CLASSIFICATION OF THE ALLUVIAL FANS IN IRAQ

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ABSTRACT

The Iraqi territory exhibits diverse topography in its different parts; from the extreme southeast, where the coastal area along the Arabian Gulf, passing northwards to the Mesopotamia Plain, and more north and northeast to hilly, low mountainous and high mountainous areas, respectively. Whilst towards west, the plateau of the Southern and Western Deserts exist and in the northwestern part is the Jazira Plain. This diversity in the topography with climatic changes has caused development of different systems of alluvial fans, with different ages, stages, shapes, sizes and constituents.

This study aims to establish a classification of alluvial fans developed in Iraq depending mainly on the stages, for the main types and the size, shape and covering constituents for the types and sub-types. Consequently, two main types were found: Single Stage and Multi Stage Alluvial Fans. Furthermore, each main type is classified into many types, depending on the size, shape and top covering materials. The age is not included in the classification, because almost all the existing alluvial fans in Iraq have the same age range (Pleistocene – Holocene). Moreover, no accurate dating is available to use for the fan classification. The constituent factor is not used, because it depends on the type of the exposed rocks in the source area. Examples are given for each type and sub-type from different parts of Iraq. Some of the examples have fan names, used in other studies.

تصنيف المراوح الفيضية في العراق

فاروجان خاجيك سيساكيان و مواهب فاضل عبد الجبار

المتسخلص

هناك اختلاف كبير في طوبوغرافية سطح العراق، فمن ساحل البحر المطل على الخليج العربي في أقصى الجنوب، ومن ثم مروراً بالسهل الرسوبي لنهري دجلة والفرات باتجاه الشمال، وبعد ذلك الى المناطق الجبلية الواطئة ثم مناطق الجبال العالية، تباعاً باتجاه الشمال والشمال الشرقي. أما باتجاه الغرب، فتوجد هضبة الصحراء الجنوبية والصحراء الغربية، وفي اقصى الشمال الغربي يوجد سهل الجزيرة. إن هذا التنوع في الطوبوغرافية، إضافةً الى الاختلافات المناخية قد أدت الى تكون مجاميع من المراوح الفيضية المختلفة، مع اختلافات في العمر والمراحل والشكل والحجم والرسوبيات.

ان هذه الدراسة تهدف الى اعداد تصنيف للمراوح الفيضية في العراق. اعتماداً على المراحل، تم تصنيف المراوح الى صنفين رئيسيين، ومن ثم تم تصنيفهما الى صنوف وصنوف ثانوية اعتماداً على الحجم والشكل وأنواع الرسوبيات التي تغطي سطح المراوح. وعليه تم تصنيف المراوح الى صنفين رئيسيين هما: المراوح الفيضية ذات المرحلة الواحدة والمراوح الفيضية ذات المراحل المتعددة. كما تم تصنيف الصنفين الرئيسيين الى صنوف ومن ثم الى صنوف ثانوية. ولم يعتمد العمر في التصنيف لان غالبية المراوح لها نفس المدى العمري وهو البلايستوسين – الهولوسين، كما انه لا يتوفر في العراق امكانية تحديد العمر بشكل دقيق.

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ولم يتخذ كذلك عامل المكونات الرسوبية للمراوح، لان ذلك يعتمد على الصخور المتكشفة في منطقة المصدر. وقد ذكرت امثلة عن كل صنف رئيسي وصنف وصنف ثانوي ومن مختلف مناطق العراق. وان لبعض المراوح اسماء وقد ذكرت وكما جاءت في الدراسات السابقة المتوفرة عن وصف المراوح الفيضية.

INTRODUCTION

An alluvial fan is a fan- or cone-shaped deposit of sediment crossed and built by streams. If a fan is built up by debris flows it is properly called a debris cone or colluvial fan. These flows come from a single point source at the apex of the fan, and over time move to occupy many positions on the fan surface. Fans are typically found where a canyon draining from mountainous terrain emerges out onto a flatter plain, and especially along fault-bounded mountain fronts. A convergence of neighboring alluvial fans into a single apron of deposits against a slope is called a Bajada, or compound alluvial fan (A.G.I., 1962).

In Iraq, alluvial fans are developed almost in all physiographic provinces, but with different types, shapes, sizes and constituent materials. However, few of them are presented on the geological maps, especially those, which have considerable areas. Google Earth and satellite images show very clearly the occurrence of the alluvial fans. Alluvial fans are apron-like deposits of granular debris that extend from the base of a mountain front to the low land below. Each fan radiates from a single source channel, and has fan-like shape in plain view. Its transverse profile is arched, and the longitudinal profile is slightly concave. Slopes are usually less than 10°. The fans are best developed in semiarid terrains, where elongate mountain ranges that are tectonically active (basin-and-range topography) and lack protective vegetation cover, are subjected to erosion by episodic heavy rain precipitation (Bull, 1991).

The aim of this study is to establish a classification, which deals with the present alluvial fans in different parts of Iraq, which have different characteristics; as to the number of stages, sizes, shapes and cover materials. The classification can be applied on the existing alluvial fans, in Iraq.

The geological and topographical maps with the Google Earth and Satellite images were used to recognize the present alluvial fans in different parts of Iraq. GIS techniques were used to calculate the coverage area and other geometrical parameters of the main large alluvial fans. Field description points in different geological reports and relevant published articles were reviewed to indicate the number of the stages, shape, sizes, covering materials and constituents of the existing alluvial fans. Geological maps (GEOSURV, 1992 – 2012, and Sissakian and Fouad, 2012a) were reviewed to indicate the relation between the exposed geological formations and the present alluvial fans. Some already existing classifications, worldwide were used, directly or indirectly to establish the basics of this introduced classification.

PREVIOUS WORK

Specialized studies, dealing with the various aspects of alluvial fans in Iraq, are very rare. The following studies, however, though not closely related to the main aim of the present study, are thought to be useful as a background to the proposed classification.

- Ma'ala (1977) executed regional geological mapping of Sinjar anticline and surrounding areas. He reported alluvial fans and recognized only two stages that were developed during Pleistocene – Holocene.
- Jassim (1981) recognized the Fatha Alluvial Fan, along the Tigris River, in Al-Fatha Stretch. He mentioned details of the fan and its extensions.

- Al-Sharbati and Ma'ala (1983) studied Al-Batin Alluvial Fan, in the Southern Desert, and divided it into four stages.
- Yacoub (1983) and Domas (1983) studied the alluvial fans of Mandali – Al-Fak'ak area and divided them into five stages.
- Ghalib (1988) studied the Najaf Plateau and concluded that it forms a big alluvial fan.
- Al-Daghastani (1989) mapped Sinjar Anticline and related alluvial fans using remote sensing data. He recognized one stage of alluvial fans surrounded by accumulation glacis.
- Hamza *et al*. (1990) and Yacoub *et al*. (1990) studied Al-Fatha Alluvial Fan and mentioned its details.
- Yacoub *et al*. (1991) studied Al-Fatha Alluvial Fan and divided it lithologically into two main components.
- Hamza (1997) compiled the Geomorphological Map of Iraq at scale of 1: 1000 000 and presented the main alluvial fans in Iraq.
- Al-Daghastani *et al*. (2004) mapped Sinjar alluvial fans to be used for rainwater harvesting, using remote sensing techniques. They recognized two types of alluvial fans, one stage and multi stages of alluvial fans, beside active and dormant fans.
- Al-Khateeb and Hassan (2005) studied Al-Najaf – Karbala Alluvial Fan and considered it as the Dibdibba Formation.
- Aqrawi *et al*. (2006) in Yacoub (2011a) studied Al-Batin Alluvial Fan and reported about the presence of heavy minerals.
- Al-Daghastani and Al-Dewachi (2009) executed the most comprehensive geomorphological work in Sinjar area and mapped the northern plain of Sinjar mountain using remote sensing technique. They concluded the presence of alluvial fans that form "Bajada". They also concluded that the fans are related to different episodes of neotectonics and to the fluctuation of the base level in the area.
- Sissakian and Abdul Ahad (2009) compiled the Geological Hazards Map of Sinjar Quadrangle, at scale of 1: 250 000 and mentioned the presence of alluvial fans around Sinjar anticline, especially the northern plain. They considered the coverage areas by the alluvial fans to be of active erosional areas, exhibiting geological hazards.
- Ma'ala (2009a) studied Al-Qusair Alluvial Fan and claimed it is of Holocene age.
- Ma'ala (2009b) studied the alluvial fans of Al-Jazira Plain and recognized small fans along Tharthar Valley and along Snaisla – Tel Abta Cliff.
- Sissakian (2011) presented a detailed study of the alluvial fans of Sinjar vicinity. He recognized 4 stages within the alluvial fans.
- Yacoub (2011a) described the alluvial fans in the Mesopotamia Plain.
- Sissakian and Abdul Jab'bar (2013a) studied the alluvial fans of the Hab'bariyah Depression in Iraqi Western Desert. They recognized two stages of alluvial fans.
- Sissakian and Al-Jiburi (2012) gave general description of the alluvial fans within the Low Folded Zone.
- Yacoub *et al*. (2012) described the alluvial fans in the Low Folded Zone.
- Zaini and Abdul Jab'bar (2014) presented the alluvial fans of the Slaibat Depression in the Southern Desert of Iraq. They recognized two stages of alluvial fans, with two different groups.
- Sissakian and Al-Jiburi (2014) gave general description of the alluvial fans within the High Folded Zone.
- Sissakian *et al.* (2014) described the alluvial fans in the High Folded Zone.

PHYSIOGRAPHIC UNITS IN IRAQ

Because the alluvial fans are very closely related to the physiographic provinces, and because within each physiographic province the fans have different characteristics, therefore, the physiographic provinces are briefly reviewed hereinafter. The physiographic map of Iraq is given in Fig. (1).

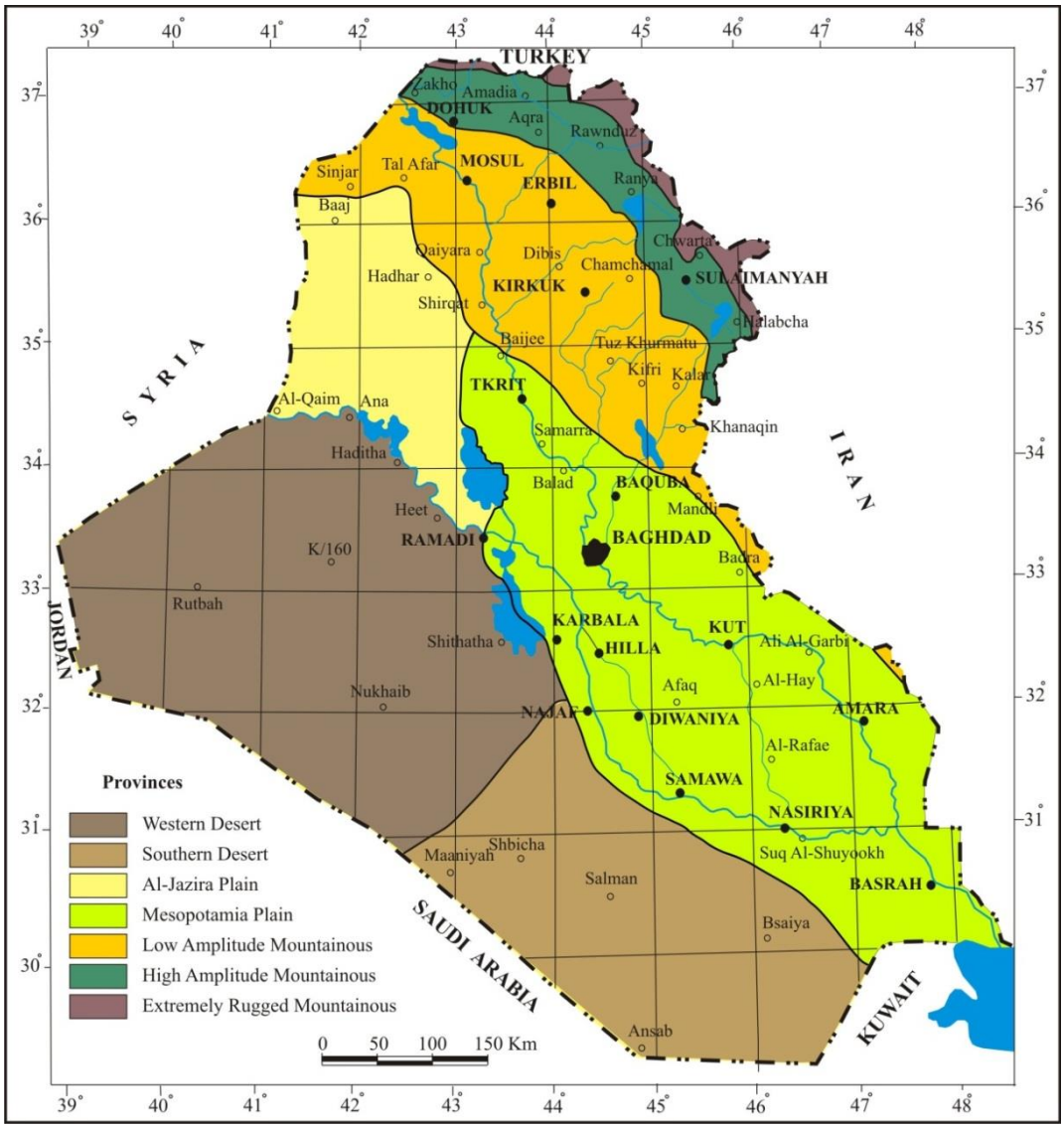

Fig.1: Physiographic Map of Iraq (after Sissakian and Fouad, 2012a)

▪ Western Desert Province

It occupies the western part of the Iraqi Territory, south and west of the Euphrates River; it is limited between Iraqi – Syrian and Iraqi – Saudi Arabian borders. It is a gently sloping where the height rises from about 300 m (a.s.l.), in its eastern margin to 998 m (a.s.l.), in the extreme southwestern part, in Jabal An'aza, near the Iraqi – Jordanian – Saudi Arabian triplet border point. It is dissected by long valleys. In the western part, isolated hills and plateaus form outstanding geomorphological features. Ga'ara Depression is another outstanding feature in this province, with its well-known three isolated hills, namely "Al-Afayif". Along the ridges and some depressions, many alluvial fans are developed.

▪ **Southern Desert Province**

It is the southeastern continuation of the Western Desert Province, being divided by Al-Khir valley, and extends west of the Euphrates River to the Iraqi – Saudi Arabian borders. It is more flat as compared with the Western Desert, dissected by very complex drainage system, inform of shallow and wide valleys, which commonly open in circular depressions of karst type the forming blind valleys. The elevation of the land ranges from (100 – 300) m (a.s.l.). This province is characterized by presence of dense karst phenomenon in the form of sinkholes or shallow circular depressions, and the presence of some alluvial fans in the main valleys.

▪ **Mesopotamia Plain Province**

It forms the central part of the Iraqi territory, being of flat nature, with elevation of 150 m (a.s.l.) in the extreme northern parts, limited by Himreen and Makhoul Ranges, and zero elevation along the Arabian Gulf, in its extreme southern edge. There is also gentle gradient sloping towards the central parts from both eastern and western sides. The western limits are represented by Abu Jir – Euphrates Fault Zone, which is indicated by shallow, wide, and long depression, along which many alluvial fans are developed. It is totally covered by Quaternary sediments, mainly of the alluvial plains of the Tigris and Euphrates Rivers and their tributaries. However, in its eastern marginal part, well developed alluvial fans are developed followed by sheet run-off plain.

▪ **Al-Jazira Province**

It occupies the western part of the Iraqi territory. It is limited from the north and south by Sinjar Mountain and the Euphrates River, respectively. Tharthar valley and the Iraqi – Syrian border form its eastern and western limits, respectively. It is almost a flat plain, with elevation ranges from (100 – 600) m (a.s.l.). The land slopes from its central part towards the east, south, and west. However, its northern parts slope towards the west, south and east. It is characterized by very dense karst phenomenon and the presence of salt marshes; such as Snaisla, Ashqar, Albu Gharis, Taweel. Moreover, many alluvial fans are developed in different parts.

▪ **Low Amplitude Mountainous Province**

It has an oblong shape, extending from the east along the Iraqi – Iranian borders, to the west along the Iraqi – Syrian borders. It forms the first hilly and mountainous areas, ascending towards the north. The elevation ranges from (150 – 1000) m (a.s.l.), with different sloping directions due to the presence of longitudinal anticlines, which form linear elevated areas, separated by wide synclines, forming wide and almost flat plains. Along the ridges and in some stretches, many alluvial fans are developed.

▪ **High Amplitude Mountainous Province**

It occupies short and elongated strips in the northern and northeastern parts of the Iraqi territory (Fig.1). It is a mountainous area, with elevation ranges of (500 – 2500) m (a.s.l.) and very rough topography due to the presence of a series of anticlines separated by narrow synclines, many of which are faulted. Along the limbs of the anticlines and some fault escarpments many alluvial fans are developed.

▪ **Extremely Rugged Mountainous Province**

It forms a narrow strip along the Iraqi – Iranian – Turkish borders; in the extreme northern and northeastern parts of the Iraqi territory. It is a mountainous area, with very rugged topography due to the complex tectonic effect. The elevation ranges from

(1500 – 3600) m (a.s.l.). Along the limbs of the anticlines and fault escarpments, many alluvial fans are developed.

ALLUVIAL FANS

Alluvial fans are formed due to decrease of gradient of a stream, caused by drop in local base level; hence the coarse grained solid materials carried by the water are dropped. As this reduces the capacity of the channel, the channel will change direction over time; gradually building up a slightly mounded or shallow fan shape. Therefore, the sediments are usually poorly sorted. "The fan shape can also be explained with a thermodynamic justification: the system of the sediment introduced at the apex of the fan will trend to a state, which minimizes the sum of the transport energy involved in moving the sediment and the gravitational potential of material in the cone" (A.G.I, 1962). Therefore, there will be iso-transport energy lines forming concentric arcs about the discharge point at the apex of the fan. Thus, the materials will tend to be deposited equally about these lines, forming the characteristic cone shape (National Aeronautics and Space Administration, 2009).

CLASSIFICATION OF ALLUVIAL FANS IN IRAQ

Classification attempts of alluvial fans in Iraq are rare; therefore, this is an attempt to establish a new classification, which could be applied for all existing fans in Iraq. Al-Daghistani *et al*. (2004) classified the fans as one stage and multi stages, as an attempt for classification of the fans in Sinjar Mountain. Worldwide, different classifications of alluvial fans are present, among them are Gams (1964 and 2001); Sauro (2001); and Goudie (2004), in Stepisnik *et al*. (2007) and Blair and McPherson (1994) in Ritter *et al*. (2002). The details of the classification are mentioned hereinafter.

▪ The Concept of Classification

In this study, all the alluvial fans in Iraq are classified depending on the number of the stages into two main types (Single Stage and Multi Stage) and each main type into many types, and into sub types based on other characters, such as the size, shape and the top cover materials. The constituents and the age are not considered in this classification, because the constituents of each fan depend on the source rocks; therefore, fans with same characteristics may have different constituents. As to the age of the fans, there is no accurate age determination for Quaternary sediments in Iraq. Therefore, the age cannot be considered as a significant character in the classification. Moreover, the majority of the fans in Iraq have Pleistocene age, with different stages, and, some of them extend into the Holocene, and others are still active.

▪ Single Stage Alluvial Fans

These are fans, which show only one stage in their mass; indicating most probably continuous deposition, due to very gentle gradient. This main type of fans includes 3 types, which depends mainly on the size of the fans. Such type of alluvial fans is developed in the Extremely Rugged Mountainous Province, along limbs of anticlines and fault escarpment, High Amplitude Mountainous Province, especially along the limbs of anticlines, Low Mountainous Province and Mesopotamian Plain, especially along the stretches and/ or crossing of the rivers and streams to topographic highs, and also in Western Desert Province, particularly in Al-Ga'ara Depression.

– Small Alluvial Fans: These are Single Stage Small Fans developed from a single valley running down slope, usually not more than few hundred meters up to (1 – 3) Km in length, and usually coalesce with each other forming "Bajada". Their size is limited due to the existence of a stream or valley, which terminates their extension and runs perpendicular to their orientation. The age of these fans is most probably early – late Holocene. This type includes four sub-types of fans, these are:

Delta Shaped Alluvial Fans: These are fans with delta-like shape, with flat tops, broad, flattened profiles, because they are built of silt, sand and fine gravels and/ or rock fragments, therefore have delta shape (Bull, 1991).This sub-type is very common along majority of slopes (different types and origins) in different physiographic provinces; originated from single valley of small size. Good examples are alluvial fans along the limbs of anticlines, especially when hard rocks overly soft rocks (Fig.2); it is very common in Low Amplitude Mountainous, High Amplitude Mountainous, and Extremely Rugged Mountainous Provinces. In Al-Jazira Plain, Ma'ala (1977) recognized this sub-type along the banks of Thar Thar valley, covered mainly by gravels.

Longitudinal Shaped Alluvial Fans: These are fans with longitudinal shape; developed when the valleys are closely spaced; therefore, there is no enough space to form typical fan shape. Such sub-type of fans is developed around majority of cliffs and/ or anticlinal limbs, especially when the exposed formations include soft rocks; particularly in the Extremely Rugged Mountainous, High Amplitude Mountainous and Low Amplitude Mountainous Provinces and where the gradient is very gentle and the sediments are very fine.

Rock Fans: These are alluvial fans without any cementing materials, usually of monolith type, made by small valley downwards from a cliff. The fragments of the fan are sub-angular to sub-rounded, range in size from a few centimeters up to 30 cm, occasionally slightly more. Good examples are developed along the slopes of the Pila Spi Formation along the road between Koi Sanjaq – Dokan, and along the slopes of the carbonate formations in different parts of the Extremely Rugged Mountainous and High Amplitude Mountainous Provinces. The rock fragments are sprayed in a typical fan shape, with fan lengths of up to 100 m.

Landslides – Derived Fans: These are alluvial fans derived from the sliding masses of landslides, especially when the slide mass consists of soft materials (Fig.3). The fans have typical cone shape, with variable lengths (few meters up to 100 m). Such fans are developed everywhere, where landslides occur, within the Extremely Rugged Mountainous and High Amplitude Mountainous Provinces.

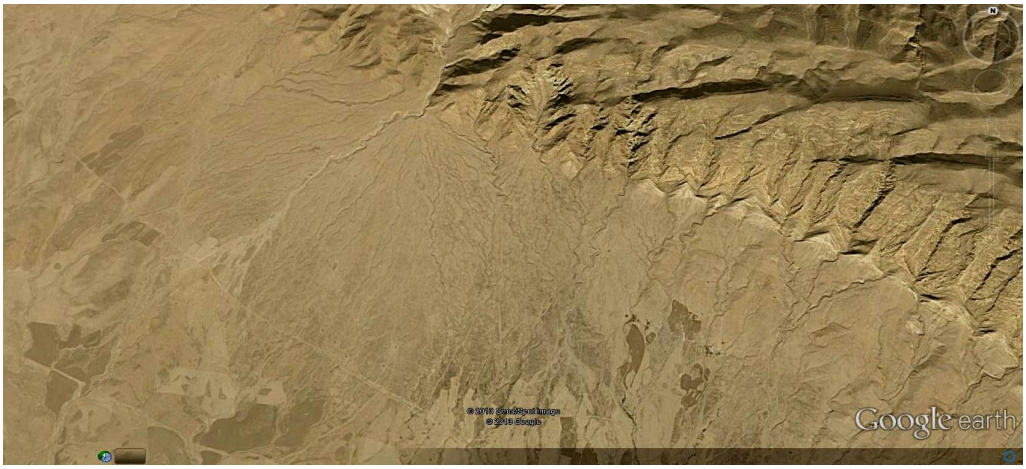

Fig.2: Google Earth image of the Qara Chough Alluvial Fan of Single Stage Medium type, surrounded by Single Stage Small type alluvial fans, forming Bajada

Fig.3: Single Stage Small alluvial fan derived from slid mass of a landslide (**A**), which is originally a Single Stage Medium alluvial fan, top covered by calcrete (**B**) in Qara Dagh Mountain

– Medium Alluvial Fans: These are Single Stage Fans of Medium type, with medium areal coverage, and their lengths range between (3 – 10) Km, developed from one single stream or valley, usually flowing out of a mountain, after deep erosional cutting; forming locally cirques, such as Azkand cirque in Qara Chough Mountain, south of Erbil forming Qara Chough Alluvial Fan (Fig.2) (Al-Samarrai and Al-Mubarak, 1978) and Ziwi Alluvial Fan (Fig.4) at Ziwi Cirque in Pera Magroon Mountain, west of Sulaimaniyah (Al-Shwaily *et al*., 2011). Many other such type of fans are developed in different parts of the High Folded and Imbricate Zones; the most common are those developed along Drabandi Khan (Fig.5) and Dokan lakes, Qalat Diza and Ranya towns, Qara Dagh, Pera Magroon, Azmir, Balambo Mountains. The age of these fans is most probably Pleistocene – Holocene. According to the top cover material, this type of fans is divided into three sub-types, these are:

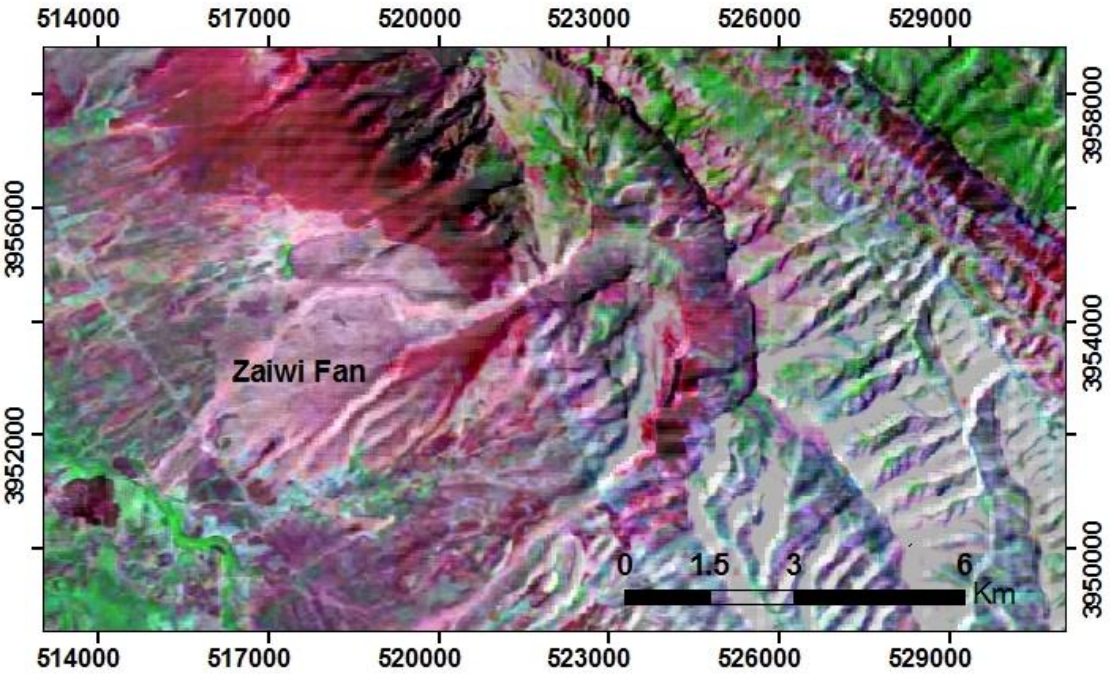

Fig.4: Landsat 7 image of a Single Stage Fan of Medium type derived from Pera Magroon Mountain (Ziwi Fan)

Fig.5: Google Earth image of a Single Stage Fan of Medium type around Darbandi Khan Lake

Calcrete Covered Fans: These are Single Stage Fans of Medium type with calcrete top cover, with thickness that ranges from (1 – 5) m. The presence of the calcrete indicates that the condition, prevailing during the deposition, was very wet, when calcrete was developed on the top surface. Such fans are very common in Qara Dagh Mountain (Fig.3) and south of Darbandi Khan town (Sissakian and Fouad, 2012b).

Soil Covered Fans: These are Single Stage Fans of Medium type with top soil cover, locally large boulders may scatter on the top, rolled down the mountain where the fan was originated. The soil is developed as alluvial sediments, the thickness ranges from (1 – 3) m, whereas the size of the boulders ranges from (0.3 – 1) m, occasionally may exceed that, but very rarely, as in Ziwi Alluvial Fan (Fig.4).

Gravely Covered Fans: These are Medium Alluvial Fans with top cover of gravel. The gravels are cemented by fine clastics and range in thickness from (1 – 3) m, the size of the gravels range from a few centimeters up to 30 cm, but locally may reach 50 cm, mainly of carbonates, rounded to sub-round. Such fans are typically developed along the slopes of the first Pila Spi ridge that forms the contact between the Low Folded and High Folded Zones. They were observed up to 30 Km south of the aforementioned contact in different places such as Cham Chamal, Degala, Bana Bawi, Permam, Darbandi Bazian, and Qara Dagh (Sissakian and Al-Jiburi, 2012 and 2014).

– Large Alluvial Fans: These are Single Stage Large Alluvial Fans with large areas; their lengths exceed tens of kilometers. They are usually developed by large rivers; as the Tigris, or streams; such as Khassa Soo, Tawooq Soo, Tooz Chai. Examples are Al-Fatha Alluvial Fan (Jassim, 1985; Hamza *et al*., 1990; Yacoub *et al*., 1990 and C.E.S.A., 2002), Kirkuk**,** Daqooq, Tuz and Kifri Alluvial Fans (Sissakian and Abdul Jab'bar, 2013b). Such large fans are usually difficult to recognize in the field; they are more clearly visible in Google Earth and Satellite images and aerial photographs. Al-Jaf and Kadhim (2010) in Yacoub *et al*. (2012) recognized Kirkuk Fan using satellite image and found its length to be 17 Km. These fans usually have flat top surfaces, with very gentle gradient that does not exceed 1:10 – 1:15. Their natural shape is mostly modified and deformed by human activities, because they are usually occupied as agricultural lands. Two sub-types were recognized, these are:

Gypcrete Covered Fans: These are Large Alluvial Fans with gypcrete top cover. Al-Fatha Alluvial Fan is a typical one, the thickness of the lower gravel body ranges from (12 – 20) m, but may reach 40 m, as in Abu Dalaf vicinity, whereas, the thickness of the top gypcrete layer ranges from (2 – 4) m, but occasionally reaches 6 m (Yacoub *et al*., 1991). In such extremely large alluvial fan with length of about 160 Km, the presence of one stage is not common. The authors, however, agree with the assumption of Yacoub *et al*. (1991) for the deposition of one stage only. They attributed that to "the lateral and vertical variations in grain size of the gravels which reflect the changing of stream capacity and loads. The rivers capacity considerably decreased during Late Pleistocene, which is represented by the deposition of fine clastics (sand, silt and mud with fewer amounts of gravels). On the other hand, the gypcrete deposition may reflect intensive evaporation from the surface solutions and ground water rich in Sulphate". Another good example is the Alluvial Fan of Karbala – Najaf Plateau (Ghalib, 1988) (Fig.6), which has a length of about 64 Km, with typical delta shape and flat top. It is originated from Al-Khir valley, with SW – NE trend, starting from the Saudi Arabia, being one of the largest valleys in the Iraqi Southern Desert. The size of the gavels of the fan range from (1 – 2 cm), with a thickness that varies from (8 – 14) m (Al-Khateeb and Hassan, 2005).

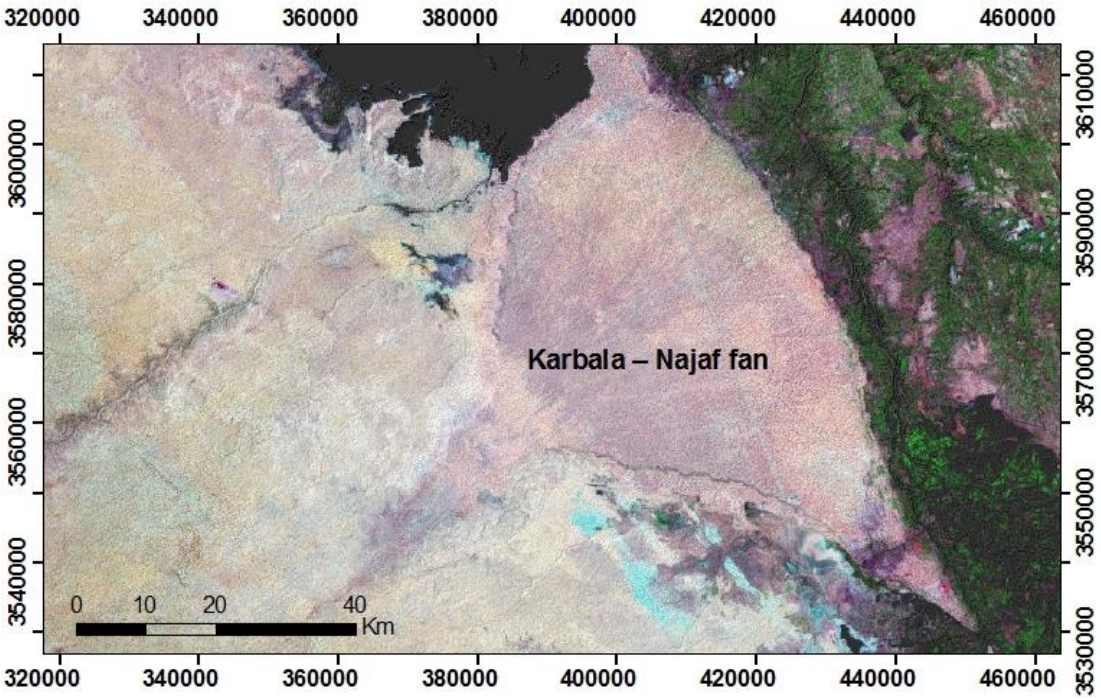

Fig.6: Landsat 7 image of a Single Stage Fan of Large type;
the Karbala – Najaf Plateau, top covered by gypcrete

Soil Covered Fans: These are Large Alluvial Fans with top cover of soil, consists usually of loam or silty – sandy clay with some small rock fragments and/ or pebbles, whereas the main constituents of the fans are gravels of up to 30 cm size, but the common size ranges from (1 – 12) cm. Locally, some aeolian accumulations may occur too, especially in shallow and wide depressions. The thickness of the top soil cover ranges from (0.5 – 3) m (Sissakian and Al-Jiburi, 2012). Good examples are Kirkuk, Daqooq (Fig.7), Tuz Khurmatu, Kifri (Fig.8) Alluvial Fans (Sissakian and Abdul Jab'bar, 2013b), and Al-Breem Fan (Fig.9) in the Iraqi Western Desert (Sissakian, 1988).The length and coverage areas of the fans ranges from (13.4 – 38) Km and (71.04 – 805.6) Km^2, respectively. All the alluvial fans are covered by soil, which range in thickness from (1 – 5) m, dark reddish brown in color, clayey – silty – sandy soil, rich in carbonate, because they have been derived mainly from carbonate bearing formations, as shown on the geological map of Iraq (Sissakian and Fouad, 2012a). Locally, these alluvial fans side-lap, loosing their original shapes. Otherwise they are longitudinal in shape, with flat top, because of the fine size of their constituents. However, their toes are always curved; concave downstream, keeping their original delta (fan) shape.

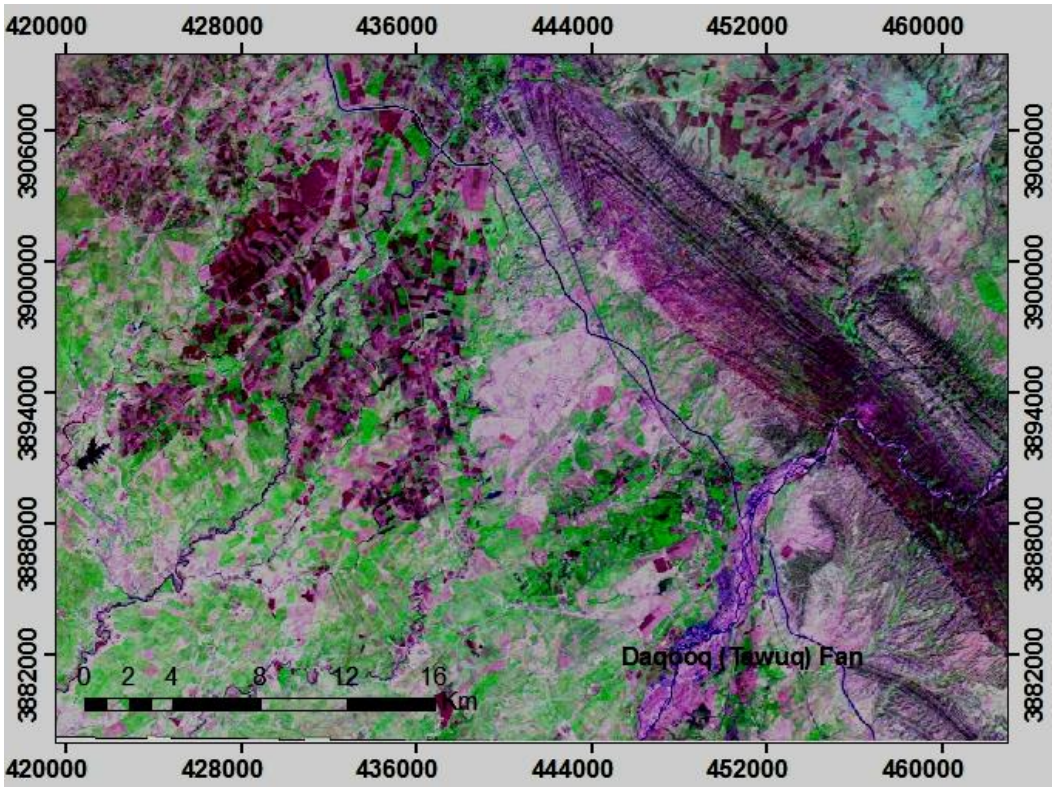

Fig.7: Landsat 7 image of a Single Stage Fan of Large type,
Daqooq (Tawuq) Fan, top covered by soil

Fig.8: Google Earth image of a Single Stage Fan of Large type,
Kifri Fan, top covered by soil

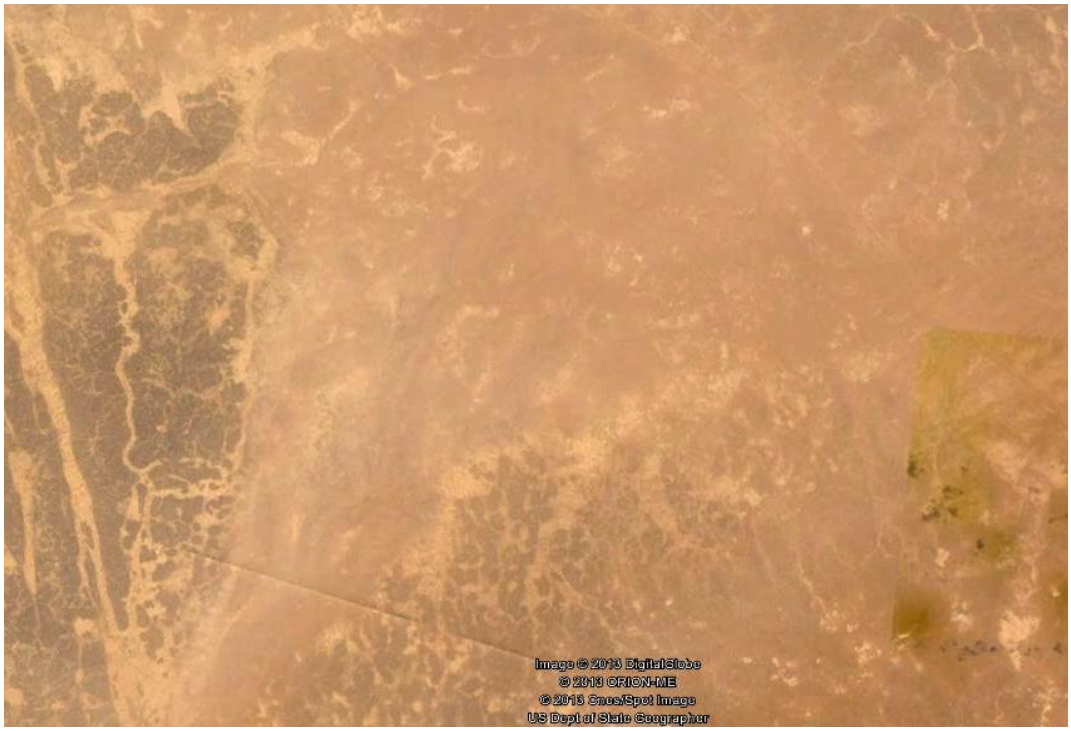

Fig.9: Google Earth image of Al-Breem Alluvial Fan of Single Stage Large type; Soil covered sub-type, in the Iraqi Western Desert

▪ **Multi Stage Alluvial Fans**

These are the second main type of fans, which show more than one stage; indicating discontinuous deposition of the fan body, due to climatic changes, tectonic effect, and/ or the type of the feeder stream or channel, besides the morphology of the source area and the gradient. This type of fans is developed in the Low Amplitude Mountainous Province, Iraqi Southern Desert Province and Iraqi Western Desert Province. This main type of fans includes 3 types, based on the number of the developed stages in the fans. The details are:

– Two Stages Fans: These are two-stage fans, with a break in between; formed by a single ephemeral valley. This type is found in the Hab'bariyah Depression, in the Iraqi Western Desert (Sissakian and Abdul Jab'bar, 2013a) and in the Slabiat Depression, in the Iraqi Southern Desert, south and southwest of Nasiriyah town (Zaini and Abdul Jab'bar, 2014), along the southern rim of Al-Ga'ara Depression, and along the southern limb of Sinjar anticline. The age of these fans is Late Pleistocene – Holocene. This type includes two sub-types, they are described hereinafter.

Fans with Gravels: These are restricted to the Hab'bariyah Depression, the two stages are divided by a gypcrete horizon, which has a thickness of about (13 – 18) m. The main constituents of both stages are gravels, mainly derived from the Iraqi Western Desert. The two stages are formed due to a break in the gradient of the depression, where they are laid down. The first stage fan has ideal fan shape, because the shape is a function of the size, as coarse the materials are, as typical concave shape is formed (USGS, 2004). The typical concave shape also indicates the activity and transportation ability of the feeder stream, because there will be iso-transport energy lines forming concentric arcs about the discharge point at the apex of the fan. However, the fans of the second stage have concave – longitudinal shape with broad flattened top. This is because the deposits of the second

stage fans are finer as compared to the constituents of the first stage, insufficient renewal of the these deposits caused by climate change to more dry with less rain fall, consequently less sediments supply, and finally due to lateral erosion by the flood water in the Hab'bariyah Depression. It is believed that the break in the gradient is due to neotectonic movements, which was also assumed by Sissakian and Deikran, (2009) and Sissakian and Abdul Jab'bar (2013a).

Fans with Fine Clastics: These are restricted to the Slabiat Depression, the two stages can be distinguished by the size of the constituents, which are fine pebbles grading to sand and silt upwards, to the younger stage, which consists mainly of sand and loamy soil. They are mainly derived from the Iraqi Southern Desert. The thickness of both stages is about (3 – 6) m. The shape of the fans is delta like with broad and flattened profiles, because they are formed by fine materials. Such shapes are confirmed by Bull (1991). The two stages are formed due to a break in the gradient of the depression, where they are laid down. The break is caused by neotectonic movement along Abu Jir – Euphrates Fault Zone (Sissakian and Deikran, 2011 and Zaini and Abdul Jab'bar, 2014). Yacoub (2011a and b) considered them as small coalescent alluvial fans deposited by the desert valleys, but they lost their fan shape due to weathering and erosion. In Al-Ga'ara Depression, especially along the southern rim (Fig.10), typical fans of this sub-type are developed; they were mapped and presented in the geological and geomorphological maps (Buday and Huk, 1980 and Al-Bassam *et al*., 1990).

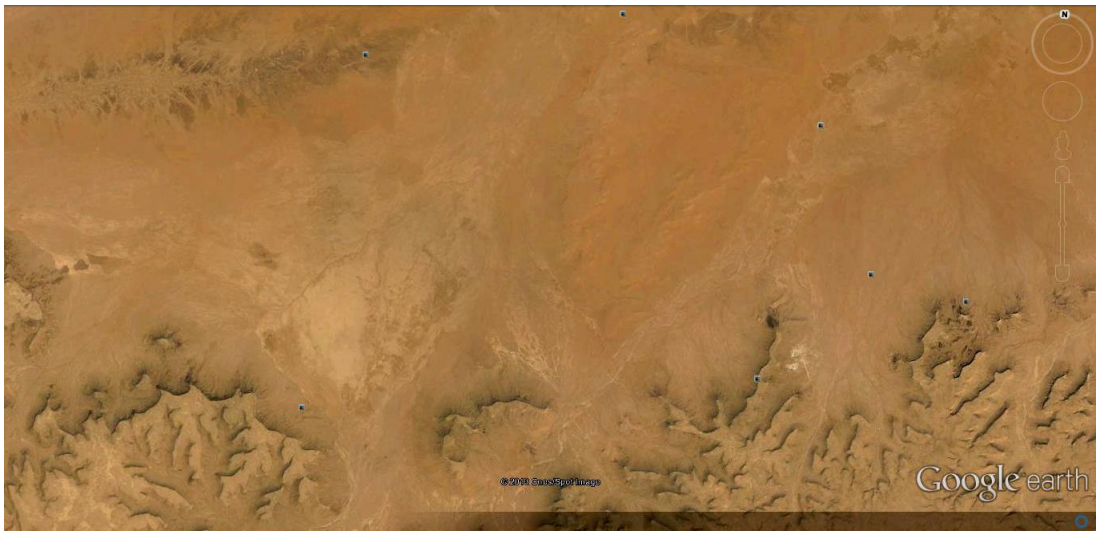

Fig.10: Google Earth image of Two Stage Fans type, with Fine Clastics sub-type, along the southern rim of Al-Ga'ara Depression

– Four Stages Alluvial Fans: These are fans of four stages, usually with a slope break in between; they are formed by a single ephemeral valley. This type is found in two areas: in the extreme southern part of Iraq, in wadi Al-Batin, and along the northern flank of Sinjar Mountain. The fans of both areas have different characters, therefore, this type is divided into two sub-types, and they are:

Concentric Delta-Shaped Fans: This type includes only one fan that is called Al-Batin Alluvial Fan. It is located in the extreme southern part of Iraq, along the Iraqi – Saudi Arabian – Kuwaiti international boundaries. It is one of the ideal cases of alluvial fans of

a desert plateau. It comprises essentially ill-sorted gravely sand, with gypcrete top cover. The size of the gravels varies from coarse gravels (5 – 20 cm), around the apex of the fan, to fine gravels and pebbles (2 – 5 cm), in the peripheral parts. The thickness of the gypcrete varies from (0.5 – 1.5) m (Yacoub, 2011a and b). The four stages are concentric with parallel iso-transport energy lines forming concentric arcs about the discharge point, having typical fan shape for the four stages; almost with flat top and very gentle gradients, small break separates between the four stages. It is very long fan, about 154 Km, the length of the four stages is 65 Km, 42 Km, 39 Km and 18 Km, respectively (Deikran, 1995), whereas the coverage areas is about 6400 Km^2. The feeding channel is one of the largest valleys in the Iraqi Southern Desert called Al-Batin valley, it is still active, but has changed its location, being now in the extreme eastern part of the fan body, and almost without feeding the fan with new sediments, due to climatic changes, especially the annual precipitation, as confirmed by Given (2009).

Multi-Shaped Fans: These are four stages fans having multi shapes in different stages, i.e. the four stages have not a unified shape. This type is developed along the northern flank of Sinjar Mountain, where Sissakian (2011) recognized four stages. Only the first stage fans have ideal fan shape (Figs.11 and 12), others are longitudinal in shape. The first stage of Sinjar Alluvial fans has typical delta (fan) shape, with concentric iso-lines represented by concentric contour lines radiated from one single outlet, which are visible even in topographic maps at scale of 1: 100 000 (Fig.11). The first stage fans consist of coarse sized boulders and pebbles, which reach up to 1 m in size (Ma'ala, 1977). However, the fans of the other three stages have longitudinal shape with broad flattened top (Figs.11 and 12). It is believed that the fans of the second, third and fourth stages have lost their shapes due to weathering, and type and size of the constituents. They are finer as compared to the constituents of the first stage because of the insufficient renewal of the supplied materials that decrease as the fans are farther from the apex (Sinjar Mountain), and also due to man activities, especially cultivation. Besides, the transportation energy was neither homogeneous nor equally distributed along isolines, as they are in the first stage, because the energy had drastically reduced due to the gradient decrease.

– Five Stages Alluvial Fans: These are five stages fans' have unified shapes in all stages, i.e. the shape in all five stages is delta shaped with typical concave tops, indicating iso-transport energy lines forming concentric arcs about the discharge point at the apex of the fan. They vary in their lengths from (6 – 27) Km (Yacoub, 1983 and Yacoub *et al*., 1985), whereas the coverage areas range nearly from (225 – 1500) Km^2. This type of fans includes all individual fans developed alongside the southwestern flank of Himreen Structure, starting from Mandali to Al-Fak'ka (north of Amara) (Figs.13 and 14). The alluvial fan sediments consist of unsorted and massive gravel beds with sand or mud matrix. Sharp reduction in grain size occur down-stream, from the apex and in different directions towards the distal fringes, because internally formed dendritic channels within older deposits that erode the developed surfaces and redistribute the debris to depositional areas down slope" (Bull, 1991). Some of these fans are still active; others are not, due to neotectonic forces exerted by the growing of subsurface anticlines in nearby areas (Fig.14).

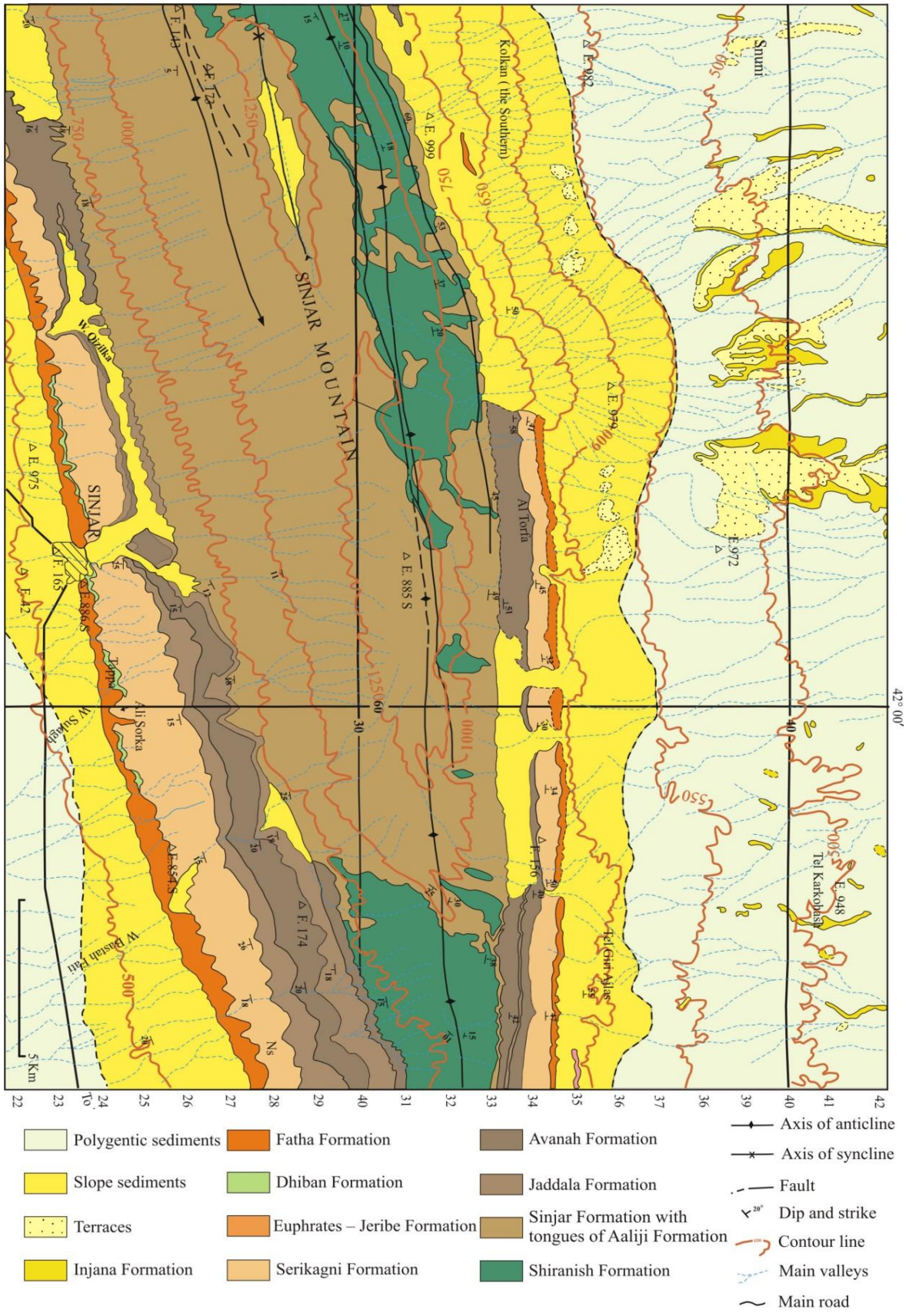

Fig.11: Geological Map of Sinjar anticline, note the concentric contour lines radiating from one single outlet, forming the first stage alluvial fans (after Sissakian, 2011)

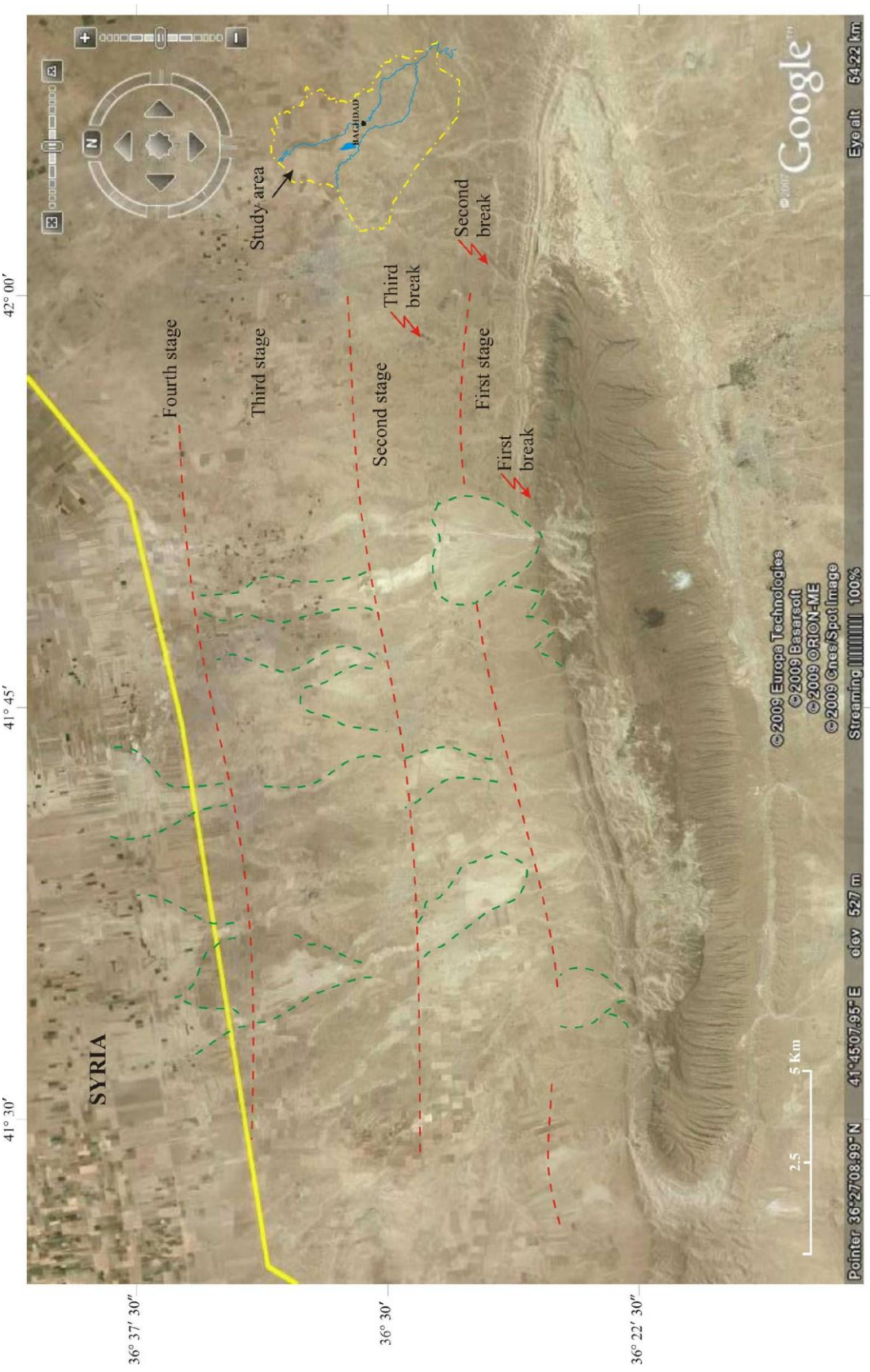

Fig.12: Google Earth image showing the location of the four stages of the Sinjar alluvial fans; at the northern limb of the anticline
The red lines are the location of subsurface faults (after Sissakian, 2011)

The grain size of the gravels of the Five Stages varies from few millimeters to 30 cm, or even large boulders (Yacoub, 1983). The gravels are sub-rounded to rounded, discoidal, rod like, blade or irregular. They are mainly of carbonate rocks, chert and some igneous and metamorphic rocks. Commonly, secondary gypsum is concentrated in the surface layers and occasionally forms gypcrete crust. The exposed thickness of the individual alluvial fan ranges from (5 – 6) m, such as in Mandali, Zurbatiya, and Badra vicinities. The four stages were recognized by Domas (1983) and Yacoub (1983). Moreover, there is a fifth stage, which represents the recent and sub-recent fan sediments of Holocene age.

The five stages were differentiated according to their geomorphic positions, lithological variations and weathering. The 1st stage (oldest) was deposited at the beginning of Pleistocene or even earlier (Pliocene/ Pleistocene). The 2nd stage is deposited at the foot of the 1st stage, it is well developed in the Zurbatiya vicinity (Fig.13), and its age is Early Pleistocene. The 3rd stage (Middle Pleistocene) is widespread with respect to the 1st and the 2nd stage, and they are separated by a sharp break, indicating a period of erosion. The 4th stage was deposited during the Late Pleistocene at the peripheral part of the Bajada; and it is characterized by finer clastic sediments and smoother surfaces, as compared with older stages. The 5th stage (youngest) is represented by Holocene wide valley and channel fill sediments, which form small fans (Domas, 1983 and Yacoub, 1983).

The active and inactive parts of this type of alluvial fans can be clearly recognized due to the tone differences. Those in dark tones are inactive, while the active parts have lighter tones (Figs.13 and 14).

Fig.13: Google Earth image of Multi Stages Alluvial Fan in Zurbatiya vicinity, note the tone differences in different stages, as well in different parts

Fig.14: Google Earth image showing two big alluvial fans, Al-Teeb to the left and Al-Fak'ka to the right, between Kumait and Amara, the fans are most probably partly inactive; due to uplifting of Buzurgan (**B**) and Halfaya (**H**) subsurface anticlines

GIS APPLICATIONS

Using GIS technique, the dimensional parameters of some selected fans were determined, as ideal fan for each type and sub-type, where Landsat data are available. The results are shown in Table (1).

Table 1: The dimensional parameters of some studied alluvial fans

Alluvial Fan	Length (Km)	Width (Km)	Coverage area (Km^2)	Gradient (Degrees)	Figure
Al-Breem	**38**	**21.2**	**805.6**	**5 – 8**	**9**
Ziwi	**7.3**	**2.7**	**19.71**	**7 – 21**	**4**
Karbala – Najaf	**58.5**	**59.9**	**3463.34**	**0 – 8**	**6**
Kirkuk	**13.4**	**5.3**	**71.04**	**2.1 – 2.6**	**___**
Kifri	**16.1**	**13.2**	**213.52**	**2.6 – 3.2**	**8**
Al-Ga'ara	**7.4**	**4.5**	**33.30**	**0 – 1**	**10**
Sinjar	**2.8 – 4.5**	**1.5 – 5.1**	**22.95 – 420.0**	**6 – 9.5**	**11 & 12**
Zirbatiya	**13.7**	**10.8**	**148.96**	**6 – 11**	**13**
Al-Fatha	**189.8**	**58.9**	**11179.22**	**1.4 – 2.5**	**___**

The data in Table (1) represents the best clear alluvial fans within a vicinity and/ or a type. However, when there is only one fan in the considered type and/ or vicinity, then the dimensional parameters of that fan were measured. Examples are: Al-Breem, AlFatha, Kifri and Karbala – Najaf Alluvial Fans.

Landsat 7 images were used to identify the limits of the studied fans, especially the number of the stages within each fan. However, when the images are not so clear or not available, then Google Earth images were used for the same purpose.

RESULTS

The attempt of classification of the alluvial fans in Iraq, has led to introduce 21 main types, types and sub-types (Table 2). The classification into main types is based on the number of the stages. The main types are classified into types based on the size, shape, top cover materials and number of stages. The types are subdivided into sub-types based on the shape, size, top cover materials, or genesis.

Table 2: The established classification scheme, of the alluvial fans in Iraq

Main Type	Type	Sub-type	Examples
Single Stage Fans	Small Fans	Delta-shaped fans	Qara Chough Fans (Fig.2)
		Longitudinal-shaped fans	Along main cliffs, when the valleys are closely spaced
		Rock fans	Along Pila Spi ridge fans
		Landslide derived fans	Qara Dagh Fan (Fig.3)
	Medium Fans	Calcrete covered fans	Qara Dagh Fans (Fig.3)
		Soil covered fans	Ziwi Fan (Fig.4)
		Gravely covered fans	Cham Chamal Fans
	Large Fans	Gypcrete covered fans	Karbala – Najaf Fan (Fig.6)
		Soil covered fans	Daqooq Fan (Fig.7)
Multi Stages Fans	Two Stage Fans	Fans with gravels	Al-Hab'bariyah Fans
		Fans with fine clastics	Ga'ara Fans (Fig.10)
	Four Stage Fans	Concentric Delta-Shaped fans	Al-Batin Fan
		Multi-Shaped fans	Sinjar Fans (Fig.12)
	Five Stage Fans	--------	Mandili – Al-Fak'ka Fans (Fig.14)

------- Not applicable

The Single Stage Fans' main type is divided into three types, depending on the size: Small, Medium and Large Alluvial Fans. The Single Stage Small Fans' type is divided into four sub-types, based on the shape of the fans and genesis: Delta (fan) Shaped Fans, Longitudinal Shaped Fans, Rock Fans, and Landslide Derived Fans. The Single Stage Medium Fans' type is divided into three sub-types based on the type of the top cover material: Gypcrete cover, Soil cover and Gravelly cover. The Single Stage Large Fans' type is divided into two sub-types based on the type of the top cover material: Gypcrete cover and Soil cover.

The Multi Stage Fans' main type is divided into three main types, based on the number of stages: Two Stage, Four Stage and Five Stage Alluvial Fans. The Two Stage Fans' type is divided into two sub-types, based on the constituents: Fans with Gravels and Fans with Fine Clastics. The Four Stage Fans' type is divided into two sub-types, based on the shape: Concentric Delta-shaped Fans and Multi Shaped Fans. The Five Stages Fans' type has not further classified.

The classification into types and sub-types depends on fans' characteristics, such as the size, shape and top cover materials, but not using a constant character in all cases. This concept is attributed to the presence of alluvial fans with different characters in different parts of Iraq, which means there is no constant character that can be applied for the classification of all present alluvial fans into types and sub-types.

DISCUSSION

Although there are many classifications dealing with the alluvial fans, but this is an attempt to establish a special classification, which can be applied upon all the existing alluvial fans in different parts of Iraq. For example, fans according to the genetic sense are classified by Blair and McPherson (1994) in Ritter *et al*. (2002) into two types: **Type I** and **II**. This classification depends mainly on: grain size; their shape and sorting, feeder channel length, drainage basin size, bed rock lithology and average slope.

In the present classification, the concept depends mainly on the number of the stages that are developed in the alluvial fan; accordingly, two main types are proposed (Table 2). These two main types are divided into different types and further into sub-types, in both cases the classification is based on the main characters of the fans, such as shape, size, top cover materials, and partly the constituents and genesis. Some characters and features of the alluvial fans, such as grain size, sorting, feeder channel length, bed rock lithology, average slope, basin characters were not considered in this classification, because this classification is a regional and deals with all alluvial fans that are developed in different parts of Iraq. Consequently, the fans have very wide range of characters, which differ in different parts of Iraq, due to climatic change, physiographic nature and diversity of lithology. Therefore, the most applicable characters were used to establish this classification. It is clear that the reason for the development of different types of alluvial fans in different parts of Iraq is beyond the scope of this study, not even in a single area, such as the fans along the northern limb of Sinjar anticline (Figs. 11 and 12), and the southern limb (Fig.15).

As aforementioned, the classification depends mainly on the number of the developed stages, which indicate the age, climatic change, tectonic activity in the depositional basin. The used factors are discussed hereinafter.

▪ Stages of Alluvial Fans

Those fans, which consist of single stage (Figs.5 and 6), indicate continuous sediments supply, consequently indicating constant climatic factors for long periods, especially rain fall and tectonic activity, (whether active or inactive). Whereas, the multi stage fans (Figs.10, 12, 13, 14 and 15) indicate break in deposition, which means break in supply of the sediments, this is attributed to inconstant climatic factors and tectonic unrest. The latter indicates active tectonisim, since "fans are better developed in tectonically active areas" (Bull, 1991 and Ritter *et al*., 2002).

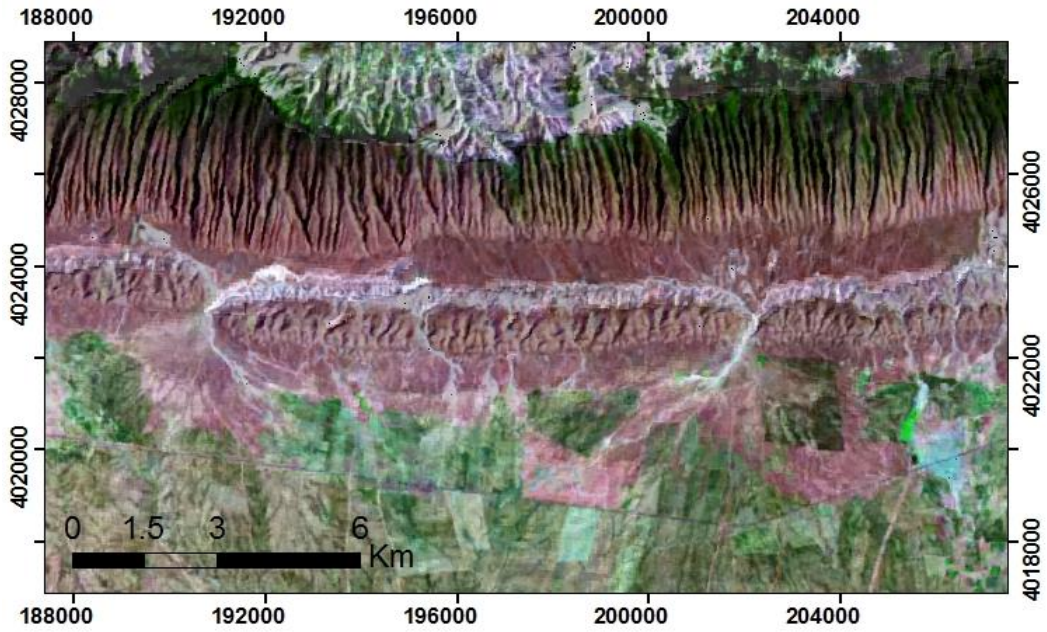

Fig.15: Landsat 7 image of Two Stages alluvial fans, along the southern limb of Sinjar anticline, compare with Fig. (12) concerning the number of the stages

- **Size of the Alluvial Fans**

Fans of small size indicate, shortage in sediments supply; this is attributed either to small size of the source area, and small size of the feeding channel, or continuous eroding of the proximal edge of the fan by a stream, which is a common form in the Extremely Rugged Mountainous and High Amplitude Mountainous Provinces. In contrast, large sized alluvial fans indicate continuous supply of the sediments; this is attributed to large source area, large feeding channel, existence of effective basin-and-range topography, especially in Extremely Rugged Mountainous and High Amplitude Mountainous Provinces, such as the fans of Qalat Diza vicinity and around Dokan and Darbandi Khan Lakes.

- **Shape of the Alluvial Fans**

The shape indicates the activity and transportation ability of the stream, because there will be iso-transport energy lines forming concentric arcs about the discharge point at the apex of the fan. Moreover, the shape and the size also are considered in the classification, because "the size of the sediments is a function of the shape" (Bull, 1991 and USGS, 2004). "The fan shape can also be explained with a thermodynamic justification: the system of the sediment introduced at the apex of the fan will trend to a state, which minimizes the sum of the transport energy involved in moving the sediment and the gravitational potential of material in the cone" (American Geological Institute, 1962). Therefore, there will be iso-transport energy lines forming concentric arcs about the discharge point at the apex of the fan. Thus, the materials will tend to be deposited equally about these lines, forming the characteristic cone shape (National Aeronautics and Space Administration, 2009). Whereas, longitudinal shaped fans indicate fine size sediments and very gentle gradient, as it is in the second, third and fourth stages of the Sinjar Alluvial Fans, and that of wadi Al-Breem Fan, in the Iraqi Western Desert.

▪ **Top Cover Materials**

The top cover materials indicate the activity and age of the fan, indirectly. Those fans, which are covered by gypcrete (Fig.6) and/ or calcrete (Fig.3) are inactive (dormant) and of Pleistocene age, whereas those which are covered by soil (Figs.7 and 8); indicate active fans with age that extends to Holocene.

CONCLUSIONS

This study has the following conclusions.

- The established classification of the alluvial fans includes 21 main types, types and sub-types.
- Within the established classification, 2 main types, 6 types and 13 sub-types of alluvial fans are introduced.
- The classification depends on the number of the stages for dividing the fans into two main types, whereas the types and sub-types are divided according to the shape, size, top cover materials and partly based on genesis, and number of the stages, too.
- The established classification is applicable in different parts of Iraq, as far as the existing alluvial fans are concerned.
- The age is excluded from the classification, because almost all the fans are within Pleistocene – Holocene age.

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REFERENCES

A.G.I. (American Geological Institute), 1962. Dictionary of Geological Terms. New York: Dolphin Books. Wikipedia, the Free Encyclopedia

Al-Bassam, K.S., Karim, S.A., Hassan, K.M., Saeed, L., Yakta, S., and Salman, M., 1990. Report on geological survey of the Upper Cretaceous – Lower Tertiary phosphorite bearing sequence, Western Desert, Iraq. GEOSURV, int. rep. no. 2008.

Al-Daghastani, N.S., 1989. Remote sensing in geomorphologic mapping and mass movement study of the Sinjar Anticline, northwest Iraq. Jour. I.T.C., 1989-2, p. 92 – 101.

Al-Daghastani, H.S., Al-Salim, T.H. and Al-Shakergee, B.M., 2004. Hydrologic system observation and rainwater harvesting in alluvial fans in the north of Jabel Sinjar using remote sensing data. Iraqi Jour. Earth Scie., Vol.4, No.1, p. 15 – 28.

Al-Daghastani, H.S. and Al-Dewachi, B.A., 2009. Evidences for discovering subsurface structures using remote sensing data in Nineva Governorate, Northwest Iraq. Iraqi Bull. Geol. Min., Vol.5, No.1, p. 35 – 46.

Al-Khateeb, A.A.G. and Hassan, K.M., 2005. Detailed geological survey for mineral exploration in Karbala – Najaf area. GEOSURV, int. rep. no. 2891.

Al-Sammarai, A.I. and Al-Mubarak, M.A., 1978. Report on the regional geological mapping of Makhmour – Kirkuk Area. GEOSURV, int. rep. no. 905.

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

Al-Shwialy, A.Kh., Al-Mosawi, H.A., Al-Saffi, I.K., Bashir, W.Ph., Ibrahim, A.A., Al-Jubouri, B.S., Al-Kubaisi, K.N., Mahmood, A.A. and Al-Shawi, S.A., 2011. Semi detailed geological mapping of Sulaimaniyah – Surdash area. GEOSURV, int. rep. no. 3340.

American Geological Institute, 1962. Alluvial Fan. Dictionary of Geological Terms. New York, Dolphin Books. Wikipedia, the Free Encyclopedia.

Barwari,A.M., Yacoub, S.Y. and Buni, Th.J., 2003. Quaternary Sediments Map of Iraq, scale 1: 1000 000. GEOSURV, Baghdad, Iraq.

Buday, T., and Hak, J., 1980. Report on geological survey of the western part of the Western Desert, Iraq. GEOSURV, int. rep. no. 1000.

Bull, W.B., 1991. Geomorphic Responses to Climate Change. Oxford University Press.

C.E.S.A., 1992. Final report on site selection for a nuclear power plant. GEOSURV, int. rep. no. 2027.

Deikran, D.B., 1995. Geological Map of Al-Rukhaimiyah and Kuwait Quadrangles, scale 1: 250 000. GEOSURV, Baghdad, Iraq.

Domas, J., 1983. The Geology of Karbala Kut and Ali Al-Gharbi Area. GEOSURV, int. rep. no. 1384.

Fouad, S.F., 2012. Tectonic Map of Iraq, scale 1: 1000 000, 3rd edit. GEOSURV, Baghdad, Iraq.

Fouad, S.F., and Nasir, W.A.A., 2009. Tectonic and structural evolution of Al-Jazira Area. In: Geology of Al-Jazira Area. Iraqi bull. Geol. Min., Special Issue No.3, p. 33 – 48.

Given, J., 2009. The climatic paradigm: The correlation of climate to dry land alluvial fan evolution and morphology. Geog. 689, Internet data.

Hamza, N.M., 1997. Geomorphological Map of Iraq, scale 1: 1000 000. GEOSURV, Baghdad, Iraq.

Hamza, N.M., Lawa, F., Yacoub, S.Y., Mussa, A.Z. and Fouad, S.F., 1990. Regional Geological Stage Report, Project C.E.S.A., Geological Activity. GEOSURV, int. rep. no. 2023.

I.M.O. (Iraqi Metrological Organization), 2000. The Climatic Atlas of Iraq, Baghdad, Iraq.

Jassim, S.Z., 1985. Early Pleistocene gravel fan of the Tigris River from Al-Fatha to Baghdad, Central Iraq. Jour. Geo. Soc. Iraq, Vol.14, p. 25 – 34.

Ma'ala, Kh.A., 1977. Regional geological mapping of Sinjar area. GEOSURV, int. rep. no. 860.

Ma'ala, Kh.A., 2009a. Geomorphology. In: Geology of the Southern Desert. Iraqi Bull. Geol. Min., Special Issue, No.2, p. 7 – 33.

Ma'ala, Kh.A., 2009b. Geomorphology. In: Geology of Al-Jazira Area. Iraqi Bull. Geol. Min., Special Issue, No.3, p. 5 – 31.

National Aeronautics and Space Administration, 2009. Geomorphology From Space; Fluvial Landforms, Chapter 4. Internet data.

Ritter, D.F., Kochel, R.C. and Miller, J.R., 2002. Process Geomorphology. McGraw Hill, Higher Education, 560pp.

Sissakian, V.K., 1988. Engineering Geological Report on Al- Rutbah – Kilo 160 – H1– Akashat –Tinif area. GEOSURV, int. rep. no. 1745.

Sissakian, V.K., 2000. Geological Map of Iraq, scale 1: 1000 000, 3rd edit. GEOSURV, Baghdad, Iraq.

Sissakian, V.K., 2011. Alluvial fans of Sinjar Mountain, northwest Iraq. Iraq Bull. Geol. Min., Vol.7, No.2, p. 9 – 26.

Sissakian, V.K. and Deikran, D.B., 1998. Neotectonic Map of Iraq, scale 1: 1000 000. GEOSURV, Baghdad, Iraq.

Sissakian, V.K. and Abdul Ahad, A.D., 2009. Geological Hazards Map of Sinjar Quadrangle, scale 1: 250 000. GEOSURV, int. rep. no. 3162.

Sissakian, V.K. and Deikran, D.B., 2009. Neotectonic movements from west of Iraq. Iraqi Bull. Geol. Min., Vol.5, No.2, p. 59 – 73.

Sissakian, V.K. and Fouad, S.F., 2012a. Geological Map of Iraq, scale 1: 1000 000, 4th edit. GEOSURV, Baghdad, Iraq.

Sissakian, V.K. and Fouad, S.F., 2012b. The Geological Map of Sulaimaniyah Quadrangle**,** scale 1: 250 000, 2nd edit.GEOSURV, Baghdad, Iraq.

Sissakian,V.K. and Al-Jibouri, B.M, 2012. Stratigraphy. In: Geology of the Low Folded Zone. Iraqi Bull. Geol. Min., Special Issue, No.5, p. 63 – 162.

Sissakian, V.K. and Abdul Jab'bar, M.F., 2013a. Alluvial fans of Al-Hab'bariyah Depression, Iraqi Western Desert. Iraqi Bull. Geol. Min., Vol.9, No.2. p27 – 45.

Sissakian, V.K. and Abdul Jab'bar, M.F., 2013b. Geomorphology and morphometry of the three tributaries of the Adhaim River, central part of Iraq. Journal of Research in Environmental Science and Toxicology (ISSN: 2315-5698) Vol. 2(3) pp. xx-xx, March 2013. Available online http://www.interesjournals.org/JRES

Sissakian, V.K. and Al-Jiburi, B.M, 2014. Stratigraphy. In: Geology of the High Folded Zone. Iraqi Bull. Geol. Min., Special Issue, No.6 (in press).

Sissakian, V.K., Kadhim, T.H. and Abdul Jab'bar, M.F., 2014. Geomorphology. In: Geology of the High Folded Zone. Iraqi Bull. Geol. Min., Special Issue, No.6 (in press).

Stepisnik, U, Ferk, M., Gostincar, P, Cernuta, L., Peterneu, K., Stembergar, T. and Ilic, U., 2007. Alluvial fans on contact karts: An example from Matarsko Pololje, Slovenia. ActaCarsologica, Vol. 36, No.2, p. 209 – 215.

USGS, 2004. Desert Working Group**,** Knowledge, Science Incorporation, Alluvial Fans. Internet data.

Yacoub, S.Y., 1983. The Geology of Mandali Area. GEOSURV, int. rep. no. 1383.

Yacoub, S.Y., 2011a. Geomorphology. In: Geology of the Mesopotamia Plain. Iraqi Bull. Geol. Min., Special Issue, No.4, p. 7 – 32.

Yacoub, S.Y., 2011b. Stratigraphy. In: Geology of the Mesopotamia Plain. Iraqi Bull. Geol. Min., Special Issue, No.4, p. 47 – 82.

Yacoub, S.Y., Purser, B.H., Al-Hassni, N.H., Al-Azzawi, M., Orzag-Sperber, F., Hassan, K.M., Plaziat, J.C. and Younis, W.R., 1981. Preliminary Study of the Quaternary Sediments of SE Iraq. Joint research project by the Geological Survey of Iraq and University of Paris XI, Orsay. GEOSURV, int. rep. no. 1078.

Yacoub, S.Y., Roffa, S.H. and Tawfiq, J.M., 1985. Geology Al-Amara – Al-Nasiriya – Al-Basrah Area. GEOSURV, int. rep. no. 1386.

Yacoub, S.Y., Sissakian, V.K. and Deikran, D.B., 1990. Final Geological Report Contract of the Earth Sciences Activities (C.E.S.A.). GEOSURV, int. rep. no. 2022.

Yacoub, S.Y., Deikran, D.B. and Ubaid, A.Z., 1991. Local Geological Stage Report, Vol.1, Contract of the Earth Sciences Activities (C.E.S.A.). GEOSURV, int. rep. no. 2016.

Yacoub, S.Y., Al-Jaf, A.O. and Kadhim, T.H., 2012. Geomorphology. In: Geology of the Low Folded Zone. Iraqi Bull. Geol. Min., Special Issue No. 5, p. 7 – 37.

Zaini. M.T. and Abdul Jab'bar, M.F., 2014. Alluvial fans of the Salaibat Depression, south Iraq. Iraqi Bull. Geol. Min. Special Issue (in press).

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