubarak, 1971; Tyracek and Younan, 1975 and Sissakian and Hafidh, 1993 and 1995).

▪ **The Middle Miocene (Fat'ha Formation)**

This rock unit, is exposed widely in the Hadhr Plain, is well developed in cyclic nature succession, each cycle consists of mudstone-marl, limestone and gypsum-anhydrite (Hamza, 1975; Ibrahim and Sissakian, 1975; Al-Jumaily, 1976; Ma'ala, 1976; Jassim *et al.*, 1984 and Sissakian and Hafidh, 1993 and 1994). Locally, within a single cycle, one of the three rocks is missing due to common lateral variation of the lithology (Al-Jumaily, 1976; Ma'ala, 1976 and Sissakian and Hafidh, 1995). Halite is missing in the exposed cycles, but Ma'ala (1976) pointed out that halite horizons are encountered in Dibshiya water well (west of Hadhr town, Fig.1) at depths 63 m and 168.7 m (from the surface), i.e. within the Lower Member. The Fat'ha Formation is divided into two members depending on the first appearance of red mudstone in the formation. The Middle Miocene rock unit passes vertically to Injana Formation of fluvio – lacustrine clastic facies (Al-Jumaily, 1976 and Ma'ala, 1976).

▪ **The Late Miocene (Injana Formation)**

This rock unit is exposed widely in the Ba'aj Plain and locally at narrow strip southwest of Tharthar Lake. The Injana Formation, which overlies conformably the Fat'ha Formation, consists of rhythmic fining upward cycles, each cycle consists of reddish brown and grey sandstone, siltstone and claystone or mudstone, thin horizon of oolitic limestones occurs in Jabel Al-Mana'if and Al-Madhb'ah localities (Ma'ala, 1976). The Late Miocene rock unit represents the last regression phase of the Tethyan Sea.

▪ **The Pliocene (Mukdadiya Formation)**

This rock unit is not deposited in Al-Jazira Area due to the initial upheaval of Sinjar area in Pliocene Period (Ma'ala, 1977), where the denudational processes were commenced in that time, which marked by down cutting erosion and fluvial deposition.

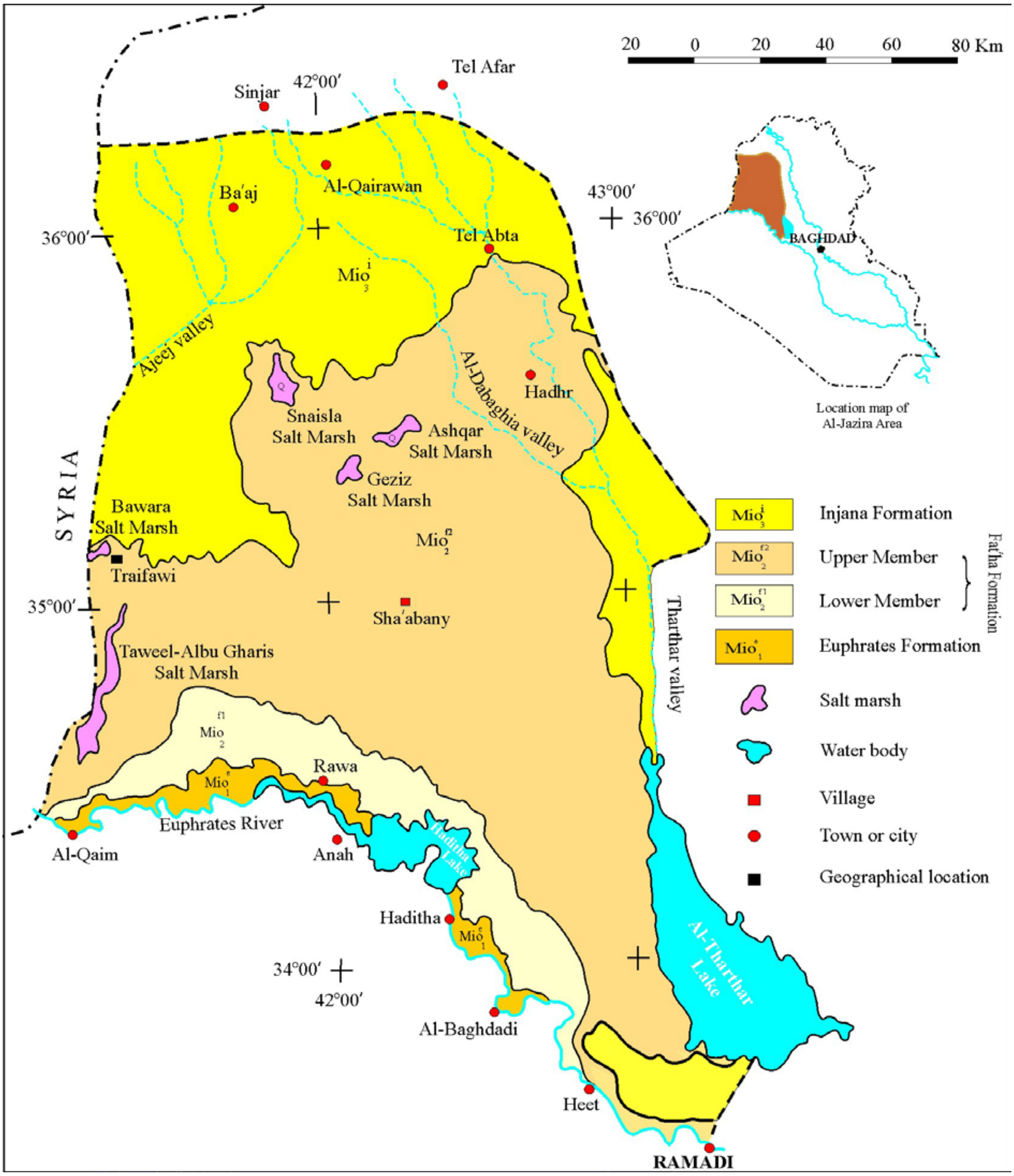


Fig.4: Geological Map of Al-Jazira Area (after Sissakian, 2000)

▪ **Quaternary Period**

The denudational and depositional processes were common, which led to the development of present day relief, river terraces, calcrete, gypcrete, halcrete and wind blown sediments.

From tectonic point of view, Al-Jazira Area is located within the Stable Shelf, represented by the Rutba – Jazira Zone (Buday and Jassim, 1987) and Salman – Hadhar Zone (Al-Kadhimy, *et al*., 1996). However, it is considered to be within the Unstable Shelf by Fouad (2010). Al-Jazira Area is characterized by flat nature, due to almost horizontal beds, with regional dip towards the east. Some subsurface folds, however, exist within the involved area, like Khlesia Uplift and Tayarat anticline, which have NE – SW trend, without clear surface expression (Al-Jumaily, 1976 and Buday and Jassim, 1987). Sissakian and Abdul Jabbar (2008) pointed out that two main lineaments with trend of NE – SW are the main outstanding features in Al-Jazira Area, they are about 100 Km in length crossing the Tigris River and are only 8 Km apart from each other. The area limited by the two lineaments, is subsided as indicated from the topographical maps with clear rims of (8 – 15) m in the height.

From neotectonic point of view, Sissakian and Deikran (1998) showed that the Jazira Area is uplifted with amount of (200 – 250) m, with estimated rate of uplift to be (0.1 – 0.2) cm/ 100 years.

Geomorphologically, Hamza (1997) pointed out that the Jazira Area is dissected by main valleys and interrupted by salt marshes and sinkholes. The main valleys, Tharthar, Ajeej and the Euphrates River, are canyon-like; in some parts of their courses, while their tributaries led to hilly and badlands morphology. The salt marshes and sinkholes are developed randomly in the southern part. The former is formed as isolated shallow depressions, while the latter is accompanied with collapses.

Remark: The Paleogene – Neogene sequence, which is built up by shallow marine sediments, is expressed by two sedimentary cycles. Each cycle starts by sea transgression and terminates by sea regression. The latter represents the beginning of the continental phase, displaying two periods of continental phases:

─**The first continental phase**, which occupied the whole gap between the Late Oligocene Anah Formation and the Early Miocene Euphrates Formation, is due to the sea regression in the Late Oligocene.

─**The second continental phase** marks a period of the last sea regression in the end of the Middle Miocene, which extends to the Quaternary.

MORPHOGENETIC PROCESSES

The surface of Al-Jazira Area is marked by different types of denudational and depositional processes, which appeared during two continental phases (Table 1).

▪ **The first continental phase of evolution**

The older phase of the continental evolution is pre-Miocene in age (28.4 – 23.03 Ma), which is marked by landforms: Hamada, Serir and deflation depressions along the left bank of the Euphrates River. These landforms are developed by mechanical weathering processes with the effect of the semiarid climate, by temperature changes and wind agent. On the other hand, development of subterranean hollows and caves filled by Terra rossa soil, which gives remarks of chemical weathering.

Table 1: Distribution of the morphogenetic processes and agents on the phases of the continental evolution periods

Periods of the continental evolution	Climate	Morphogenetic processes	
		Type	**Agent**
Late Oligocene	Semiarid	Mechanical weathering	Temperature changes and wind action
		Chemical weathering	Groundwater
Late Miocene	Wet	Depositional	River
Pliocene	Wet	Erosional	Rainwater
		Depositional	River
Pleistocene	Wet	Depositional	River
		Chemical weathering	Rainwater
	Semiarid	Deposition	Evaporation
early Holocene	Wet	Depositional	River
		Chemical weathering	Rainwater
late Holocene	Semiarid	Depositional	River, wind action, evaporation
		Erosional	Wind action

▪ **The Second Continental Phase of Evolution**

The younger phase of the continental evolution is Late Miocene in age (~11.6 Ma), which is marked by landform assemblages that attributed to depositional and denudational processes at different times and climatic changes; as follows:

─Depositional Processes

Several types of depositional process have been started since the last sea regression in the Late Miocene. During the Late Miocene, the terrigenous sediments, which were derived from Zagros Mountain by perennial rivers, were deposited in the Late Miocene basin in form of fluvio – lacustrine environment (served as potential localities for deposition of Injana Formation).

River terraces of the main perennial rivers were deposited in the Jazira Area, during Pleistocene as well as alluvial fans and valley fillings were deposited during Holocene. Most of the depressions are filled by fluvial sediments during the rainy seasons. The arid climate sedimentations (calcrete, gypcrete, halcrete and drift sands) were deposited throughout the Jazira Area since Early Pleistocene. The calcrete and sand dunes are well developed in the Ba'aj Plain. While, the gypcrete, halcrete (Sabkha) and sand dunes are common in the Hadhr Plain.

─Denudational Processes

Several types of denudational processes are recognized in Al-Jazira Area:

Mechanical weathering is common in the Ba'aj Plain to produce deflation depressions. Vertical erosion, in the present dry valleys, is active in the area most probably due to the tectonic uplifting and prevalence of arid climate. Lateral erosion causes toppling, sliding in different stages of river evolution. Gully erosion is locally active in the area situated south of Tel Abta locality due to the activity of Tharthar Valley, which dissects the erosional cliff between Ba'aj and Hadhr Plains. Rill and gully erosions are locally working around salt marshes (e.g. Snaisla, Ashqar, Bawara, Albu Gharis – Taweel) and main valleys which have developed badlands.

The fluvio – lacustrine sediments (sandstone, siltstone and claystone), which occupy the Ba'aj Plain, have been influenced by wind action in the summer seasons and being transported for long distance and accumulated in form of sand dune fields on the Hadhr Plain and outside of the Jazira Area.

─Chemical Processes

The chemical processes, which started during Quaternary period, contributed in reduction of the Hadhr Plain. Solutions of evaporate and carbonate rocks have formed karsts, blister voids and salt marshes. The hydration of anhydrite to gypsum is common in the Hadhr Plain to produce great number of blister voids.

GEOMORPHOLOGICAL UNITS

Based on the observed individual geomorphic units and landforms from dynamic, tectonic and morphogenetic aspects, the Jazira Area is divided into eight major geomorphic units (Fig.5), these are:

- **Units of Structural – Denudational Origin**

Two units are developed in the area:

─Plateau

The Jazira Area is characterized by a main plateau, due to flat lying strata of evaporate and clastic rocks, upland region (elevated more than 150 m in altitude), highly dissected and limited (partly) by folded mountains (from north and northeast) and deep valleys (from east and south). The area was emerged in two periods: Late Oligocene and Late Miocene – onward. The plateau includes structural form such as **Ashqar Cliff,** which is a form of structural cliff developed in the Hadhr Plain, along the southern limit of Ashqar Salt Marsh. Sissakian and Abdul Jabbar (2008) showed that two main lineaments with NE – SW trend are the main features in the Jazira Area. The severe differential erosion, during Quaternary, was removed the northern cliff and left off about 20 Km from the southern cliff.

─Dissected Slopes

The course of the Euphrates River is running in E – W direction then changes to NW – SE. The former, which extends about 85 Km, coincides roughly with the strike of northern flank of Anah anticline; whereas, the latter extends for about 120 Km, coincides roughly with the strike of Abu Jir Fault Zone (Fouad, 2000). The deep incision of the Euphrates River is forming prominent dissected slopes along its left bank.

- **Units of Denudational Origin**

Four units are developed in the area:

─Pediment

It is well developed in the Ba'aj Plain, which occupies the area between foot-slopes of Sinjar – Shaikh Ibrahim mountains (in the Foothill Zone) and the Hadhr Plain. It is characterized by gently inclined erosional surface, dissected by Ajeej and Tharthar Valleys, with their tributaries, and comprises the clastic sediments of Late Miocene (Injana Formation). The erosional surface is covered by thin mantle of rain-wash sediments, which are mixed with carbonate debris of variable sizes and shapes.

─Badlands

These are well developed on dissected slopes of the Euphrates River and both banks of Tharthar and Ajeej Valleys, because they are dissected by dense net of tributaries. As well, due to the effects of alternation of hard and soft rocks of both Fat'ha and Injana formations.

─Erosional Cliff

The main cliff, in the area, is **Snaisla – Tel Abta Cliff**, which extends for about 100 Km in NE – SW direction, forming the southern margin of the Ba'aj Plain, which faces toward southeast. The steep face consists of sandstone and claystone of the basal part of the Late Miocene rock unit (Injana Formation), with height of about 6 m.

─Erosional Plains

The surface of the main plateau is characterized by step-like topography between Injana and Fat'ha formations, which are separated by the Snaisla – Tel Abta Cliff on level of 230 m (a.s.l.). Two plains were recognized, these are:

Ba'aj Plain: It covers the northern sector of the main plateau between Snaisla – Tel Abta Cliff (from the south) to the pediment of Sinjar – Sheikh Ibrahim mountains (from the north) and Tharthar Valley (from the east) to Chagh Chagh Valley, inside the Syrian territory (from the west) (Fig.5). The plain, which is built up by clastic sediments with lenticular horizons of carbonate at the base, is dissected by dense and shallow dendritic tributaries of Tharthar and Ajeej Valleys from east and west, respectively. Generally, the Ba'aj Plain is usually covered by rainwash sediments and locally by sand dunes with variable thicknesses.

Hadhr Plain: It covers the southern sector of the main plateau between Snaisla – Tel Abta Cliff (from the north) to the Euphrates River (from the south) and Tharthar Valley and Lake (from the east) to Chagh Chagh Valley (from the west) (Fig.5). The plain, which is built up by repeated cycles of marl-carbonate-gypsum, is modified later on by karstification and dissection. Generally, Hadhr Plain is covered by gypseous sediments and locally by sand dunes with variable thicknesses. Three geomorphic forms are well developed in the Hadhr Plain, these are:

Mesas and Hills, several mesas are well developed in Al-Jazira Area, especially within the Hadhr Plain. Many mesas are well developed alongside of Bawara – Snaisla Cliff, which are capped by hard rocks of sandstone or oolitic limestone (of Injana Formation) or by calcrete, underlain by softer rocks. The main isolated mesa is situated about 30 Km south of Snaisla Salt Marsh; named as Jable Al-Mana'if, which has exception relief about 60 m (from the surrounding surface). Ma'ala (1976) referred this type of mesa to Monadnock feature because it represents relict of an old topographic surface of Miocene – Quaternary plateau, which is still standing. Another, several mesas occur in the closest vicinity of Tharthar and Euphrates Valleys (Ibrahim and Sissakian, 1975). Some of them suffer from rill erosion and toppling, which reduced them to buttes.

Hamada and Serir, the rocky limestone terrain of the Late Oligocene Plateau had been influenced by mechanical weathering, which produced rock fragments of variable sizes known as Hamada and Serir. The ancient landform is restricted with stratigraphic break between Late Oligocene and Early Miocene rock units. These forms are developed along the incision of Euphrates Valley.

Deflation Depressions: The rocky limestone terrain of the Late Oligocene Plateau was characterized by ancient hilly topographic nature; the height was up to 15 m (Tyracek, 1978). The basal conglomerate of the Early Miocene rock unit (Euphrates Formation) was copying several ancient deflation depressions throughout the hilly terrain. These forms are developed along the incision of the Euphrates Valley. As well, few deflation depressions are recognized on the surface of the Ba'aj Plain, resulted from removal of detrital sediments by wind action.

▪ Units of Solutional Origin

The following three units are well developed in the Hadhr Plain:

─Sinkholes

Sinkholes are either formed in the Early Miocene rock unit (Euphrates Formation) due to solution of limestones, or in the Middle Miocene rock unit (Fat'ha Formation) due to solution of gypsum rocks. In the former case, sinkholes are developed in two localities: Northwest of Rawa town and Haditha Dam site, their apertures are almost circular or oval shapes with

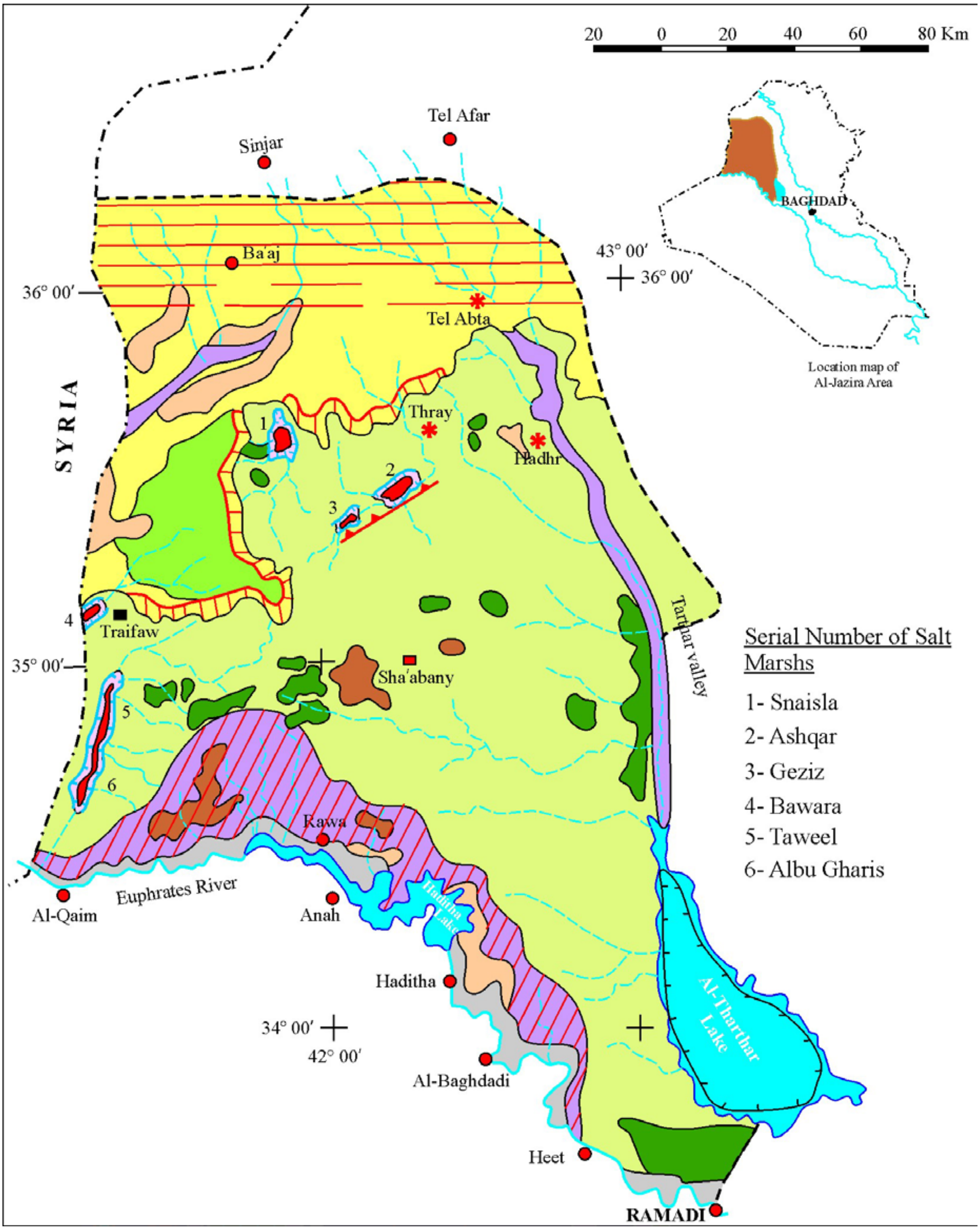
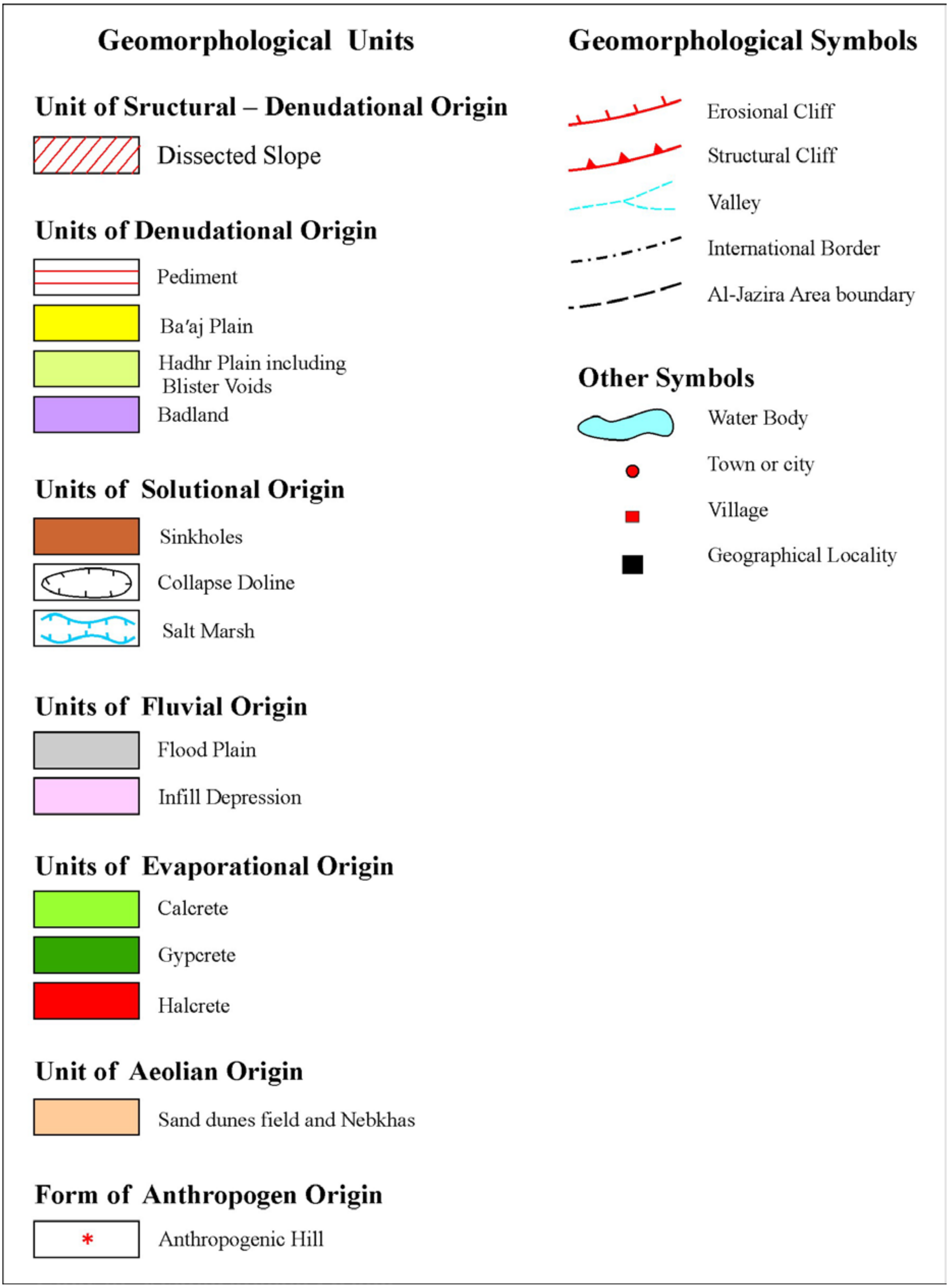


Fig.5: Geomorphological Map of Al-Jazira Area
(For Legend, refer to page 17)



Legend for Fig.5

diameters ranging from few meters up to 50 m, with depths of few meters up to 30 m(Sissakian and Hafidh, 1995). It is worth to mention that Haditha Dam site is one of the most karstified areas in Iraq (Sissakian and Ibrahim, 2005); this locality is characterized by presence of numerous surface and subsurface sinkholes and caverns (Sissakian and Al-Mousawi, 2007). In the latter case, sinkholes are developed in three localities: Northeast and northwest of Rawa town and Sha'abany vicinity, their apertures and shapes are irregular and the depth does not exceed 5 m (Sissakian and Hafidh, 1995).

─Salt Marshes

Salt marshes are isolated drainless depressions, which are developed in the karstic terrain of the Hadhr Plain. Their sides are gently sloping towards the depression centers, which are dissected by radial valleys. They are distributed in three localities: **A)** Along Iraqi – Syrian frontier (e.g. Albu Gharis – Taweel and Bawara). **B)** In the northern part of the plain (e.g. Snaisla, Ashqar, Geziz, Gattar and Kubisha). **C)** Tharthar Lake (before inundation). The dimensions of the salt marshes are listed in the Table (2).

Table 2: Names and coverage areas of Salt Marshes in Al-Jazira Area

Salt marsh	Area (Km^2)
Tharthar	2062.5
Albu Gharis – Taweel	70
Snaisla	44
Ashqar	37.5
Bawara	12
Geziz	≈ 10
Kubisha	3
Gattar	1.2
Umm Dhiaba	> 1

The salt marsh depressions are shallow, with exception of Tharthar Depression, which is about 85 m deep. The depressions are filled with water during rainy seasons, and then become shallow pools and lakes, they dry up and leave thin salt crust during the summer season and became salt pans or sabkhas (Ibrahim and Sissakian, 1975; Al-Khateeb, 1995 and Tobbia, 1996). It is worth to mention that Tharthar Lake was salt marsh before inundation by water of Tigris River, starting from 1956.

─Blister Voids

A great number of Blister Voids in gypsum beds are common in the Hadhr Plain with variable dimensions. They are initially formed as minor pseudo-domes due to the volume changes that accompanied the hydration of anhydrite to gypsum. Some of them are collapsed partially or completely where the underlying mudstone is washed out, most of them are filled by windblown sand.

There are two forms of solutional origin; it is recognized in the Hadhr Plain:

Blind valleys are developed in the northern part of the Hadhr Plain, within the Middle Miocene rock unit (Fat'ha Formation), due to solution of gypsum rocks. Ma'ala (1976) pointed out that few valleys are terminated by a series of small pits (more than five) are arranged along trace of valleys. Each pit is circular in shape, with (1 – 2) m in diameter and vertical walls.

Terra rossa soil is well developed in the subterranean hidden caves in the Rawa vicinity, in which up to (3 – 4) m thick horizon of red silty claystone was penetrated by deep boreholes (Technopromexport, 1974, in Tyracek, 1978). The hollows are totally filled with red claystone. The analogous residual varicolored silts and clays occur in the Anah – Rawa region, which are developed in the same stratigraphic level and their thicknesses reach several meters (Al-Mubarak, 1971).

- **Units of Fluvial Origin**

Five units are developed in the area:

–Flood Plain

Flood plain is well developed along Euphrates River and Tharthar Valley. The flood plain, along Euphrates River is restricted along the meandering belts. It is composed of silt, clay and mud. The flood plain, along Tharthar Valley, however, is composed of highly gypsiferous sediments, the thickness is variable; it is about (1 – 2) m, as average.

–River Terraces

These are well developed along Euphrates River and valleys of ancient rivers like: Tharthar and Ajeej, in (3 – 4) stages. The Euphrates River terraces are developed in four stages: (5 – 10) m, (25 – 35) m, (50 – 60) m and (65 – 90) m above the present river level, respectively (Ibrahim and Sissakian, 1975). They are composed mainly of limestone and chert gravels with some igneous and metamorphic rocks too. The gravels are mainly rounded to well rounded, cemented by calcareous and gypsiferous sandy matrix.

Terraces of Tharthar Valley are well developed in four stages: (15 – 25) m, (30 – 50) m, (55 – 60) m and (65 – 90) m above the present valley floor, respectively (Ma'ala, 1976). They are composed mainly of limestone and chert gravels. The gravels are mainly rounded to subrounded.

Terraces of Ajeej Valley are well developed in three levels: (15 – 25) m, (30 – 40) m and (50 – 60) m above the present valley floor, respectively (Ma'ala, 1976). The fourth stage might be developed in the Syrian territory.

–Infilled Valleys

Many ephemeral valleys, which occur in the Ba'aj Plateau, are potential areas for flooding during heavy rain showers. They are filled by sediments of different geological formations. Generally, the valleys in the Ba'aj Plain are rich with sand, whereas in Hadhr Plain are rich with gypsum fragments. The thickness of the sediments ranges from less than one meter to 2.5 m, some exceptional cases may occur too. Few solutional valleys, in the Hadhr Plain are filled by brown and black muddy sediments rich by SO_4, underlying the halcrete crust, such as Bawara, Taweel and Albu Gharis Salt Marshes.

–Infilled Depressions

Several closed depressions, which are developed in Hadhr Plain, are filled by brown and black muddy sediments rich by SO_4, underlying the halcrete crust, such as Snaisla, Ashqar, Geziz, Umm Dhiaba, Gat'tar Salt Marshes. These sediments are derived from washing-out of surrounding exposed rocks during the rainy seasons. The thickness of the muddy sediments does not exceed few centimeters (Tobbia, 1996).

–Alluvial Fans

Several localities with gravel accumulations were recognized at the foot of Snaisla – Tel Abta Cliff. These accumulations are most probably relict sediments, which are referred to ancient alluvial fans at their embouchures into the foot of the cliff. Ma'ala (1976) showed that isolated spots of gravel accumulations are defined at the following levels: (230, 295, and 300) m (a.s.l.). The sediments consist of well rounded pebbles of limestone, sandstone and chert, up to 2 cm in diameter, mixed with sandy – silty material, partly cemented by secondary gypsum. This landform is not presented on the map due to the scale limitation. The author believes that the accumulation of gravel is formed due to sudden change in slope to low land (along Snaisla – Tel Abta Cliff) and to washing-out of old terraces; during rainy seasons. Many small alluvial fans are developed along both sides of Tharthar Valley. Their lengths are less than 25 m and height of apex less than 6 m (Ma'ala, 1975).

- **Units of Evaporational Origin**

The following three units are developed in the area:

─Calcrete

Calcrete, covers the southwestern part of the Ba'aj Plain by uniform and compacted blanket of calcareous material, range in thickness between (0.25 – 0.5) m. The calcrete is composed of heterogynous rock fragments of limestone and sandstone cemented by sandy calcareous material. At the northwestern part of the Hadhr Plain, few remnants of calcrete cap the isolated hills with elevations of (300 – 306) m (a.s.l.).

─Gypcrete

The Gypcrete covers many parts of the Hadhr Plain, top of hills and mesas and partly their slopes. As well, gypcrete is developed along the rims of salt marshes, it is believed to be precipitated by the evaporation of $CaSO_4$ bearing solution during summer seasons (Al-Khateeb, 1995; Tobbia, 1996 and Jassim *et al*. 1999). The gypcrete in the Jazira Area is composed of powdery to granular secondary gypsum mixed with weathered clastic sediments of the underlying fragments of claystone, siltstone, sandstone and gypsum; certain percentage of aeolian admixture can not be excluded. Gypcrete is restricted mostly to the Lower Member of the Fat'ha Formation, whereas few patches are developed in Upper Member of the same rock unit, excluding the area south of Tharthar Lake, which is covered by Injana Formation.

─Halcrete

Halcrete is developed mainly in salt marshes and in other localities along the banks of Tharthar Lake, which are scattered on the Hadhr Plain. The depressions are filled by light brown and black muddy sediments overlain by thin crust of NaCl (Halite) with crystals of gypsum (Tobbia, 1996). The thickness does not exceed few centimeters.

- **Forms of Aeolian Origin**

The following two forms are developed in the area:

─Sand Dunes

Sand dune fields, which are locally accumulated throughout the Jazira Area, are characterized by low dunes, less than 1 m in height and length of few kilometers. The trend is NE – SW, which perpendicular on the prevailing wind direction. They consist mostly of quartz, carbonate and subordinate gypsum; loose, well sorted and light brown to grey in color. They are still active.

─Nebkhas

Nebkhas are wide spread throughout the area; they are less than 0.5 m in height; recently developed and mostly connected with shrubs, which cause accumulations of the drift sand.

- **Form of Anthropogenic Origin**

Only one form is developed in the area:

─Anthropogenic Hills

Anthropogenic hills are prominent morphological features, in the Hadhr and Ba'aj Plains. Many hills represent ancient settlements, which were built up by human along ancient rivers (e.g. Tharthar and Ajeej Valleys). Most of them are covered by aeolian sands mixed with broken pottery, which are scattered on the slope sides.

DISCUSSION

The present surface of the Jazira Area is marked by twenty seven landform assemblages, which are the product of former various denudational and depositional processes in two continental evolutional phases. The geomorphological development of the area is discussed hereinafter:

▪ The Pre-Miocene Phase

The first phase of the continental evolution started after the sea regression in Late Oligocene due to the influence of the Oligocene Uplift, which led to form the **Older Plateau.** The relict of the Older Plateau is restricted along the left bank of Euphrates River (in form of wide belt) for about 145 Km between west of Rawa to Al-Baghdadi towns. The surface of the plateau was affected by intensive mechanical weathering for more than 5 Ma, which produced shallow dish-like depressions, Hamada and Serir. These features are deduced from the rolling topographic nature of the Late Oligocene rock unit (Anah Formation) and the nature of the basal conglomerate, which exist at the base of Euphrates Formation. The basal conglomerate expresses the topography of the Late Oligocene rock unit. As well, the basal conglomerate lacks any marks about surfacial drainage (Al-Mubarak, 1971 and Tyracek and Younan, 1975) which give indication to arid climate. Therefore, most of these features might be were developed due to effective mechanical weathering processes, under influence of temperature changes and wind activity for long times. After long period of arid climate, the loose debris (Hamada and Serir) reworked by the sea transgression in Miocene to fill the shallow depression. The development of Terra rossa soil in hidden caves could give an indication to relatively intensive chemical corrosion in limestone beds of the Anah Formation. Al-Mubarak (1971) pointed out that the Terra rossa is found below the basal conglomerate of the Euphrates Formation. As well, thick horizon of Terra rossa was penetrated by boreholes in the Rawa vicinity (Technopromexport, 1971). The soil gives indication on chemical corrosion in the periodically alternating humid warm and dry warm periods (Tyracek, 1978).

▪ The Miocene – Quaternary Phase

The second phase of the continental evolution started in Late Miocene after the last Middle Miocene Sea regression, due to the influence of the last Alpine movement. The regressive sea left behind lakes, indicated by oolitic limestone, which represents a new cycle of sedimentation. The new cycle of sedimentation is so called terrigenous – continental cycle (Buday, 1980). Buday and Jassim, (1987), in: Jassim and Goff (2006) pointed out that Injana Formation reflects a progressive change from marine into fluvial environment. However, the denudational sediments, which were derived from the rising Zagros Mountains in the N and NE, were transported by ancient rivers that supplied the ancient lakes in the Jazira Area. As well, the lakes could be were supplied by marine water through estuaries, as indicated by the presence of oolitic limestone.

The arrival influx from the N and NE had been rapidly terminated in Pliocene, probably due to the initial upheaval of the Sinjar mountain (Ma'ala, 1977). In the meantime, the denudational processes could be started by heavy rainfall during Pliocene. The **Miocene – Quaternary Plateau** has been well prominent during Pliocene – Pleistocene, as the widest uplift landform within the Mesopotamia Depression Province. The plateau has the same boundaries of the Jazira Area.

The Ashqar lineaments, which represent prominent fracture traces (Sissakian and Abdul Jabbar, 2009) through the youngest plateau, could be influenced by deep erosional activity, because the erosion can be accelerated along faults and dense fractures due to heavy rains. The wearing action began with rill erosion, which might be was enlarged progressively to gully erosion later on. The clastic sediments of the Injana Formation were removed and retreated towards the north; therefore, the retreated cliff along Snaisla – Tel Abta is nearly parallel to the orientation of the Ashqar Lineament.

─Peneplanation

The surface of the Hadhr Plateau was suffered from influence of paleo-climatic fluctuations (between wet – arid and semiarid) since Pliocene till now. The clastic sediments of the Injana Formation might be were suffer from mechanical erosion under the influence of variable climates since Pliocene – Pleistocene. The soluble rocks of the Fat'ha Formation, however, might suffered from solution and hydration of gypsum and anhydrite, respectively. These processes led to lowering of the youngest plateau during Quaternary. The Ashqar lineaments accelerated the erosion processes of the clastic sediments and contributed in exposure of the surface of Hadhr Plain. As well, the lineaments accelerated the development of some salt marshes, such as Ashqar and Geziz. Therefore, the Peneplanation is developed by the influence of three factors: lithology, structure and climate.

─Terraces

Three – four stages of river terraces are concentrated locally in discontinuous strips along Ajeej and Tharthar Valleys, respectively. Terraces reflect the periods of stream rejuvenations during the Quaternary periods, due to climatic changes and uplifting of the area. Their ages are supposed to be in time span of Pliocene – early Holocene. In comparison with the terrace stages of Euphrates and Tigris Rivers they seam to be identical, as showing in table (2).

Table 2: Comparison between stages of river terraces in the Jazira Area
and its surrounding

Stage	1 m (a.w.l.)	2 m (a.w.l.)	3 m (a.w.l.)	4 m (a.w.l.)
T4 (youngest)	10	15 – 25	15 – 25	10 – 20
T3	30 – 35	30 – 40	30 – 50	40
T2	50 – 60	50 – 60	55 – 60	50 – 60
T1 (oldest)	65 – 70	──	65 – 90	80 – 90

1) Euphrates River (after Ibrahim and Sissakian, 1975).
2) Ajeej Valley (after Ma'ala, 1976).
3) Tharthar Valley (after Ma'ala, 1976)
4) Tigris River (after Buday, 1973)
a. w.l. = above water level.

The data shown in table (2) pointed out that the ancient rivers (Ajeej and Tharthar) and the present rivers (Euphrates and Tigris) are developed nearly at the same time. The sediments of the terraces of the ancient rivers are weakly cemented pebbles of variable sizes and shapes. They are composed mainly of limestones and sandstones with subordinate gypsum, which may be derived from Sinjar mountain that was exposed during that time.

Tyracek (1981) studied the terraces of the Euphrates River, between Al-Qaim and Heet area (southeast of Al-Jazira Area) and described nine terrace levels and considered them in five groups. Hamza (1997) however, reported four stages: (100, 70, 50 and 20) m above water level. The terraces of the Euphrates River are composed of the same rocks as those of the Tigris River.

Tyracek (1981) estimated the age on the basis of altitudes. He expects the higher level (90 m, a.w.l.) to be Early Pleistocene, the second level (60 m, a.w.l.) of late Early Pleistocene, the third level (35 m, a.w.l.) of Middle Pleistocene and the lower level of Late Pleistocene and Holocene. The present author believes that the fourth (higher) stage (70 m, a.w.l.) is of Early Pleistocene, the second stage (50 – 60 m, a.w.l.) of Middle Pleistocene, the third stage (30 – 50 m, a.w.l.) of Late Pleistocene and the first (lower) stage (15 – 25 m, a.w.l.) of early Holocene. This is attributed to: Sinjar mountain was denuded during Pliocene – Pleistocene of wet period and the debris were redeposited around the mountain as pediment (located north outline of the Jazira Area). The pediment was partly denuded by ancient rivers in the Early Pleistocene.

─Karstification

The Hadhr Plain is a well known karstified area, many localities are well karstified (Fig. 5). Three types of karsts are developed in different parts of the plain, these are:

- **First type;** is developed along northern slope of the Euphrates Valley (west of Rawa vicinity), sinkholes are developed within limestone of the Euphrates Formation. They have uniform forms, as circular, oval, cylindrical, with diameters ranging from 1m up to tens of meters and depth of few meters up to 30 m. These are developed due to collapse of top layers after dissolving of underlying rocks.
- **Second type**; is developed on flat land of the Hadhr Plain (Sha'abani vicinity), where sinkholes were developed within gypsum of the Fat'ha Formation. As well, few sinkholes of the second type are developed along the upper sector of the slope of the Euphrates Valley (northeast of Rawa vicinity). They are developed due to dissolving of gypsum layers, forming irregular shapes, with diameters of (1 – 20) m and depths (1 – 12) m (Sissakian *et al.,* 2006).
- **Third type;** is developed south of Tharthar Lake, where sinkholes are developed within gypcrete. Few sinkholes are very small with diameters less than 5 m and depths less than 1 m.

▪ **Genesis of some geomorphological features in the Jazira Area**

─The genesis of the Ajeej, Taweel – Albu Gharis and Bawara Depressions

The Ajeej and Taweel – Albu Gharis are the main tributaries of Chagh Chagh River in Syrian territory, named Chagh Chagh (Fig.6), as indicated from the topographic maps, river terraces and available historical references. Sussa (1965): in Al-Sakini (1993) pointed out that Chagh Chagh River was well headed from south of Turkey, which was crossing through the western side of Sinjar mountain and running toward south, along the Iraqi – Syrian border, to supply many sabkhas, named: Bawara, Taweel and Albu Gharis (in Iraq) and Rawdha and Qsair (in Syria), then flowing into the Euphrates River (north of Al-Qaim vicinity). The Chagh Chagh River was characterized by natural formation of elongated small swamps or lakes, which were developed along middle and downstream, when the river was running over the Hadhr Plain (Fig.6). Later on, the river was dried, in late Holocene, due to influence of neotectonic activity in Sinjar mountain (Mitchel, 1957), which caused the development of dry marshes or small lakes. As well, because of the high evaporation, the depressions and/ or small lakes became sabkhas or salt marshes.

─The genesis of the Tharthar Valley and Lake

The Tharthar Valley was one of the main ancient rivers in the Jazira Area, as indicated from river terraces and witness of available historical references. Mitchell (1957) pointed out that the Tharthar Valley and Lake were the course of an ancient river, which was well headed from Al-Hrmosan Valley previously (located north of Sinjar mountain). The river, which was passing through the eastern extremity of the Sinjar mountain, was running toward south to merge into Euphrates River west of Ramady town (Fig.6). Moreover, Soosa (1965) showed that the original course of the Tharthar River was divided into two branches: one was running towards southeast, merging Tigris River (south of Tikrit town), while the other was running towards southwest merging Euphrates River (near Umm Al-Ross castle, 35 Km northwest of Falluja town).

The Tharthar Lake was huge depression located in the southeastern part of the Jazira Area. There are many opinions on the origin of the Tharthar Depression:

NEDECO (1959) believed that the origin of the depression is based on the following features:

- The major part of the depression is following the supposed contact between Lower and Upper Fars formations (currently Fat'ha and Injana formations).
- The occurrences of the gravels of the Tigris fan to the east and south and thinning out toward the depression, which was not protected against the denudational processes.
- The regional dip of the Lower Fars Formation (Fat'ha Formation) is toward east.
- A graben-like subsidence of the bottom of the depression during Late Pleistocene – early Holocene resulted a step-like profile of the eastern side.
- Rejuvenated erosion through the uplifting, in the south, caused step morphology.
- The climatic variation during Pleistocene led to change of the anhydrite to gypsum with undulations for the Lower Fars Formation.
- A selective wind erosion and mechanical erosion led to further denudational processes.

The present author denied this suggestion because the area was not influenced by graben subsidence as indicated from the available geophysical data (C.G.G., 1972).

Soosa (1965) in Sissakian *et al.* (2007) pointed out that the Tharthar Lake was consists originally of two depressions, a northern one, which was called Al-Rafa'i with elevation of 42 m (a.s.l.) and a southern one, which was called Umm Al-Rhal with elevation of –3 m (b.s.l.). As well, the Tharthar depression did not exist during the historians Yaqoot Al-Hamawi (1226), Ebin Al-Haq (1338) and in the map of Al-Idrisi (1664). According to Soosa (1965), the Tharthar Depression was formed due to a karstification. However, he mentioned that it might be formed due to earthquake in 1423. But, this contradicts with the aforementioned three historian statements (Sissakian *et al.*, 2007). Moreover, the present author rejects Soosa's suggestion because the Jazira Area is located within a non-seismic region of Iraq. The recorded earthquakes in the Hadhr vicinity might be attributed to Ashqar lineament activity.

Al-Sakini (1993) showed that a neotectonic activity took place in Falluja Structure, which led to reverse running of ancient Tharthar River towards north. In this case, the ancient river was modified to influent river through sinkholes, which were developed behind the rising structure leading to the development of the Tharthar Depression due to karstification.

The present author believes that the origin of Tharthar Depression is a collapse doline; this assumption is based on the following features:

- The present course of Tharthar Valley, is running on the Hadhr Plain, which is built up by evaporate and carbonate facies of the Middle Miocene rock unit (Fat'ha Formation).
- The highest point along the bank of Tharthar Lake is 82 m (a.s.l.).
- Milih Tharthar oil well encountered the Euphrates Formation at depth equivalent to sea level.
- The course of the valley, in the sector between Hadhr town and Tharthar Lake, is interrupted by series of valley sinkholes or sabkhas or depressions.
- The irregular periphery of the present lake is pear-like, which gives impression of conjunction cluster sinkholes.

- The floor of Tharthar Depression is –3 m below sea level (Soosa, 1965; Fat'halla, 1977 and Sisskian *et al*, 2006 and 2007). Is means, the bottom of the depression is occupied by the carbonate facies of the Upper Member of the Euphrates Formation (Early Miocene) (M.P.C., 1964). Therefore, the depth of the depression is about 85 m.
- The depression has bowl-shaped profile, which consists of 50 m thickness of repeated cycles of marl – limestone – gypsum or anhydrite (Fat'ha Formation) and 3 m thickness of chalky limestone (Euphrates Formation) (M.P.C., 1964). All these rocks are soluble by fresh water. The succession produced step-like profile due to either differential weathering or slumping of walls.
- The depression can be described as closed, which is referred to collapse doline.

Tharthar lake was developed in two processes: Dissolution of the bedrock and collapse of the roofs of the underlying cavities, which could be explained as: Chemically, under saturated vadose water can be moving vertically along fractures, especially fracture intersections, which could be enlarged into surface pits. Large volumes of moving water can introduce chemical erosion, which produces a rugged and irregular periphery. Moreover, water converted the anhydrite of Fat'ha Formation into gypsum, consequently expanded upward the flat-lying rocks. The expansion took place upward due to the increase in volume, which is approximately 40% (Billings, 1972). The expansion might be accompanied by local fractures, which might be accelerated the dissolving of rocks. Another factor might be contributed in the chemical processes, such as the presence of salt layers. If the salt exists, then it is completely removed by dissolving. The differential solution of the underlying salt could led to non-tectonic down warping with local fracturing. At the same time, a subterranean chemical weathering, which took place through collapsed valleys (along Tharthar Valley), may formed hidden cavities in variable levels. The dissolution by horizontally moving water toward south may contributed to enlarge the cavities. Therefore, the combination of dissolution by vertically and horizontally moving water may lead to failure of the ceiling of the pre-existing cavities. Therefore, Tharthar Depression is a closed depression because it is resulted from dissolution and collapse phenomena, according to the definition of the closed depression (White and White, 2006).

─The Genesis of the Salt Marshes Landform

The Hadhr Plain, which consists of soluble rocks (gypsum and limestone), is suffering from karstification since Pleistocene – early Holocene, when the Ba'aj Plain was retreated towards north under prevailing rainy climate. The Hadhr Plain is characterized by abundance of sinkholes of variable dimensions, ranging from 1 m to tens of meters. For this reason all the workers in the Jazira Area referred the salt marshes to the karstification of the gypsum of the Fat'ha Formation. Salt marshes are a distinct geomorphological landform in the Hadhr Plain, including Tharthar Depression, before inundation by water (Soosa, 1965; Fath Alla, 1977 and Sissakian *et al.*, 2006 and 2007).

The present author refers the origin of the salt marshes to internal mechanical processes depending on the following features:

- Salt marshes are distributed on soluble rocks of Lower Member of the Fat'ha Formation, which is built up by succession of cycles; each cycle consists of marl, limestone and evaporates.
- Generally, the bedrock is flat-lying with exception of blister domes. The pseudo-domes are common in the Hadhr Plain due to the hydration phenomena, with volume increase. When, the pseudo-domes are collapsed, locally the underlying mudstone can be washed out to form voids of variable dimensions and shapes.

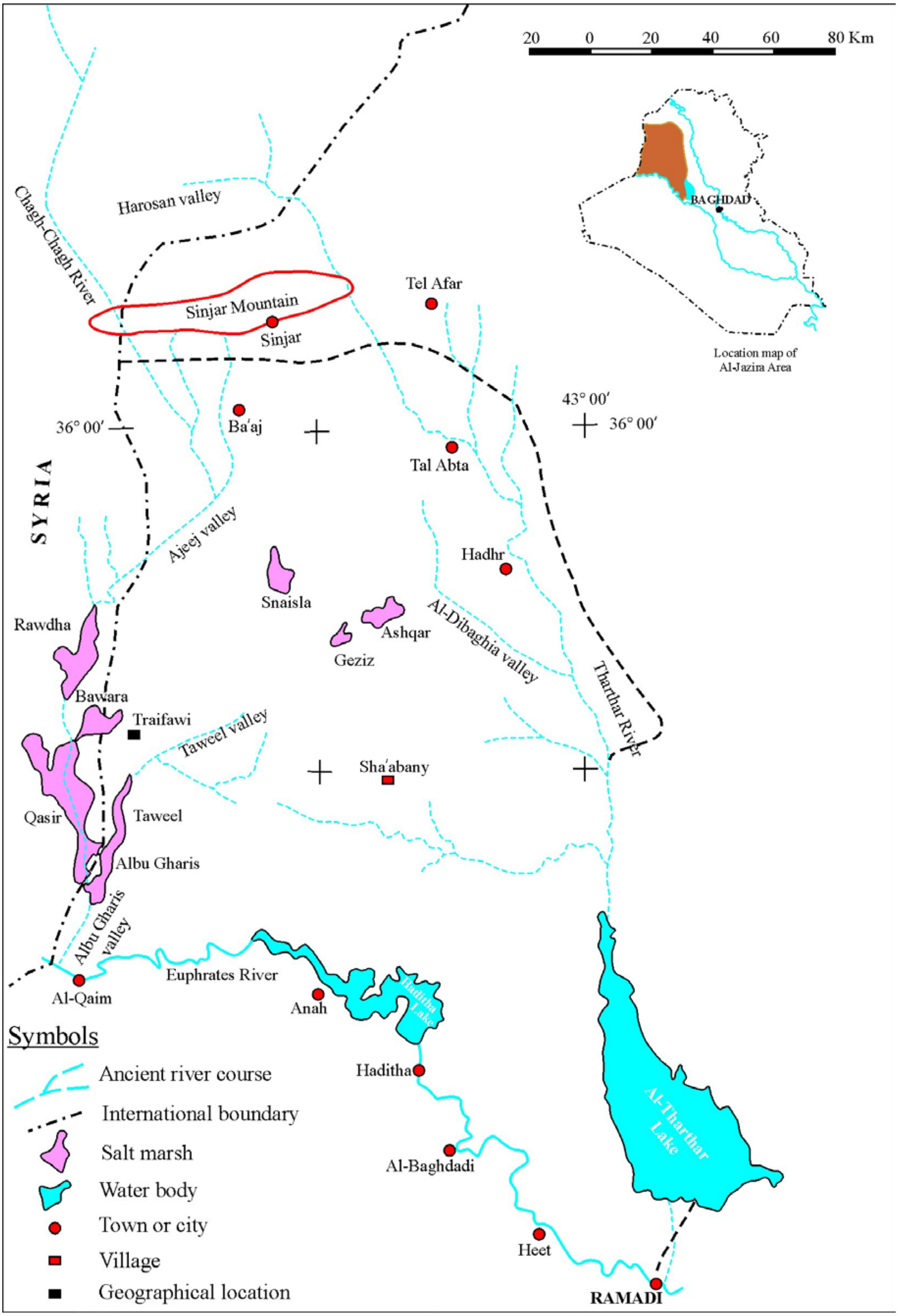


Fig.6: Courses of ancient rivers in Al-Jazira Area (Modified from Al-Sakini, 1993)

- Bawara and Snaisala Salt Marshes are developed nearby the erosional cliff between Ba'aj and Hadhr Plains (Fig.4), which indicate that marshes areas are covered by non soluble rocks of Injana Formation.
- Some salt marshes are arranged in form of beads along tributaries of an ancient river, such as Taweel and Albu Gharis (Fig.6).
- The Ashqar and Geziz Salt Marshes are arranged in form of beads along tectonic lineaments (Ashqar Cliff) (Fig.6).
- Centripetal drainage pattern occur around all salt marshes, which served as localities for collecting fine clastic sediments by ephemeral valleys.

The initial cavity, which might be developed due to dissolving of the underlying rocks along secondary fractures, might be filled by falling down blocks (from the roof) when cavity is filled by blocks the void migrate upward (Fig.7B). The accumulated debris remains and the void space become smaller. The initial cavity might be blocked up in the soluble rocks. Falling blocks which initiated in a cavity (in soluble rocks) can extend upward into non-soluble rocks (sandstone and mudstone) (White and White, 2006). The collecting clastic sediments on the surface may be down warped in form of shallow dish-like depression (Fig.7C). The indentation may conform to central part of the shaft.

The beads shape of the solution valleys might be attributed to the lateral facies changes of the soluble rocks to non-soluble rocks. Ma'ala and Al-Kubaysi (2009) pointed that the Fat'ha Formation is characterized by abundant lateral facial changes. However, the mechanical processes retreated the Ba'aj Plain during Holocene. Consequently, the surface of the Hadhr Plain became flattened with local undulations due the effect of erosional and hydration processes in Holocene.

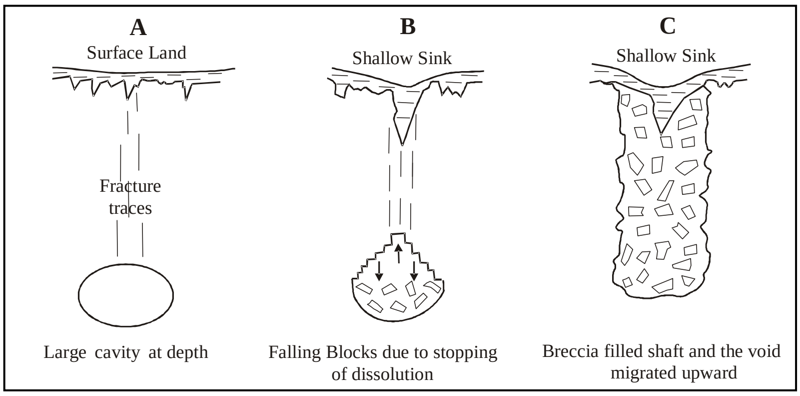


Fig.7: Sketch showing the development of a stopping shaft without removal of accumulated rubbles (White and White, 2006)

– The genesis of the Halcrete

Most of the authors agreed that the brine in the salt marshes are originated from rising of the groundwater through fractures in form of springs, which mixed with meteoric water in the rainy seasons and dried in the summer season; leaving salt crust of (1 – 2) cm thick (Al-Jumaily, 1976; Ma'ala, 1976; Al-Badri, 1986; Al-Badri *et al.*, 1990; Al-Khateeb, 1995; Tobbia, 1996 and Jassim *et al.*, 1999). The present author's opinion, about the origin of halcrete is that, the halcrete is derived from the solution of halite horizons of Middle Miocene bearing salt rocks by descending rainwater through Ashqar Lineament. The brine water may migrate to supply all voids of salt marshes in the Hadhr Plain, excluding Snaisla Salt Marsh during rainy season because it is far from Ashqar Lineament; it becomes dry in the summer season due to rise of temperature; depending on the following data:

- The source of the halcrete, in the Jazira Area, is ancient marine water (Al-Badri, 1986 and Tobbia, 1995), which can be attributed to the following rock units:

  Dhiban Formation: Thick subsurface rock salt, of Early Miocene, had been encountered by oil wells in the Ba'aj vicinity (Tel Hajar). The rock salt of pure nature (95 – 99 %), has total thickness of about 210 m (Kettaneh *et al*., 1990). The Dhiban Formation (bearing rock salt) might be contributed in supplying the Snaisla (in Iraq) and Rawdha – Qsair Salt Marshes (in Syria) by Chagh Chagh River, when the river was crossing Sinjar mountain (Fig.6), or by descending brines through Ajeej Lineament.

  Fat'ha Formation: Rock salt horizons are deposited locally in the Hadhr vicinity during Middle Miocene. Ma'ala (1976) pointed out that two horizons of halite were encountered by Al-Dibshiyah water well (Fig.1) at depths 63 m and 168.7 m (from surface). Therefore, the Ashqar Lineaments (Fracture trace) can helped in solution of Middle Miocene bearing rock salt and migration of brine to supply the breccia filling shafts of salt marshes, e.g. Ashqar, Geziz, Taweel and Albu Gharis, which are influenced by Ashqar Lineament.

  - Tobbia (1996) pointed out that all salt marshes have the same successive horizons started by halcrete (at the top), black mud horizon (rich by organic matter), then brown mud horizon mixed with crystals of halite (at the bottom).
  - Al-Badri *et al*. (1990) seemed that the hydrogeochemical and geochemical studies of brines, salts and sediments have improved that the genesis of salts may be the groundwater of meteoric origin, which gained marine water characteristics due to dissolving of salt layers present in Lower Fars (Fat'ha) Formation of marine origin. In addition to the surface run-off water washing the surrounding area.
  - The mean annual amount of evaporation is (3000 – 3200) mm, which occurs in summer months. This means, the potential of evaporation is several times more than the average rainfall.
  - The prevailing winds increase the dryness in the summer months and transport huge quantities of fine sediments from far distances.
  - The depressions of salt marshes, which are mostly small basins, are collecting clastics and surfacial materials derived from chemical weathering by ephemeral streams.

─The genesis of the Calcrete

The origin of the calcrete (caliche or duricrust) is closely related to the climate, during certain stage of Pleistocene. It is originated under moist climate with a high supply of calcareous solutions rising upward by capillary action. Certain percentage of sand grains is related to the aeolian activity in the time of calcrete formation. Ma'ala (1976) reported that the rock fragments of calcrete are associated with the third terrace stage of Ajeej River. Therefore, the age of the calcrete is probably late Pleistocene, which coincides with the suggestion of Yacoub (2002).

CONCLUSIONS

- The present surface of the Jazira Area is marked by two phases of destruction and construction processes, which took place in two continental phases. Therefore, the area is ascribed to rejuvenated plateau.
- The first continental phase, which started after the Oligocene Uplift, produced the older plateau. It is characterized by prevailing of denudation processes in a semiarid climate, as well as beginning of subterranean caves.

- The second continental phase, which started during influence of the last Alpine movements, in Late Miocene included Pliocene and Quaternary Periods, produced the younger plateau. It is characterized by climatic fluctuations (between wet – arid and semiarid), denudation – deposition processes and periodical activity of vertical movements, which contributed in growth of twenty seven landform assemblages. They are referred to seven morphogenetic units of variable origins.
- Tharthar and Chagh Chagh Rivers are ancient tributaries of the Euphrates River in Pleistocene – Holocene, which were dried later on, due to neotectonic activities in Sinjar mountain and climatic changes.
- The younger plateau witnessed intensive denudational processes, which modified the major plateau into two topographic steps of different plains; named Ba'aj and Hadhr Plains.
- The Ba'aj Plain, which comprises relatively elevated and flat lying strata of Injana Formation, is gently sloping towards south and limited by erosional cliff from the south. It is developed due to mechanical erosion processes.
- The Hadhr Plain, which comprises relatively elevated and flat lying strata of Fat'ha Formation, is gently sloping towards south and limited by dissected slopes of Euphrates Valley from the south; it includes karstification and swelling processes.
- Tharthar Depression (Lake), which is closed depression with depth of 85 m, is referred to collapse doline category.
- Taweel – Albu Gharis and Bawara Salt Marshes, which were tributaries of ancient Chagh Chagh River, were formed by the effect of solution and internal mechanical erosion processes.
- Ashqar and Geziz Salt Marshes, were developed along Ashqar Lineaments, and originated by the effect of solution and internal mechanical erosional processes.
- The halcrete, which is developed in the Hadhr Plain, is probably derived from solution of halite horizons of marine origin (in the Fat'ha and Dhiban formations) by descending meteoric water and ascending brine water in the salt marshes; under present semiarid conditions.
- The calcrete, which is developed in Ba'aj Plain, is probably derived from solution of calcareous horizons of lacustrine origin (in the basal part of Injana Formation) by descending meteoric water and ascending calcareous solution (by capillary action) under moist climate during Late Pleistocene.

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