GEOMORPHOLOGY

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ABSTRACT

This study deals with defining the 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 in the Iraqi Southern Desert.

The study reveals that the present surface of the Southern Desert is attributed to rejuvenated plateau, which originated from influence of the destruction and construction processes, during two continental phases. The first phase, which commenced after the Oligocene Uplift, formed the older plateau. It is characterized by prevailing of denudation processes in a semiarid climate; as well, beginning of subterranean hallows and caves. The second phase, which started after the last Alpine movements, included the Pliocene and Quaternary Periods, formed the younger plateau. It is characterized by climatic fluctuations between wet – arid and semiarid, which induced denudations in places and depositions in others.

Twenty four landform assemblages, related to seven morphogenetic groups of variable origins, are distributed on three physiographic units, named: Al-Hijara, Al-Dibdibba and the Periphery. Each unit has specific landform assemblages, which reflect effect of the structure, lithology and climate. Moreover, the exterior part of the younger plateau suffered from depressing due to influence of erosional process along the Euphrates Fault Zone, which modified later on to foot basin, due to supply of a clastic sediments from the elevated parts of the plateau, during the Pleistocene and early Holocene. In addition to polygenetic accumulations referred to evaporation, Aeolian, estuary and floods of Euphrates River. This phase was witnessed the development of two types of lakes: collapse lakes (in the elevated part) and seepage lakes (in the depressed part). The former is filled by clastic sediments of Zahra Formation, whereas the latter is filled by salt accumulations, excluding Sawa Lake.

The underground drainage system was active and originated network of passages and chambers since Oligocene to Recent time. While the surface drainage system was active and originated sub parallel rivers, which were running towards NE since Late Pleistocene to early Holocene and became dry later on, due to climatic changes.

The study revealed that the formed landforms, by the present semiarid climate contributed in the protection of the area by desert pavement, excluding the karstified areas (Limestone pavement) that served as passageways for rainwater. Consequently, new geomorphological map for the Iraqi Southern Desert is constructed based on the achieved data.

الجيومورفولوجـــي

خلدون عباس معلة

المستخلص

تناولت هذه الدراسة تحديد التضاريس الأرضية والعمليات الجيومورفولوجية ووسائلها والتغيرات المناخية التي رافقت الأطوار القارية في العصرين الثلاثي والرباعي، اعتمادا على المعطيات المتاحة من الدراسات الجيولوجية للصحراء الجنوبية العراقية.

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بينت الدراسة إن السطح الحالي للصحراء الجنوبية ينسب إلى الهضبة المتجددة التي نشأت من تأثير عمليات الهدم والبناء خلال طورين قاريين. بدأ الطور الأول بعد نهوض الاوليكوسين وكون الهضبة الأقدم. تميز هذا الطور بسيادة العمليات التعروية في مناخ شبه جاف، وبدء عمليات التكهف تحت السطحي. أما الطور الثاني فقد بدأ بعد آخر حركة ألبية في عصر المايوسين – البلايوسين، وشمل عصري البلايوسين والرباعي وكون الهضبة الأحدث. تميز هذا الطور بالتذبذب المناخي بين مطير وجاف أو شبه جاف، الذي أدى إلى حدوث عمليات تعروية في مكان والترسيب في مكان آخر. أنتجت هذه العمليات تجمع أربعة وعشرون نوعا من التضاريس الأرضية تنتمي إلى سبع وحدات جيومورفولوجية ذات أصول مختلفة توزعت على ثلاث وحدات فيزيوغرافية (الحجارة والدبدبة والمحيطية)، كل وحدة لها تضاريسها الخاصة وقد عكست تأثير العناصر التركيبية والصخارية والمناخية.

تعرض الجزء الخارجي للهضبة الأحدث إلى الانخفاض بسبب تأثير التعرية الشديدة على نطاق صدع أبو جير، وقد تحور إلى حوض طرفي يستقبل الفتات الآتي من الجزء المرتفع للهضبة خلال عصور البلايستوسين وبداية الهولوسين، إضافة إلى الرواسب التراكمية ذات الأصول المتعددة والعائدة إلى المتبخرات والكثبان الرملية والاخوار والرواسب الفيضية لنهر الفرات. كما شهد هذا الطور نشوء نوعين من البحيرات: البحيرات الحوضية (في الجزء المرتفع) والبحيرات النزيزية (في الجزء المنخفض)، ملأت الأولى برواسب فتاتية لتكوين الزهرة والأخرى بتراكمات ملحية، باستثناء بحيرة ساوة.

تنشط نظام التصريف تحت السطحي منذ عصر الاوليكوسين وحتى الآن، وكون ممرات وتجاويف تحت سطحية، بينما تنشط نظام التصريف السطحي منذ عصر البلايستوسين وحتى بداية الهولوسين ليشكل أنهارا شبه متوازية تجري باتجاه الشمال الشرقي، وقد جفت هذه الأنهار خلال نهاية الهولوسين بسبب التغيرات المناخية. أما المناخ شبه الجاف الحالي، فقد كون تضاريس أرضية قليلة والتي ساهمت في حماية سطح الجزء المرتفع للهضبة من التعرية بواسطة الرصف الصحراوي، باستثناء منطقة التخسف التي تعمل على تصريف مياه الأمطار. كما وأعدت هذه الدراسة خريطة جيومورفولوجية جديدة للصحراء الجنوبية العراقية اعتمادا على المعطيات الجديدة المستحصلة من هذه الدراسة.

INTRODUCTION

This study deals with the geomorphology of the Southern Desert, aiming to elucidate the landforms, morphogenetic processes and climatic fluctuations during the continental phases of the Tertiary and Quaternary periods.

Generally, the Southern Desert represents the extension of the northern part of the regional plateau of the Arabian Peninsula. The desert is built up by sedimentary facies of carbonates, clastics and evaporates sequence. Their ages range between Paleocene to Recent. The desert, which occupies about 76 000 Km^2, is located in the southern part of Iraq and bordered by Euphrates River (partly) from the NE and Wadi Al-Khir from NW. From the SW and SE, it is bordered by the Iraqi – Saudi Arabian and Kuwaiti international borders, respectively (Fig.1).

PREVIOUS STUDIES

There are many previous studies concerning the Southern Desert, but most of them dealt with the geology. The most important study, which is related to the geomorphology, is that of Hamza (1997), he compiled the geomorphological map of Iraq, scales 1: 1 000 000 and divided the Southern Desert into five genetic units. While Barwary and Slewa (1993 and 1994); Sissakian *et al*. (1994); Deikran (1994 and 1995) and Hassan *et al*. (1994) studied smaller sectors in form of compiled quadrangles, scale 1: 250 000 that represent the Southern Desert. Accordingly, the Southern Desert was divided into six genetic units; but without referring to the landforms, ages, processes and the continental phases.

METHOD OF WORK

The present study is based on the data obtained from the available geological studies about the Southern Desert in GEOSURV’s archive. The landforms are classified and described according to their presence in the physiographic units, based on Hister (1948) in Hamza (1997). Each unit has specific landforms, morphogenetic processes and paleo-climate, during the continental phases.

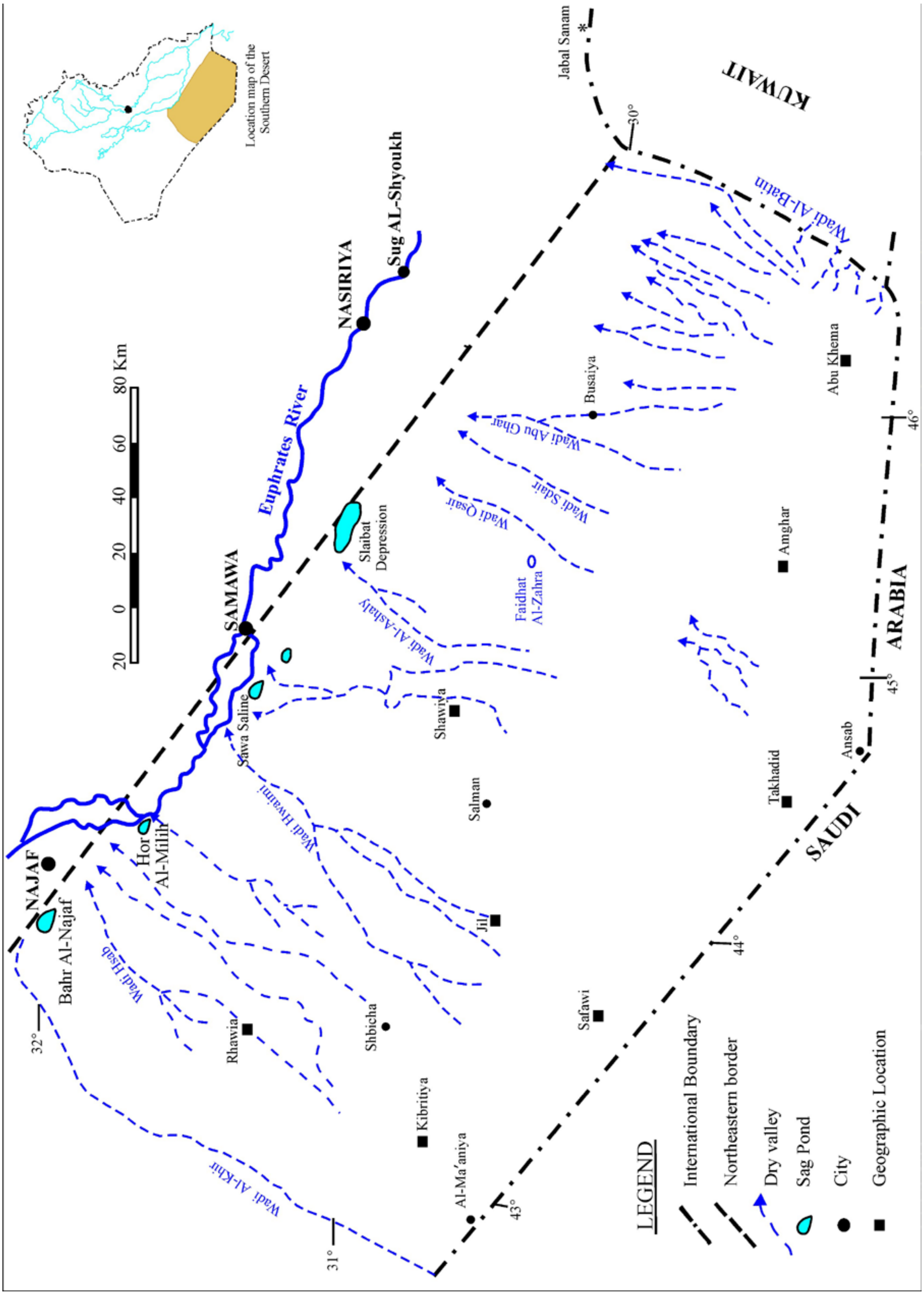

Fig.1: Location map of the Iraqi Southern Desert

The landforms classification is based on the morphogenetic processes and the development agents, whereas, the paleo-climatic changes are deduced in accordance to the type of landforms and/ or type of sedimentations.

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 (24 – 26) °C, mean annual amount of evaporation is 4500 mm. Rainfall occurs during winter months in form of heavy showers and rather sporadic, but occurs very rapidly during a short time; mean annual amount of rainfall ranges between (75 – 100) mm. According to the diagram of Peltiers (1950) the area is of desert semiarid climate (Fig.2).

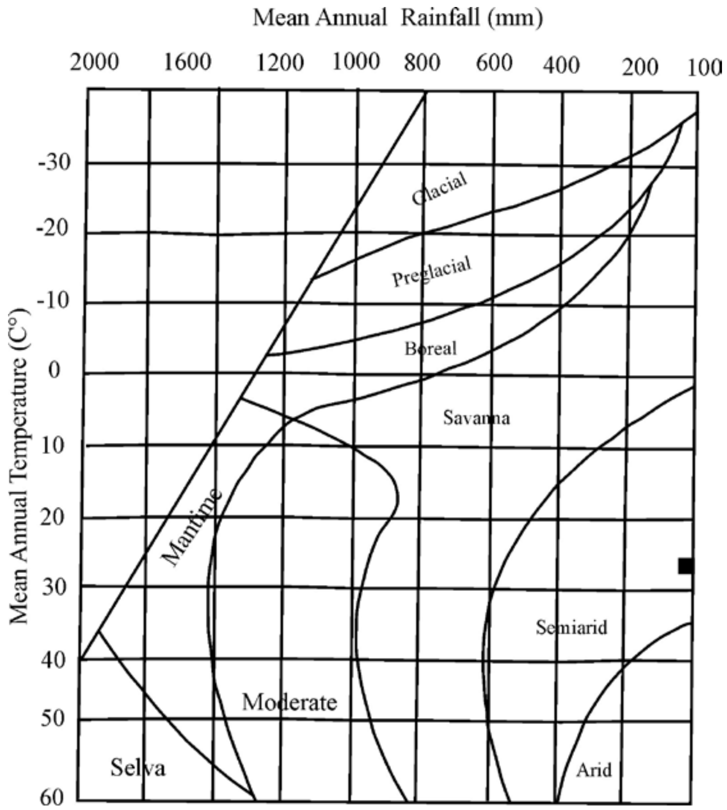

Fig.2: Location of the climatic parameters in Iraqi Southern Desert (Diagram of Peltiers (1950) hypothetical morphogenetic regions based on mean annual rainfall/ temperature)

MORPHOLOGY OF THE SOUTHERN DESERT

The Southern Desert has relatively flat terrain, sloping gently towards NE. The elevated part (300 – 400) m (a.s.l.) exists along the Iraqi – Saudi Arabian border (Ansab – Al-Ma'aniya); while the apparently depressed part (20 – 150) m (a.s.l.) is developed along the western side of Euphrates River. The depressed area comprises morphologic features, such as Bahr Al-Najaf, Hor Al-Milih, Sawa Lake, Samawa Saline and Slaibat Depressions (Fig.3).

PHYSIOGRAPHIC UNITS

The distribution of the morphogenetic processes is connected with physiographic subdivisions. The nomenclature of these subdivisions is adopted from Hister (1948) in Hamza (1997). Hister (1948) subdivided the area into the following three units (Fig.3):

- **Al-Hijara Unit**

It is an elevated terrain capped by limestone, lies in the western part of the Southern Desert, composed of carbonate strata of Paleocene and Miocene and tilting of $(1 – 2)^{\circ}$ towards NE. It is characterized by karstic depressions, isolated hills, undulations, foot slope and fault scarps.

- **Al-Dibdibba Unit**

It is an elevated terrain capped by sandstone, lies in the southern parts of the Southern Desert, composed of pebbly sandstone of Dibdibba Formation (Pliocene – Pleistocene). It is characterized by gently sloping terrain $(1 – 7)^{\circ}$ towards NE, which includes deflation depressions.

- **Periphery Unit**

It is a subsided area, lies along the western side of the Euphrates River, composed of carbonate strata of Early Miocene, which are covered by aeolian sediments. It is a long and narrow area characterized by the existence of tectonic depressions.

GEOLOGICAL SETTING

Tectonically, the Southern Desert is a part of the Stable Shelf of the Arabian Platform, which is characterized by the presence of block tectonics and the absence of tectonic folds (Buday and Jassim, 1987). It is characterized by flat nature, due to almost horizontal beds, with regional dip towards east and northeast. The Euphrates Fault Zone with NW – SE trend is the main outstanding feature along the exterior (northeastern) part of the Southern Desert (Al-Amiri, 1979; Al-Ani and Ma'ala, 1983; Al-Hadithi and Al-Mehaidi, 1983; Al-Mubarak and Amin, 1983; Buday and Jassim, 1987; Barwary and Slewa, 1994; Deikran, 1995; Al-Shamma'a, 2004 and Jassim and Goff, 2006). Fouad (2004 and 2007) believed that the Euphrates Fault Zone is extension of Abu Jir Fault Zone. Other lineaments with NE – SW trend are recognized in the internal parts of the desert, named Abu Ghar – Busaiya and Al-Batin lineaments (Al-Amiri, 1979; Al-Ani and Ma'ala, 1983 and Al-Hadithi and Al-Mehaidi, 1983).

Startigraphically, the denudation processes have exposed a sequence of marine and continental sediments, which range in age from Paleocene to Pleistocene. The exposed rock units are presented in the geological map (Sissakian, 2000) (Fig.4).

The Paleogene rock units are shallow marine sediments, which cover most of the Southern Desert. The oldest formation, which is exposed along the Iraqi – Saudi Arabian border, is Umm Er Radhuma Formation (Early – Late Paleocene). The carbonate facies of this formation passes laterally to anhydrite facies of the Rus Formation (Late Paleocene – Early Eocene) along an alignment (Rhawia – Salman – Amghar), which was defined by Al-Hashimi (1973) (Fig.5). The Dammam Formation (Eocene) of carbonate facies overly conformably forenamed two formations. A gap exists between Eocene and Early Miocene rock units due to missing of the Oligocene rock units (Al-Naqib, 1967; Al-Hashimi, 1973; Al-Ani and Ma'ala 1983a and b; Al-Hadithi and Al-Mehaidi, 1983 and Al-Mubarak and Amin, 1983).

The Neogene rock units are expressed by shallow marine and continental sediments. The former is represented by Euphrates, Ghar and Nfayil formations, whereas the Zahra and Dibdibba formations represent the latter. The Euphrates Formation of carbonate – marl facies overly unconformably the Eocene unit without any change in dip direction and amount. The Miocene sedimentation started by transgressive conglomerate after long break in deposition (after long phase of continental evolution).

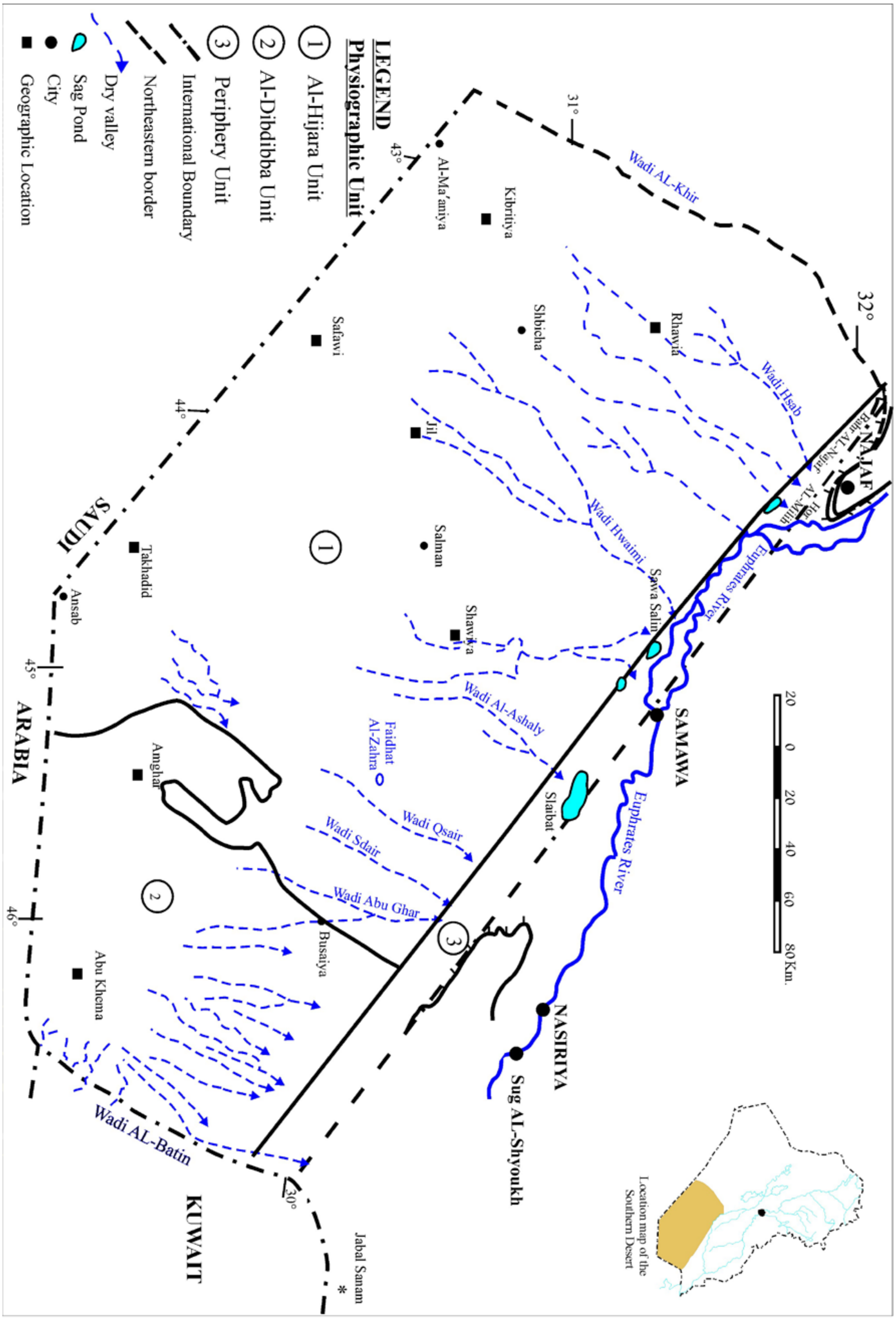

Fig.3: Distribution of physiographic Units in the Iraqi Southern Desert (Hister, 1948, in Hamza, 1997)

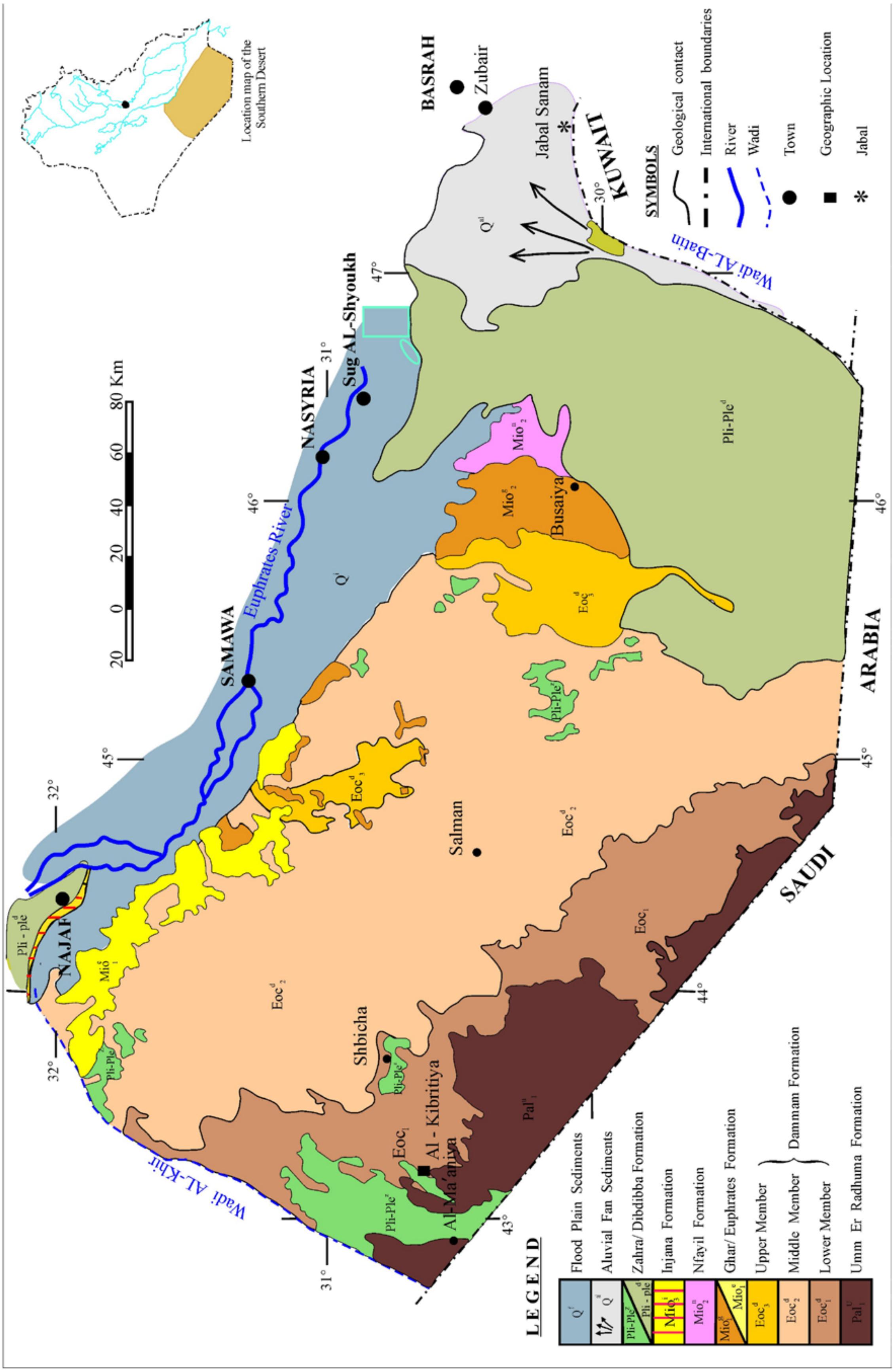

Fig.4: Geological Map of the Iraqi Southern Desert (after Sissakian, 2000)

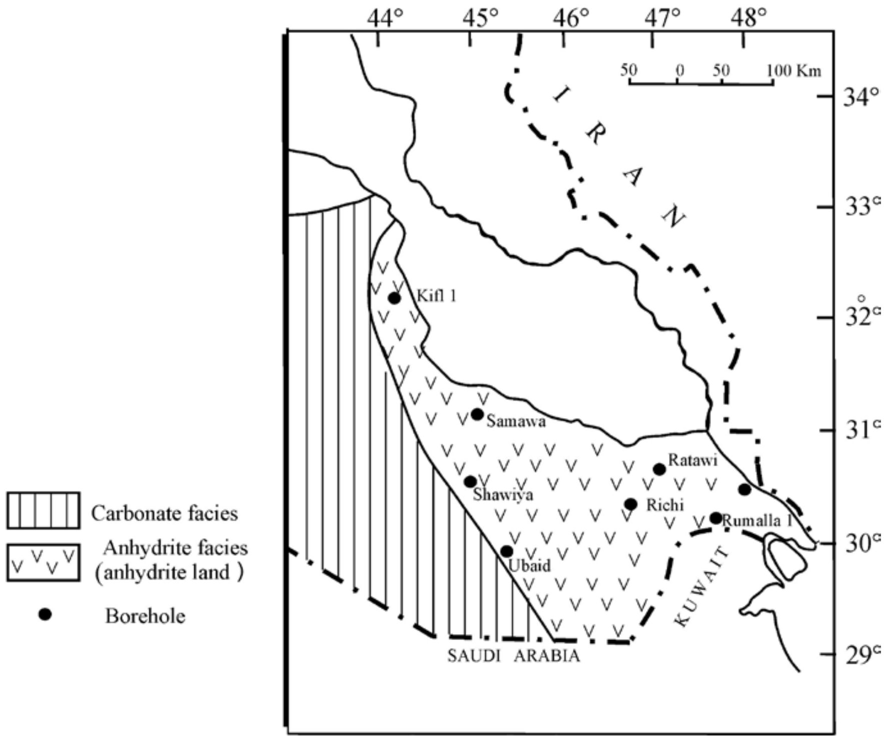

Fig.5: Facies map of the Middle – Late Eocene rock units (Al-Hashimi, 1973)
Showing the area of anhydrite land in the Southern Desert

In the eastern part of the Southern Desert, the carbonate facies of the Euphrates Formation passes laterally to lacustrine clastic – carbonate facies of the Ghar Formation, along an alignment of NE – SW direction (Ansab – Sdair lineament) (Al-Hashimi, 1973). Consequently, this lineament divided the Oligocene Uplift into two parts, in the west and east.

The top of the Early Miocene facies is marked by the beginning of a new sedimentary facies of the Middle Miocene lagoonal environment, which is exposed locally in Busaiya vicinity (Al-Ani and Ma'ala, 1983b) as clastic facies of Nfayil Formation. A typical Fat'ha Formation is missing due to lack of the evaporate facies. A typical clastic facies of Injana Formation is missing (Al-Ani and Ma'ala 1983b and Al-Hadithi and Al-Mehaidi, 1983). During the Late Miocene – Pliocene, the Alpine movement led to regression of the Miocene sea, which developed a new cycle of continental denudation.

The Late Neogene and the whole Quaternary, which represent a second phase of continental evolution, started as marked by denudational and devotional landforms. The clastic and fresh water limestone facies of Zahra Formation passes laterally to clastic facies of Dibdibba Formation, along Ansab – Sdair lineament of NE – SW trend, while the accumulations of arid conditions formed along the external part of Southern Desert (Barwary *et al.*, 2002).

Remark

The Tertiary sequence, in the Southern Desert, which is built up by shallow marine sediments, exhibit two sedimentary cycles. Each cycle starts by sea transgression and terminates by sea regression. The latter represents a beginning of the continental phase. Therefore, the stratigraphic sequence of the Tertiary includes two periods of continental phases:

─ **The First continental phase,** which occupied the whole gap between the Eocene rock unit (Dammam Formation) and the Early Miocene rock units (Euphrates and Ghar formations), formed due to the sea regression and the Oligocene.

─ **The Second continental phase** is marked a period of the last sea regression in the Late Miocene. Consequently, this phase represents a period, which extends from Late Miocene – Recent.

MORPHOGENETIC PROCESSES

The surface of the Southern Desert is marked by different types of denudational and depositional processes, which appeared during two continental phases of evolution, (in pre and post-Miocene periods) as mentioned in Table (1):

Table 1: Distribution of the morphogenetic processes and agents on each physiographic unit, during the continental evolution periods

Physiographic Unit	**Period of the continental evolution**	**Climate**	**Morphogenetic process**	
			Type	**Agent**
Al-Hijara	Oligocene	Semiarid	Chemical weathering	Groundwater
			Mechanical weathering	Temperature
			Erosional	Wind action
	Late Miocene – Pliocene	Wet	Chemical weathering	Groundwater
			Chemical weathering	Rain water
	Pliocene – Pleistocene	Wet	Depositional	Rain water
			Erosional (solution and dissection)	Rain water
	early Holocene	Wet	Chemical weathering	Rain water
	late Holocene	Arid	Mechanical weathering	Wind and Temperature
		Semiarid	Erosion and Mechanical weathering	Wind and Temperature
Al-Dibdibba	Late Miocene – Pliocene	Wet	? (Hidden landforms)	
	Pliocene – Pleistocene	Wet	Depositional	Rivers
	early Holocene	Wet	Erosional	Rivers
	late Holocene	Arid	Erosional	Wind
		Semiarid	Erosional	Wind
Periphery	Late Miocene – Pliocene	Wet	Erosional	Rain water
	Pliocene – Pleistocene	Wet	Depositional	Rivers
	early Holocene	Wet	Depositional and Erosional	River and Marine
	late Holocene	Arid	Accumulation	Evaporation and Wind
		Semiarid	Depositional	River and Wind

▪ First Continental Phase of Evolution

The older phase is pre-Miocene (33.9 – 23.03 Ma), which is marked by strong **chemical and mechanical weathering processes,** with semiarid climate. It produced the formation of Hamada, Serir and deflation depressions on the surface, by temperature changes and windblown sand, on other hand development of subterranean hollows and caves in the subsurface, by ground water. The chemical corrosion process started from Oligocene and continued to the early Holocene.

▪ Second Continental Phase of Evolution

The younger phase is Late Miocene (~11 Ma), which is marked by assemblage landforms. They are attributed to denudational and depositional processes at different periods and climatic changes, they are described, hereinafter.

─ Denudational processes

Several types of denudational processes are recognized in the Southern Desert, these are:

- Chemical Weathering Processes: These are inherited from pre-Miocene phase, were continued during Late Miocene – Holocene. Some of the subterranean hallows and caves were enlarged and collapsed during Late Miocene – Pleistocene. The first **phase of collapse sink depressions,** which became lakes and marshes, are filled by terrigenous sediments (served as potential localities for Zahra Formation), during Pliocene – Pleistocene. The limestone strata, which tilted towards northeast, have been dissected by **gully erosion,** while the rims of collapse sink depressions, structural cliffs and rims of sag ponds influenced by **rill erosion.**

- Solution Processes: In the anhydrite land, the secondary fractures, which allowed the rain water to percolate, have accelerated the **solutional processes** of limestone and anhydrite strata. In the limestone strata led to produce karst features (dolines, sinkholes, blind valleys), while in the anhydrite land led to produce undulations during early Holocene. At the same time, some of subterranean hallows and caves have been collapsed to produce second phase of collapse sink depressions.

- Climatic Processes: The denudational processes prevailed, during the late Holocene, in which the rocky surface degraded into blocks and fragments (Hamada and Serir) due to the influence of **temperature changes** as well as secondary fractures**.** At the same time, the **wind erosion** produced localized mesas and buttes; in addition the rocky surface of the Dibdibba Unit has been affected by wind erosion to produce deflation depressions and gravel pavement; while the same unit was dissected by **rill and gully erosions** to produce **badlands** during early Holocene. The deeply erosional processes were localized along the Periphery Unit to produce Tar Al-Najaf (in the northwest) and Tar Slaibat (in the southeast) during late Holocene.

─ Depositional processes

Several types of depositional landforms developed during the Pliocene – Pleistocene, when the perennial rivers deposited terrigenous sediments in form of fluvial plain (served as potential localities for deposition of Dibdibba Formation). During early Holocene, the **alluvial fans** of Al-Batin and Qsair Rivers, **terraces** of Sdair River, and flood plain of Euphrates River were deposited in the Periphery Unit. As well, the **estuary sediments** might be was deposited in Bahr Al-Najaf (Benni, 2001).

Several sag ponds, which are developed by tectonic activity, discharged groundwater above the rocky surface of the Periphery Unit. The seepage lakes have been dried by **evaporation** to produce gypcrete and inland sabkha during late Holocene. At the same time, the accumulation processes of **sand dunes** and **Nebkhas** were well developed in the Periphery and Al-Dibdibba Units.

GEOMORPHOLOGICAL UNITS

Based on observation of individual geomorphic unit and landforms of dynamic, tectonic and morphogenetic aspects, the Southern Desert is divided into seven major geomorphic units (Figs.6 and 7), these are:

- **Units of Structural – Denudational Origin**

The following two units are developed:

─ Desert Plateau

The Southern Desert is characterized by plateaus, due to flat, upland region (elevated more than 150 – 300 m in altitude), highly dissected by valleys and underlain by horizontal strata. The plateaus were developed in two periods: Oligocene and Late Miocene – Quaternary. The plateau includes few structural forms; such as linear valleys and, structural cliffs.

Linear valleys are well developed in Al-Dibdibba Unit, such as Wadi Al-Batin (50 Km in Iraq and 250 Km in Saudi Arabia long) and Wadi Sdair (60 Km long) both of them are running towards northeast.

Structural Cliffs are well developed along western limit of the Periphery Unit and along Busaiya – Amghar Fault Scarp. The former is extension of the Euphrates Fault Zone, which extends more than 280 Km with NW – SE direction, facing towards NE. Whereas, the latter extends for 70 Km with NE – SW direction, facing towards NW, which forms relatively steep cliff with height of about 6 m (Al-Ani and Ma'ala, 1983b).

─ Depression rocky terrain

The depression rocky terrain coincides with the Periphery Unit of the Southern Desert. The Oligocene Uplift formed a regional plateau, in which the exterior part was separated by the Abu Jir Fault Zone; in form of narrow and long area of NW – SE trend, with length of 385 Km and width of 15 Km. Its surface has relatively rolling nature of Early Miocene rock units due to effects of sheet erosion and presence of sag ponds (tectonic depressions). Later on, this terrain received the erosional products, from elevated part of the Desert Plateau. The unit consists of the following forms:

Sag ponds, six small and closed tectonic depressions, which are recognized along the depressed rocky terrain, are arranged along NW – SE trend, named: **Bahr Al-Najaf, Hor Al-Milih, Sawa Lake, Samawa Saline and Slaibat Depressions**. Sag ponds, which are developed by strike slip movement along Euphrates Fault Zone (Abu Jir Fault Zone), are drained by subsurface seepages, because they have not inlet or outlet drainage.

▪ **Units of Denudational Origin**

The following four units are developed:

─ Pediments

These are well developed along the exterior part of Al-Hijara Unit. The pediments are represented by gently inclined erosional plain, which is partly covered by rock fragments. The length of the pediment is 250 Km and the width is less than 10 Km.

─ Badlands

These are well developed in the Dibdibba Unit, in the central part and left side of Wadi Al-Batin (tectonic valley) during early Holocene. Because the area was barren of vegetations, the soft clastic sediments of the Pliocene – Pleistocene rock unit (Dibdibba Formation) are dissected by dense net of valleys.

─ Hamada and Serir

The rocky limestone terrain of Al-Hijara Unit has been influenced by mechanical weathering to produce rock blocks and fragments of variable sizes known as Hamada (for blocky fragments) and Serir (for small fragments). Their landforms, which have been developed in arid and semiarid climates, appeared within two phases of the continental evolution, in the Oligocene and Quaternary.

─ Deflation Depressions

They are shallow dish-like depressions resulted from wind erosion. Numerous deflation depressions are developed randomly throughout surface of plateaus, during the Oligocene and the late Holocene. Al-Sharbatti and Ma'ala (1983b) pointed out that the deflation depressions in the Dibdibba Formation resulted from removal of sands by wind action and leaving occasionally the loose gravels. Locally, they served as potential areas for accumulation of gravels or playa sediments (sandy loam).

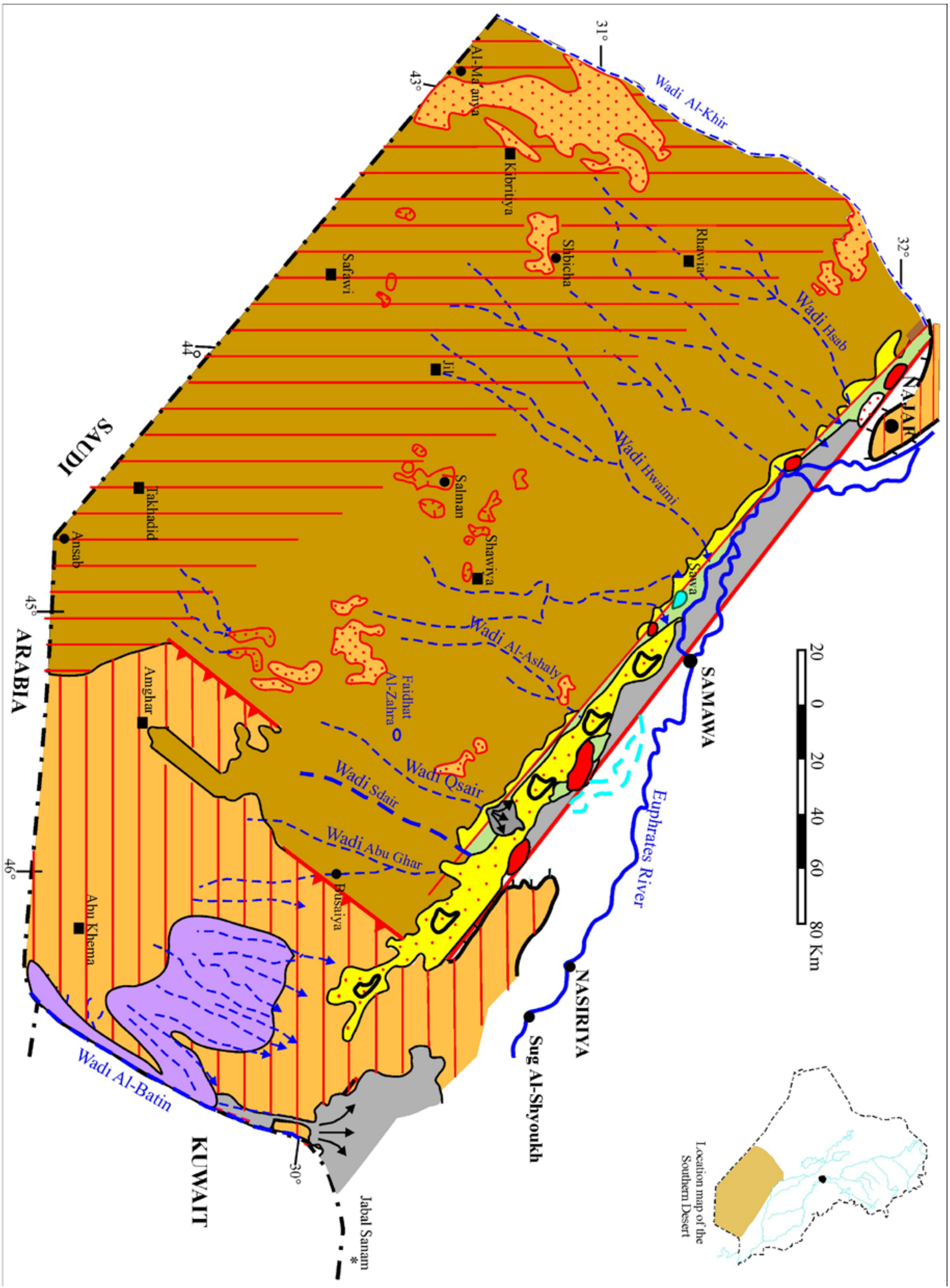

Fig.6: Geomorphological map of the Iraqi Southern Desert (for legend refer to Fig.7)

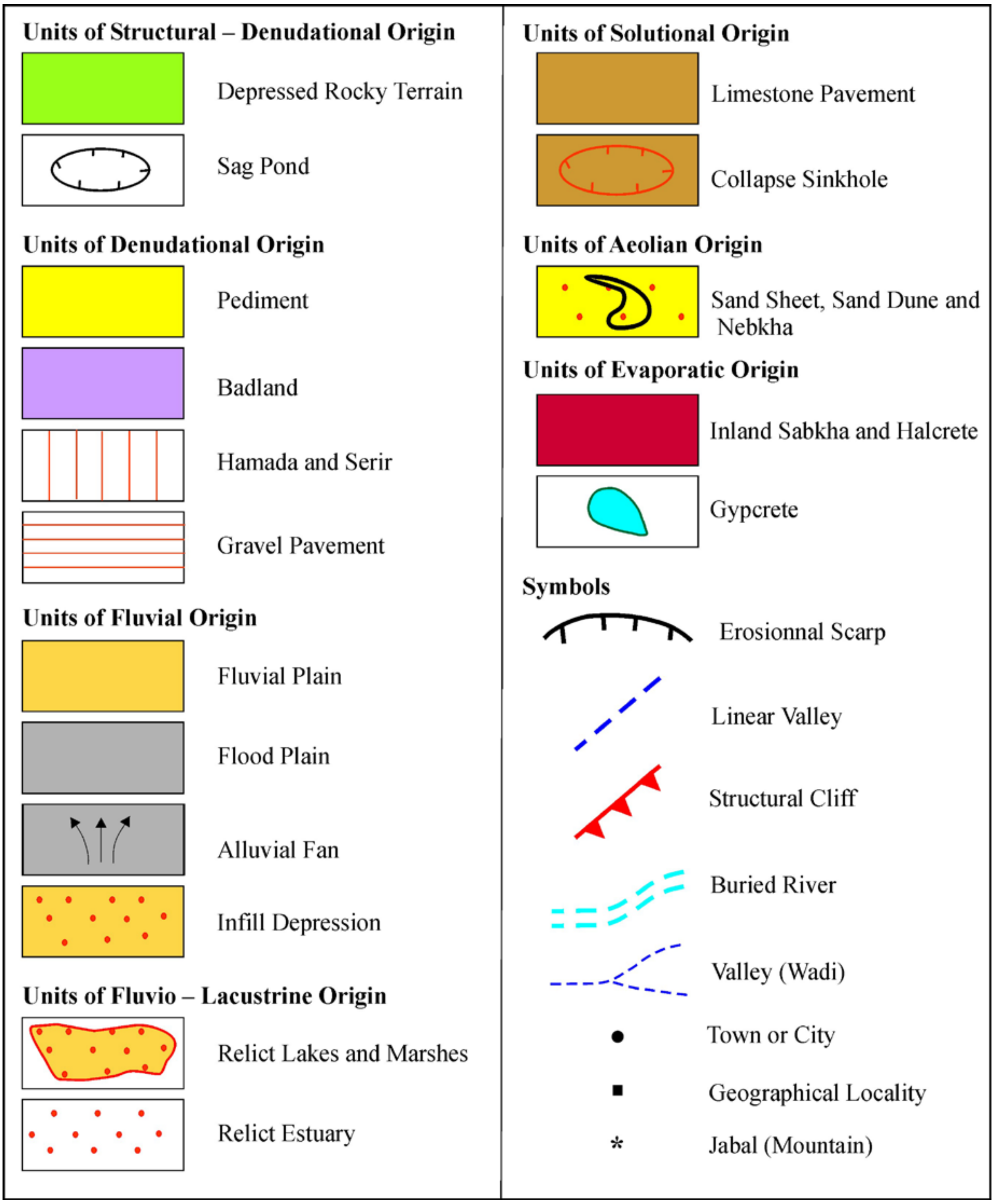

Fig.7: Legend for Fig.6

─ Denudational Forms

Several denudational forms are recognized in the Southern Desert, these are:

- Erosional cliffs: Two erosional cliffs are well recognized in the south of Najaf and Nasiriya towns, named: Tar Al-Najaf and Tar Slaibat, respectively. Their lengths are variable: 50 Km for the former and 40 Km for the latter. The soft rocks, in these localities, are denudated by mechanical processes during early Holocene.

- Mesas and Buttes: Many Mesas, which are developed in Al-Hijara Unit, are distributed randomly with variable sizes and shapes. They are capped by hard limestone beds, underlain by softer rocks. Some mesas suffer from rill erosion and toppling, which reduced them to buttes. Mesas occur either as isolated along valleys or in group, beside retreated cliff (e.g. Tlul Al-Afaif which are located south of Busaiya village).

▪ **Units of Fluvial Origin**

The following five units are developed:

─ Fluvial Plain

Fluvial plain, which is restricted to the Dibdibba Unit, represents huge sediments laid down by huge streams. The streams transported huge quantities of detrital sediments from the Arabian Shield in the Saudi Arabia during Pliocene – Pleistocene. They comprise sand and gravels of igneous rocks and white quartz, often cemented into a hard grit. They serve as potential area for deposition of Dibdibba Formation. Al-Sharbatti and Ma'ala (1983b) described this rock unit from the bottom upwards: 21 m of gravelly sandstone, 60 m of medium grained pink sandstone and 18 m of calcareous gravelly sandstone.

─ Flood Plain

Flood Plain is restricted to the Euphrates River only, in the Periphery Unit, especially along the meander belt which extends between Najaf vicinity and Samawa vicinity. It is composed of silt and mud, with variable thicknesses of (1 – 2) m.

─ Alluvial Fans

Two Alluvial fans are recognized in the Periphery Unit, they are developed by different rivers at the same time.

- Al-Batin Alluvial Fan is a huge fan; developed on the Periphery Unit and extends northwards to the Mesopotamian Plain. It starts from the extension of Euphrates (Abu Jir) Fault Scarp due to a sudden drop in the gradient. It is composed of yellowish pink sandy gravel and sands, which might be derived from erosion of the Fluvial Plain (Dibdibba Formation). The erosional materials are transported by Al-Batin stream during the Pleistocene, but the author believes it started at the beginning of Holocene. The apex of the fan is characterized by gravelly sand, whereas its toe, near Hor Al-Hammar, has fine and friable sands (Al-Sharbatti and Ma'ala, 1983b).

- Qsair Alluvial Fan is a small fan; developed within the Periphery Unit (west of Busaiya village) and starts from Euphrates (Abu Jir) Fault Scarp. It is composed of grey earthy material, dominated by carbonate fragments, which are derived from Al-Hijara Unit. The erosional materials are transported by Wadi Qsair (Fig.2) during Pleistocene, but the author believes it started at the beginning of Holocene.

─ River Terraces

Two levels of terraces are recognized in the southern margin of the Periphery Unit, they represent deposits of perennial rivers, such as Abu Ghar and Sdair valleys (Fig.1). The oldest level lies on 29 m (a.s.l.) with thickness of less than 1 m, while the youngest level lies on 22 m (a.s.l.) with thickness of more than 3 m.

─ Infilled Depressions

Different types of depressions, are developed in different physiographic units, they are filled by different materials. Four types of depressions are developed:

- Collapse sinks appeared during Late Miocene – Pliocene, have large dimensions and relatively deep. They are filled by clastic and fresh water limestone facies with variable thickness (20 – 31) m., such as Al-Ma'aniya, Al-Kibritiya, Shbicha, Zahra and Qsair Depressions. Whereas the younger collapse sinks depressions developed at the beginning of Holocene, and have large dimensions and depths, are filled by earthy materials (clays, silts, sands or gravely loam).

- New Karst Features are developed on the surface of the anhydrite land (Limestone Pavement) during early Holocene, are filled by earthy materials.

- Sag ponds are developed in the Periphery Unit, are filled by different materials. Bahr Al-Najaf Depression is filled by marine (estuary) sediments and flood sediments of Euphrates River. Hor Al-Milih and Slaibat Depressions are filled by accumulated sabkha, whereas Samawa Saline is filled by thick rock salt (halcrete).

- Deflation Depressions are connected with ephemeral valleys in the Dibdibba Unit; they are infilled by detrital sediments during the rainy seasons, at the end of Holocene. As well, in the first continental phase (Early Miocene), the deflation depressions, which are developed on the surface of the Oligocene Plateau, are filled by rock debris (deduced from existence of basal conglomerate of the Euphrates Formation) due the sea transgression in the Miocene.

▪ Units of Fluvio – Lacustrine Origin

The following two units are developed:

─ Relict of Lakes and Marshes

Numerous old lakes, which occupied the collapsed subterranean hallows and caves (e.g. Al-Ma'aniya, Al-Kibritiya, Shbicha, Zahra and Qsair), were distributed randomly on the surface of Al-Hijara Unit during Pliocene – Pleistocene. They received water from the internal drainage and rainfall. These lakes changed to old marshes and filled by clastic sediments, which served as potential areas for deposition of the Zahra Formation.

─ Relict Estuary

Bahr Al-Najaf, which is located in the northwestern part of the Periphery Unit, includes marine sediments. Benni (2001) pointed out that Bahr Al-Najaf was affected by marine sediments according to the presence of marine organisms (dinoflagellates). These sediments might be arrived to the area by drainage channels adjacent to the sea during early Holocene (Benni, 2001).

Remark:

It is worth to mention that the origin of Bahr Al-Najaf is attributed to Sag Ponds, whereas the sediments belong to marine origin.

▪ Forms of Solutional Origin

The following forms are developed:

─ Sinkholes

Areas built-up by limestone are marked by sinkholes, formed due to dissolving by water, (giving a more distinctive type of caves); even underground river channels being developed. The limestone of Al-Hijara Unit is marked by sinkholes, uvalas, dolines, caverns and karst valleys. Hamza (1997) showed that the karst features (sinkholes, blind and karst valleys) are localized in the area around Al-Salman Depression. Whereas, Sissakian and Ibrahim (2005) pointed out that the sinkholes are common types in the Southern Desert, which are developed due to dissolving of limestone. Sinkholes are well developed in the anhydrite land (Fig.5), which can be named as Limestone Pavement (Bates and Jackson, 1983). It consists of hundreds of sinkholes, which are filled by polygenetic sediments.

─ Uvalas

These are broad with uneven floor formed by breaking down of the walls between a series of sinkholes, such as Al-Sa'a Depression (13 Km long, 3 Km wide and 50 m deep); it is located southeast of Salman Depression. The exposed rocks in the cliffs are limestone of Dammam Formation (Eocene).

─ Caverns

These are subterranean hallows, enlarged by solution and erosion, consequently produced collapse sink depressions (20 Km long, 10 Km wide and 67 m deep). The exposed rocks in the cliffs are limestone of Dammam Formation (Eocene).

─ Karst Valleys

These are subterranean passages running in NE direction, developed by solution of limestones (Eocene). Several of them were collapsed and produced abandoned valleys, which often end abruptly as blind valley, such as karst valleys in the Takhadid vicinity (Fig.6).

─ Dolines

These are rounded hallows varying from (1000 – 2500) m in diameter and (10 – 65) m in depth; dish shaped cavities connected with underground drainage system in limestone regions, as Al-Ma'aniya and Al-Kibritiyah (Al-Ani and Ma'ala, 1983a and Al-Haz'za, 1996).

Remark: The **Terra rossa soil,** in the Southern Desert, is of red silty claystone, which is found at the base of Zahra Formation, it might be resulted from chemical weathering of subterranean hallows and caves. This type of soil is present in Al-Ma'aniya, Shbicha and Zahra Depressions (Al-Ani and Ma'ala, 1983a and Al-Haz'za, 1996). As well, the **Terra rossa** soil is recognized in cavities below the surface of the Oligocene Plateau, (underlying the basal conglomerate of the Euphrates Formation). The red silty claystone was penetrated by boreholes in Samawa vicinity (oral communication, members of GEOSURV’s party, 2007).

▪ **Units of Aeolian Origin**

Wind blown sediments are spread locally over the Southern Desert. They are developed in many places as simple units of Aeolian landforms, such as sand-sheets and sand dunes. The Aeolian sediments are still active but formed during late Holocene, when the climate was more arid and hotter than today (Jassim and Buday in Jassim and Goff, 2006). The following three units are developed:

─ Dibdibba Sand Sheets

Drift sand sheets are developed locally over the uneven surface in Al-Dibdibba Unit. They are composed of fine grained quartz sand with thickness less than 0.5m, which indicates a young drifting age.

─ Samawa – Nasiriya Sand Dunes

The sand dunes are restricted to the Periphery Unit. They consist of small size dune fields of Barchan type; up to 4 m in height with NW – SE trend. Many of them are active; others are fixed by vegetation due to seepages of saline groundwater. The dune fields comprise of grey color, medium sand sizes of quartz and carbonate, which may be derived from Euphrates flood plain. Some of the sand dunes extend over the neighboring Al-Dibdibba Unit.

─ Nebkhas

These are spreading locally on all physiographical units. They are formed in valleys, also in sides of mesas; hills; depressions and cliffs. The sand grains are well sorted; composed of carbonate and quartz.

▪ **Forms of Evaporates Origin**

The evaporate forms, which are developed locally in the sag ponds within the Periphery Unit, are the products of saline groundwater seepages under the influence of the arid climate. The following two units are developed:

─ **Gypcrete**

It is well developed around the rims of the Sawa Lake, it is massive, fairly to well compacted, with (1 – 2) m thickness. Another locality is Hor Al-Milih, in which the gypcrete is deposited as sheet crust.

─ **Inland Sabkha and Halcrete**

The inland sabkha, which is a kind of sediments deposited in depressions like Sag Ponds or playas, is localized in the Periphery Unit, such as Slaibat, Samawa Saline and Bahr Al-Najaf. They are rich in salt content or salt horizons (Barwary *et al*., 2002). The source of the brines is supplied from seepages of groundwater. Sissakian and Ibrahim (2005) pointed out that well known Sabkhas are in the area alongside of the Euphrates River from Samawa to Al-Najaf. Hamza (1997) described the sabkha as salt crust. In Samawa Saline, which has a high concentration of NaCl, the salt crust reaches 6 m in thickness, which may referred to Halcrete.

DISCUSSION

The present surface of the Southern Desert is marked by 24 landform assemblages, which are the product of former various denudational and depositional processes in two continental phases of evolution. The geomorphological development is discussed hereinafter:

▪ **The Pre-Miocene Phase**

The first phase of the continental evolution started after the sea regression in the Eocene due to the influence of the Oligocene Uplift, which led to form the older Plateau. The rock surface of the plateau was influenced by intensive mechanical weathering for more than 10 Ma that produced shallow dish-like depressions; called Hamada and Serir (Fig.8). These features are deducted from the rolling topographic nature of Eocene rock unit (Dammam Formation) and the uneven surface of basal conglomerates that exist at the base of Euphrates Formation. The basal conglomerate expresses the topography of the Eocene bedrocks that seem to be slightly of rolling nature. As well, the basal conglomerate lack any marks about surfacial drainage (Al-Ani and Ma'ala, 1983a and b), which often indicates arid climate. Therefore, most of these features might be developed due to effective mechanical weathering processes, under influence of temperature changes and wind activity for long times. After long period (33.9 – 23.03 Ma) of desert environment, the loose debris (Hamada and Serir) reworked by the transgression of Miocene sea to cover the rolling nature topography. At the same time, a deep subterranean chemical weathering took place in respect to activity of groundwater, as indicated from Salman and Al-Sa'a Depressions with depths of 65 m and 55 m (from present ground surface), respectively. As well, Salman Depression is connected with apparent canyon like valley (63 m deep). Emldeton and Thornes (1979) pointed that the chemical weathering in arid and/ or semiarid climates produced deep subterranean hallows and caves. Jassim and Buday in Jassim and Goff (2006) showed that the drainage trace in ground of the Salman Depression could be observed by landsat image. Terra rossa soil is developed in hidden caves, which give indication of relatively intensive chemical weathering. Tyracek (1978) believed that Terra rossa soil might be developed in the periodically alternating humid warm and dry warm periods. Therefore, Terra rossa soil might be developed in Pliocene – Pleistocene.

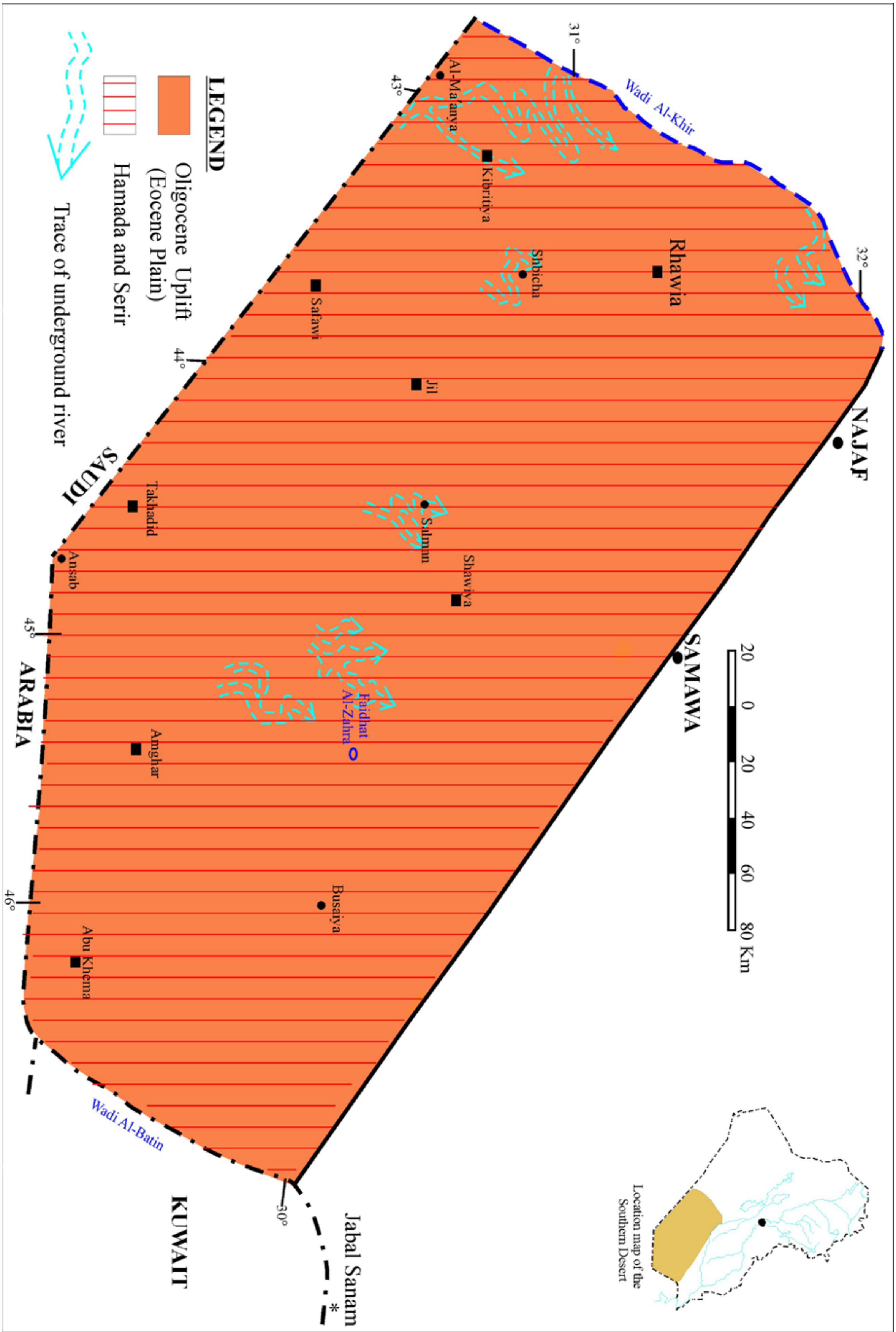

Fig.8: Denudational land forms during the first continental phase of evolution (Older Plateau)

▪ **The Miocene – Quaternary Phase**

The second phase of the continental evolution started in Late Miocene, after the last sea regression during Miocene, due to influence of the last Alpine movement, which led to form the younger Plateau. Meantime, the exterior part (the Periphery Unit) of the younger plateau was separated by influence of Euphrates Fault Zone (Ma'ala, 2008). Several sag ponds appeared along the fault zone. Fouad (2000) pointed out that Abu Jir Fault Zone exhibits some geomorphologic features (pressure ridges and sag ponds) that are related to the lateral movement of the fault zone. At the same time, the Dibdibba Basin was emerged tectonically in the area along Ansab – Sdair lineament of NE – SW trend (Ma'ala 2008). Buday and Jassim (1987) pointed out that faults of NE – SW trend were disrupted by NW – SE trending dislocation. Moreover, Ditmar *et al*. (1972) showed that the amplitude of depression, in the Southern Desert, is not exceeding some tens of meters, according to the geophysical data.

─ **Denudational Processes and Landforms**

After the last Alpine movement, the continental landforms were commenced in the Southern Desert. The marks of denudational processes and landforms are discussed hereinafter according to their existence in each physiographic unit:

- Periphery Unit: The rill erosion activity started along cliffs of Euphrates Fault Zone (Abu Jir Fault Zone) and the rims of sag ponds, because vertical erosion accelerated along faults, dense fractures and high relieves with heavy rain showers. These rills were later enlarged into gullies. Sheet erosion might be contributed to remove the clastic facies of the Nfayil Formation. Lateral erosion was common along the northwestern course of the Euphrates River, between Bahr Al-Najaf vicinity and Samawa town, due to existence of vertical fractures, as indicated from presence of dense meandering. As well, the lateral erosion might cause mass-wasting along the meander belts. Hamza (1997) pointed out that the lateral erosion caused slumping, sliding and rock falls. Therefore, the Periphery Unit was well visible depression terrain during Pleistocene – early Holocene. Vertical erosion is expressed along Abu Ghar and Sdair valleys as indicated by presence of river terraces.

- Al-Hijara Unit: The surfacial chemical weathering processes produced Terra rossa soil and rock fragments. This assumption is based on presence of the red mudstone facies of the Zahra Formation, which infilled later on the collapse sink depressions.

Some of the subterranean hallows and cavities, which inherited from the first continental phase (in Oligocene), were enlarged and collapsed partly in Late Miocene (e.g. Al-Ma'aniya, Al-Kibritiya, Zahra and Qsair), while others were enlarged and collapsed in early Holocene (Fig.9). The age suggestion is based on presence or otherwise of the clastics of the Zahra Formation. This suggestion is compatible with that proposed by Tyracek (1978) and Sissakian and Al-Mousawi (2007). The collapse of subterranean hallows and cavities occurred due to enlargement of chambers and thinning of roofs. Therefore, the tectonic activity has never contributed in development of these landforms. The present author refers this type of karst to the first phase of karstification. Whilst the second phase of karstification is concentrated in the anhydrite land (Al-Hashimi, 1973) (Fig.5), which is named by the present author as Limestone Pavement (Fig.10). The surfacial dissolution processes were developed in Pleistocene – Holocene due to dense heavy rains, soluble rocks (limestone beds of Euphrates Formation) and fractures. Tamar-Agha (1984) pointed out that fractured strata allowed the running off water to percolate and aid the groundwater in dissolving the limestone strata.

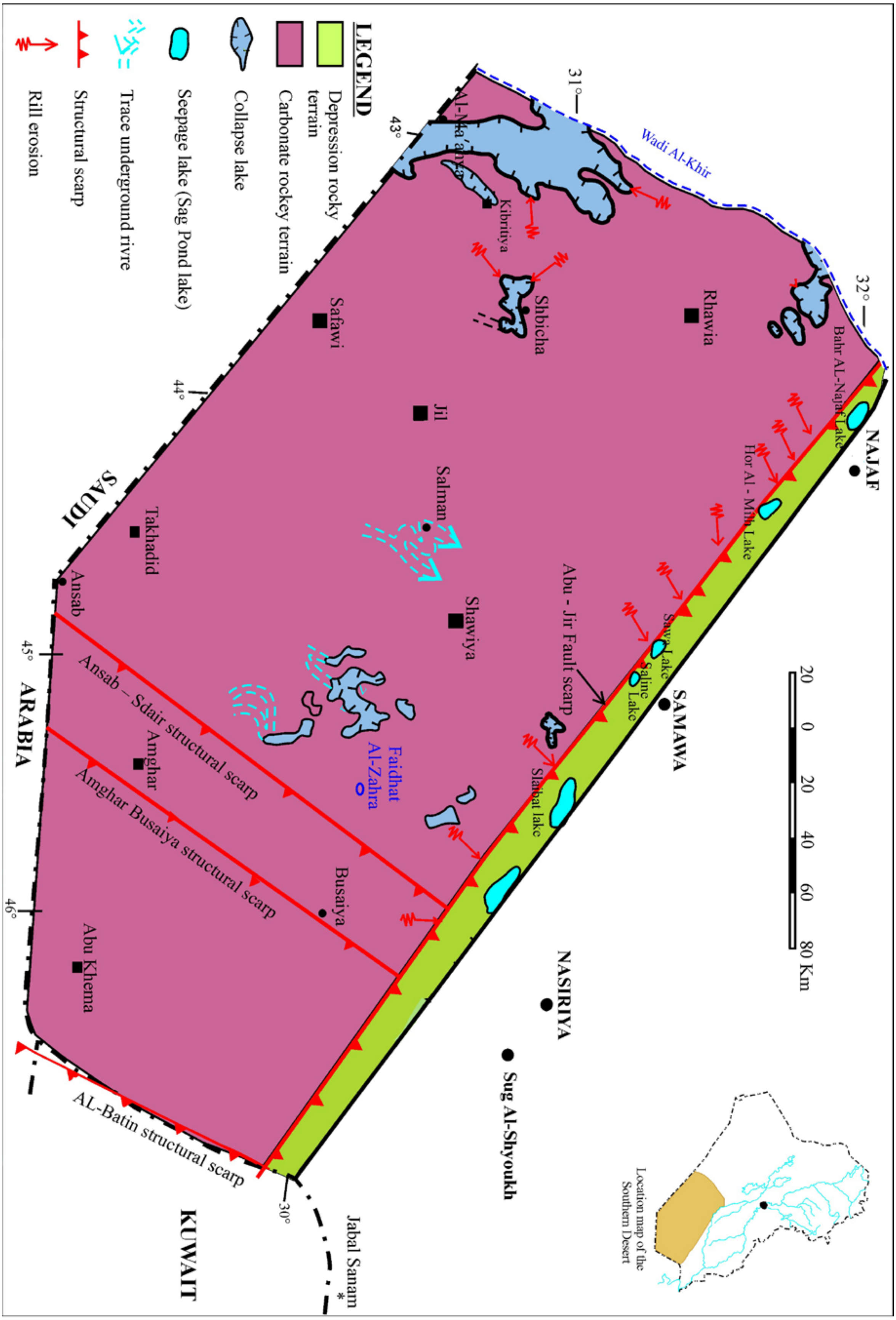

Fig.9: Distribution of lakes and structural scarps during the beginning of the second continental phase of evolution (Late Miocene – Pliocene)

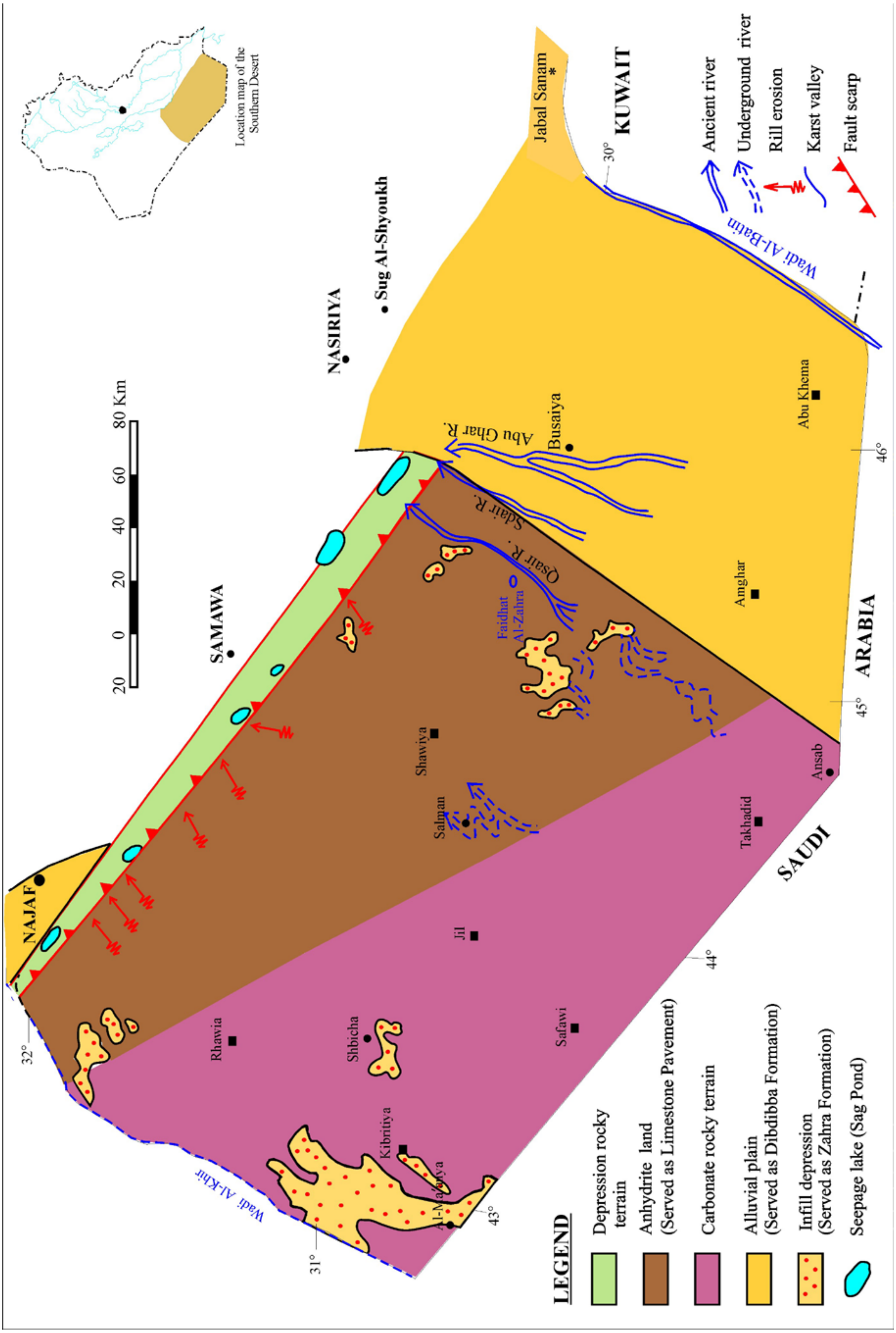

Fig.10: Distribution of land forms during the Pliocene – Pleistocene

Hundreds of sinkholes are filled by polygenetic sediments and rock fragments, of the Zahra Formation. Therefore, the age suggestion is based on the absence of clastic sediments of the Zahra Formation. This suggestion is compatible with that proposed by Tyracek and Younan (1975) and Sissakian and Al-Mousawi (2007). They believed that a new karstification formed in Late Pleistocene. Few sinkholes are still active in the Al-Hijara Unit, which may give indication for continuation of the subterranean hallows and caves to present day. Sossa (1966): in Sissakian and Al-Mousawi (2007) displayed that on 5/ 3/ 1944a large sinkhole was formed in limestone strata of the Dammam Formation (Eocene) after collapse of the roof forming beds, near Shbicha Police Post. The diameter and length of the sinkhole are 33 m and 27 m, respectively. The present author believed that the former sinkholes are still active (sinking) since early Holocene due to the continuous leaching of evaporates facies of the Rus Formation by groundwater. This mechanism led to net of undulations too.

Most of authors agreed that the Holocene period started during (6000 – 1000) Y.B.P., due to the commencement of Flandrian transgression (Benni, 2001). The early Holocene climate was wet and hot with increasing of rainfall in summer season, which led to rise of the sea level. This climate affected on some former subterranean hallows and caves, which were subdued to collapse due to their enlargement, such as Salman, and Haddaniya Depressions (Fig.11). Some dolines are enlarged by conjunction of more dolines to form irregular depressions, e.g. Al-Sa'a Depression.

The vertical erosion manifested itself along a canyon located south of Salman Depression. This phenomenon might be developed along dense fractures or master joint of N – S trend, associated with heavy rainfall and change in the base level of erosion, during early Holocene.

The perennial rivers were developed due to heavy rainfall with high humidity. Those rivers, which started from the present location of the Iraqi – Saudi Arabian borders, were running in NE direction due to the regional gradient. Few rivers were across the scarps of Euphrates (Abu Jir) Fault Zone into the Periphery Unit, as indicated by the presence of river terraces along Abu Ghar and Sdair Rivers, as well alluvial fan (Qsair River) (due to lowering of the Periphery Unit). Few rivers disappear abruptly, due to the presence of sink holes, such as Agrawi River (north of Ansab) (Figs.10 and 11). At the same time, the exterior (northeastern) part of Al-Hijara Unit was modified to pediment (Fig.11).

During the late Holocene, the rocky surface of Al-Hijara Unit was influenced by wind erosion, which produced Hamada, Serir and mesas. The limestone strata, which were entirely heated by temperature, were broken to variable dimensions with contribution of bedding planes and secondary fractures, the larger blocks formed Hamada and smaller formed Serir. Therefore, these phenomena represent second stage of development Hamada and Serir landform.

Several mesas are developed randomly along dry valleys and beside of cliffs. Some of them are reduced to small hills or buttes. The latter may represent a last stage of the dissection process in Al-Hijara Unit. Many sites of toppling are occur along cliffs of depressions, e.g. Al-Salamn, Al-Sa'a, Al-Had'daniya, and sides of mesas.

- Al-Dibdibba Unit: The rocky surface of Al-Dibdibba Unit was dissected by water erosion during early Holocene (rainy stage), which produced badlands, east of Busaiya village, and around Wadi Al-Batin. During the late Holocene (dry stage), the Al-Dibdibba Unit was influenced by wind erosion, which produced deflation depressions. In these depressions, coarse gravels were led in site to form pavement landform. Most of the deflation depressions are covered by sand drift. However, some of them, which are connected to ephemeral dry valleys, are modified to playas and their muddy sediments cover the residual gravels. The soft rocks of the erosional plain, which are dissected by net of dry valleys, are modified to badlands (Fig.6).

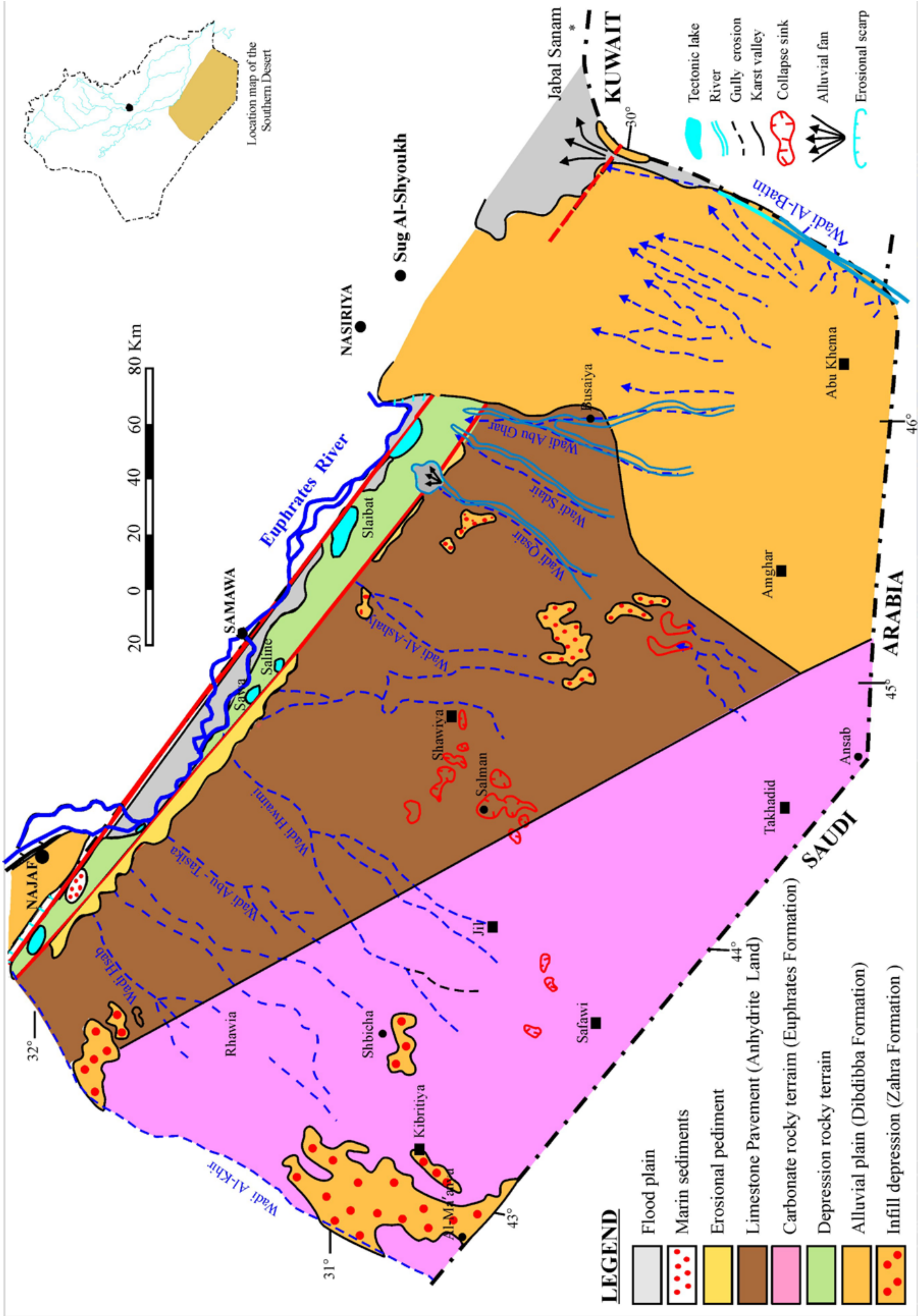

Fig.11: Distribution of landform during early Holocene

─ Depositional Processes and Landforms

These are discussed hereinafter according to their existence in each physiographic unit:

- Al-Dibdibba Unit: In Pliocene – Pleistocene, the wet climate led to washing processes on the pediment plain of the Arabian Shield, in the area known now as Saudin Arabia. The debris of igneous rocks were transported by huge river courses, such as Al-Batin River, which was running northeastward and filling the Dibdibba Basin (served as locality for deposition of Dibdibba Formation) to form fluvial plain (Fig.10). The basin extends northward to cover the southeastern part of the **Periphery Unit**. In late Holocene, Al-Batin River was modified to dry valley, which is partly covered by sand drift accumulations and Nebkha.

- Al-Hijara Unit: In Pliocene – Pleistocene, the heavy rainfalls filled the previously collapse sink depressions that were developed in Al-Hijara Unit and caused perennial fresh-water lakes (Fig.9). The heavy rainfalls removed the previously formed Terra rossa soil and rock fragments (resulted from surfacial chemical corrosion during Late Miocene – Pliocene), which supplied the collapse lakes by red mudstone. Al-Haz'za (1996) believed that the lime mudstone facies of Zahra Formation represents deep lake sediments. The heavy rainfalls also contributed in filling of the collapse lakes by washed surfacial sediments. The lakes became shallow and passed to ephemeral marshes, which led to growing of reeds. The reeds may represent the terminal stage of ephemeral marshes. Al-Haz'za (1996) believed that the presence of gypcrete in the burrows of the Zahra Formation indicates climatic changes from wet to dry.

Some of the earthy materials were washed by rainfalls to the depression rocky terrain (the Periphery Unit), which led this unit as foot basin for the younger Plateau. Most of the sag ponds, which were developed tectonically along the Periphery Unit, were remaining active as seepage lakes during Pliocene – Pleistocene (Fig.10).

- Periphery Unit: All existing landforms in the Periphery Unit show that the depositional processes started during Holocene. The early Holocene, which is characterized by wet and hot climate with increasing of rainfalls in summer seasons (Benni, 2001), led to rise of the sea level. The marine sediments might be arrived Bahr Al-Najaf by drainage channels which deposited the Estuary sediments in this unit (Fig.6). The early Holocene climate contributed in the deposition of alluvial fans, river terraces and flood plains. Many rivers which were developed in the Al-Hijara and Al-Dibdibba Units, extended to the Periphery Unit. Two sorts of alluvial fans are recognized in the Periphery Unit: The smaller one produced from Qsair River, while the bigger are formed from Al-Batin River (Fig.11). The former is dominated by limestone fragments, which might derived from Al-Hijara Unit, due to the exposure of Early Miocene rocks. Whereas the latter is dominated by sands and gravels of igneous rocks and quartz, which might derive from Al-Dibdibba Unit, due to the exposure of Dibdibba Formation. Due to the heavy rainfalls, the rivers were capable to carry boulders more than 256 mm and cobbles (64 – 256) mm, in diameter. Al-Ani and Ma'ala (1983a) and Al-Sharbatti and Ma'ala (1983b) observed boulders and cobbles at the apexes of the alluvial fans. The river, in each locality, might diminished nearby the extension of the Euphrates (Abu Jir) Fault Zone, due to overloaded stream, which dammed its channel and permits to develop alluvial fan.

Two levels of terraces are developed along Abu Ghar and Sdair rivers. Al-Ani and Ma'ala (1983b) recognized two levels of terraces with difference between levels about 7 m. Tyracek (1978) believed that presence of several levels of terraces in the valleys of ephemeral streams with existing gypcrete reflect Pleistocene climatic changes. The present author modified the time of this suggestion to be early Holocene climatic changes.

The late Holocene started with development of arid climate, which are represented by inland sabkha, aeolian and depression infill sediments (Barwary *et al.*, 2002). At the same time, all seepage lakes were modified to dry depressions, excluding Sawa Lake, which might be connected with Euphrates River.

The sabkha sediments filled the dry lakes (Bahr Al-Najaf, Hor Al-Milih, Samawa Saline and Slaibat Depressions), due to seepages of the groundwater. Samawa Saline includes thick crust of Halcrete, which reaches up to 6m in thickness. The brine might be derived from the leaching of evaporate facies of the Rus Formation, which were recharging the dry lakes through the Euphrates (Abu Jir) Fault Zone.

The wind blown accumulation, which occupied the eastern area of the depression rocky terrain (SE of Sawa Lake), built narrow and longitudinal dune fields. Many dunes are still active; others are fixed by shrubs, due to the seepages of saline groundwater. Jassim and Buday in Jassim and Goff (2006) believed that storms moving from SW in the desert often drop their sandy fractions within depressions along Euphrates River. But, the existing Nebkhas in Sawa Lake vicinity express those storms are from NW. In addition, their silty and clayey fractions are often transported further into Mesopotamian Plain.

The present climate indicates that the potential of evaporation is several times more than the average rainfall. The area still possess semiarid climate (Fig.2). Therefore, in many localities sand dunes and Nabkhas are still active.

The depression rocky terrain (the Periphery Unit) is influenced by deposition of flood sediments, which are restricted to the meandering of the Euphrates River and along the buried channel (Fig.11). The latter may express the trace of old Euphrates River course which was following the trace of Euphrates (Abu Jir) Fault Zone and shifted later northwards.

CONCLUSIONS

- Two phases of destruction and construction processes mark the surface of the Southern Desert, which took place during two continental phases. Therefore, the Southern Desert is attributed to rejuvenated plateau.
- The first continental phase, which commenced after the Oligocene Uplift, led to forming of the older plateau. It is characterized by prevailing of denudation processes in a semiarid climate, as well as beginning of subterranean hallows and caves.
- The second continental phase, which started after the last Alpine movements, included the Pliocene and Quaternary Periods, led to forming of the younger plateau. It is characterized by climatic fluctuations between wet – arid and semiarid, which induced denudation in places and deposition in others. They produced twenty four landform assemblages, referred to seven morphogenetic units of variable origins; they are distributed on three physiographic units (Al-Hijara, Al-Dibdibba and the Periphery).
- Each physiographic unit has its specific landforms that reflect the effects of the structure, lithology and climate.
- The northeastern exterior part of the younger plateau has been subsided due to the influence of erosional processes along Euphrates (Abu Jir) Fault Zone which modified later on to foot basin, because it received the clastic sediments from the elevated parts of the plateau, during the Pleistocene and early Holocene. In addition to the polygenetic sediment referred to evaporation, aeolian, estuary and flood of Euphrates River.
- The Southern Desert converted to Lake District in Pliocene due to climatic changes. Two types of lakes appeared: collapse lakes in the elevated rocky terrain and seepage lakes in the depression rocky terrain. The formers were infilled by clastic sediments of Zahra Formation, while the latter by salt accumulations, excluding Sawa Lake.
- The underground drainage system was active and originated network of passages and chambers since Oligocene to Recent time.

- The surface drainage system was active and originated sub parallel rivers, which were running in NE direction, since Late Pleistocene to early Holocene and became dry later on.
- The present semiarid climate formed sparse landforms that contributed in the protection of the surface of the plateau by desert pavements, excluding the karstified area (Limestone Pavement), which served as passage ways for rainwater.

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