ALLUVIAL FANS OF SINJAR MOUNTAIN, NW IRAQ

Varoujan K. Sissakian*

Received: 25/ 01/ 2010, Accepted: 06/ 05/ 2010
Key words: Alluvial fans, Bajada, Fan stages, Bar and Swale, Iraq

ABSTRACT

Sinjar Mountain is the most conspicuous outstanding geomorphic feature in the central northwestern part of Iraq; it is surrounded from north and south by gently inclined plains. The highest peak attains 1462 m, whereas the elevation of the surrounding plains ranges in height between (407 – 432) m. The mountain forms asymmetrical anticline, almost with E – W trend that has steeper northern limb (45 – 80)° and gentler southern limb (15 – 25)°, its length is about 80 Km, whilst the width is about 20 Km. The oldest exposed rocks belong to Shiranish Formation (Late Cretaceous), which is the main source for development of the alluvial fans, beside many other formations.

A well developed set of alluvial fans can be observed along the northern limb of Sinjar anticline; they extend northwards to (20 – 22) Km, partly out of the Iraqi territory, inside Syria. Generally, four stages of alluvial fans are developed, the fourth being in Syria. Locally, the fans of the first stage overlap laterally forming "Bajada".

The first stage alluvial fans; genetically are of Type **I** being still active, whereas the fans of the remaining three stages are of Type **II**; being partly dormant. The formers are of very coarse size sediments, deposited in low water/ sediments ratio with typical fan shape. On contrary the remaining fans have longitudinal shape, mainly of fine size materials, being deposited in high water/ sediments ratio. The age of the first stage alluvial fans is Early Pleistocene, whereas, the fans of the other three stages are of Pleistocene – Holocene age. No pavement and/ or desert varnish were observed in the alluvial fans. The main reason for the development of the fans is the neotectonic movement of the Sinjar Basin, besides the exposures of Shiranish Formation, which are overlain by hard and massive limestone of Sinjar Formation.

المراوح الفيضية لجبل سنجار، شمال غرب العراق

فاروجان خاجيك سيساكيان

المستخلص

يكوّن جبل سنجار ظاهرة جيومورفولوجية فريدة من نوعها في وسط شمال غرب العراق لكونه محاطاً من الشمال والجنوب بسهول مستوية واسعة. يبلغ ارتفاع أعلى قمة في جبل سنجار 1462 متر، بينما يتراوح ارتفاع السهول المحيطة بالجبل بين (407 – 432) متراً. يكوّن جبل سنجار طية محدبة تمتد تقريباً باتجاه شرق – غرب وجناحها الشمالي أكثر ميلاً (45 – 80)° من جناحها الجنوبي (15 – 25)°، ويبلغ طول الطية حوالي 80 كم بينما عرضها حوالي 20 كم. إن أقدم تكوين متكشف هو الشيرانش (الطباشيري المتأخر) وصخور هذا التكوين هي المصدر الرئيسي للمراوح الفيضية المتكونة على الجناح الشمالي للطية، إضافةً للتكوينات الأخرى.

توجد مجموعة من المراوح الفيضية على طول الجناح الشمالي لطية سنجار، تمتد باتجاه الشمال إلى مسافة تتراوح بين (20 – 22) كم. يمكن ملاحظة أربعة مراحل من المراوح الفيضية، والأخيرة تكون داخل الأراضي السورية. وان مراوح المرحلة الأولى تتراكب جانبياً على بعضها مكونةً "بجادا".

* Expert, S.C. of Geological Survey and Mining, P.O. Box 986, Baghdad, Iraq
e-mail:varoujan49@yahoo.com

من ناحية النشوء، فان مراوح المرحلة الأولى هي من النوع **I** وتمتاز بشكلها المروحي وتتكون من مواد خشنة ترسبت في محيط ذات نسبة واطئة من المياه/ الترسبات، ولا تزال نشطة. أما المراحل الثلاثة الأخرى فهي من النوع **II** وتتميز بشكلها الطولي وتتكون من مواد ناعمة ترسبت في محيط ذات نسبة عالية من المياه/ الترسبات، وهي بشكل عام غير نشطة. إن عمر المراوح الفيضية للمرحلة الأولى هو البلايستوسين المبكر، بينما المراحل الثلاثة الأخرى هي من عمر البلايستوسين – الهولوسين. لم تشاهد ظاهرة "التسطح" ولا الصبغة الصحراوية في المراوح الفيضية. إن السبب الرئيسي لتكون المراوح هو النشاط البنيوي الحديث لحوض سنجار، إضافة لتكشف الصخور الرخوة لتكوين الشيرانش والصخور الصلدة لتكوين سنجار فوقها.

INTRODUCTION

The central northwestern part of Iraq comprises of flat plain that attains in elevation about (407 – 432) m (a.s.l.), within this wide plain an outstanding geomorphic feature exists that is Sinjar Mountain (anticline); it extends almost E – W for about 80 Km, with maximum height of 1462 m (a.s.l.). The Sinjar Mountain divides the main plain into two plains, to the south is Al-Jazira Plain, whereas towards the north is Rabee'a Plain. Therefore, the former has inclination towards the south, whereas the latter is towards the north; in which the alluvial fans are developed (Fig.1).

Along the northern slopes of Sinjar Mountain, dense drainage system is developed, due to steep northern limb of Sinjar anticline, consequently a well net of alluvial fans is developed (Fig.1). The alluvial fans are of different shapes; they extend northwards to (20 – 22) Km, covering very vast part of Rabee'a Plain and extend out of Iraq, in Syria. Only the fans of the first stage overlap laterally each other forming "Bajada". In Al-Jazira Plain, however, few alluvial fans are developed too, but they are not well developed as compared to those existing in Rabee'a Plain.

The alluvial fans along Sinjar Mountain are one of the most well developed and common alluvial fans in Iraq. They are very clear and very well expressed in topographic maps of scale 1: 25 000 and partly in topographic maps of scale 1: 100 000 (Fig.2). They are also very well visible in aerial photographs of 1: 42 000 scale. Unfortunately, the available Landsat images of the study area are not of acceptable quality for GIS uses; therefore, only visual interpretation was carried out.

CLIMATE

The role of the climate in formation of alluvial fans is discussed by different authors, among them are Tuan (1962); Lusting (1965); Melton (1965); Wells *et al*. (1990); Bull (1990) and Dorn (1994) in Given (2009). They all believe that the climatic changes influence the weathering, stream flow, mass movements and sediment supply in the drainage basin above the fan; as well as the gullying, and soil development on fan deposits, besides the base-level of a closed basin. Therefore, the role of the climate in formation of alluvial fans is essential, and it is one of the main and major factors that play role in their formation.

The alluvial fans of the study area indicate prevailing of a wet climate that had caused the formation of the existing alluvial fans through running water in the streams down Sinjar Mountain. This is true, because water is the creative force that builds the alluvial fans through surges of water down slope (USGS, 2004). Although the present climate is quite different from that, which was prevailing during the formation of the alluvial fans; drier climate prevails now, but, still part of the alluvial fans are active and are supplied by recent sediments. Those which exist in the last stage, inside Syria, rarely receive sediments. This is because "the supply of the sediments to develop alluvial fans is possible even in scarce rainfall" (USGS, 2004). Moreover, "the fan characteristics can only be explained by cyclic changes in processes by climatic changes and thus, every fan has trace properties unrelated to the present conditions acting on the fan system" (Lusting, 1965; in Given, 2009).

This assumption coincides with the present climate of the study area and the characteristics of the studied alluvial fans. The climate of the study area, according to the Climatic Atlas of Iraq (1951 – 2000) is characterized by the following data (I.M.O., 2000).

- mean annual temperature ranges from $(16 – 18)^{o}$ C
- mean annual amount of rainfall ranges from (800 – 850) mm
- mean annual relative humidity ranges from (50 – 55) %
- mean annual amount of evaporation is (1800 – 2000) mm

It is also believed that all fans do not necessarily develop gradually over long time intervals, nor do their characteristics reflect average climatic controls. This is especially true when we consider fan deposits as proxies for climate, and certain periods of erosion or deposition as a process that occurs only in response to climatic change (Blair, 1987 in Given, 2009). In the study area, the climatic changes; during the formation of the alluvial fans, had clearly influenced the shape, extent and lithological constituents of the studied fans, as it is clear from the characteristics of each stage, among four.

PREVIOUS WORKS

The following works were carried out concerning the Sinjar alluvial fans:

- Ma'ala (1977) executed regional geological mapping of Sinjar anticline and surrounding areas. He reported about the alluvial fans and designated only two stages that were developed during Pleistocene – Holocene. The size of the blocks in the first stage is (20 – 70) cm but up to 1 m occur too, whereas in the second stage it is smaller and range in size from few centimeters to 20 cm. Far from Sinjar Mountain, he described valley terraces to cover vast areas within the Rabee'a Plain. Moreover, he considered the remaining sediments in the Rabee'a Plain as Sheet run-off sediments and partly as valley terraces.
- 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.
- Hagopian *et al*. (1992) compiled the geological map of Sinjar Quadrangle, scale 1: 250 000 and mentioned the presence of Pleistocene alluvial fans with thickness up to 20 m, with well rounded limestone boulders that are up to 70 cm in size. They mentioned about the coverage areas of each fan and recorded the largest one to be of 48 Km^2.
- Al-Daghastani *et al*. (2004) mapped Sinjar alluvial fans to be benefited 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-Daghastani and Al-Dewachi (2009) executed the most comprehensive geomorphological work in the study area and mapped the northern plain of Sinjar mountain using remote sensing technique. They concluded the presence of alluvial fans that form "Bajada" and presented them on a map, but they did not mention about the stages. They also concluded that the fans are related to different episodes of neotectonic and to the fluctuation of the base level in the area. Moreover, they mentioned that the fans respond to the neotectonic activity, which confirms the continuous activity of the area. They also mentioned that the apexes of the fans are aligned on parallel lines that may indicate active tectonic lines and may indicate active tectonic structures.
- 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.

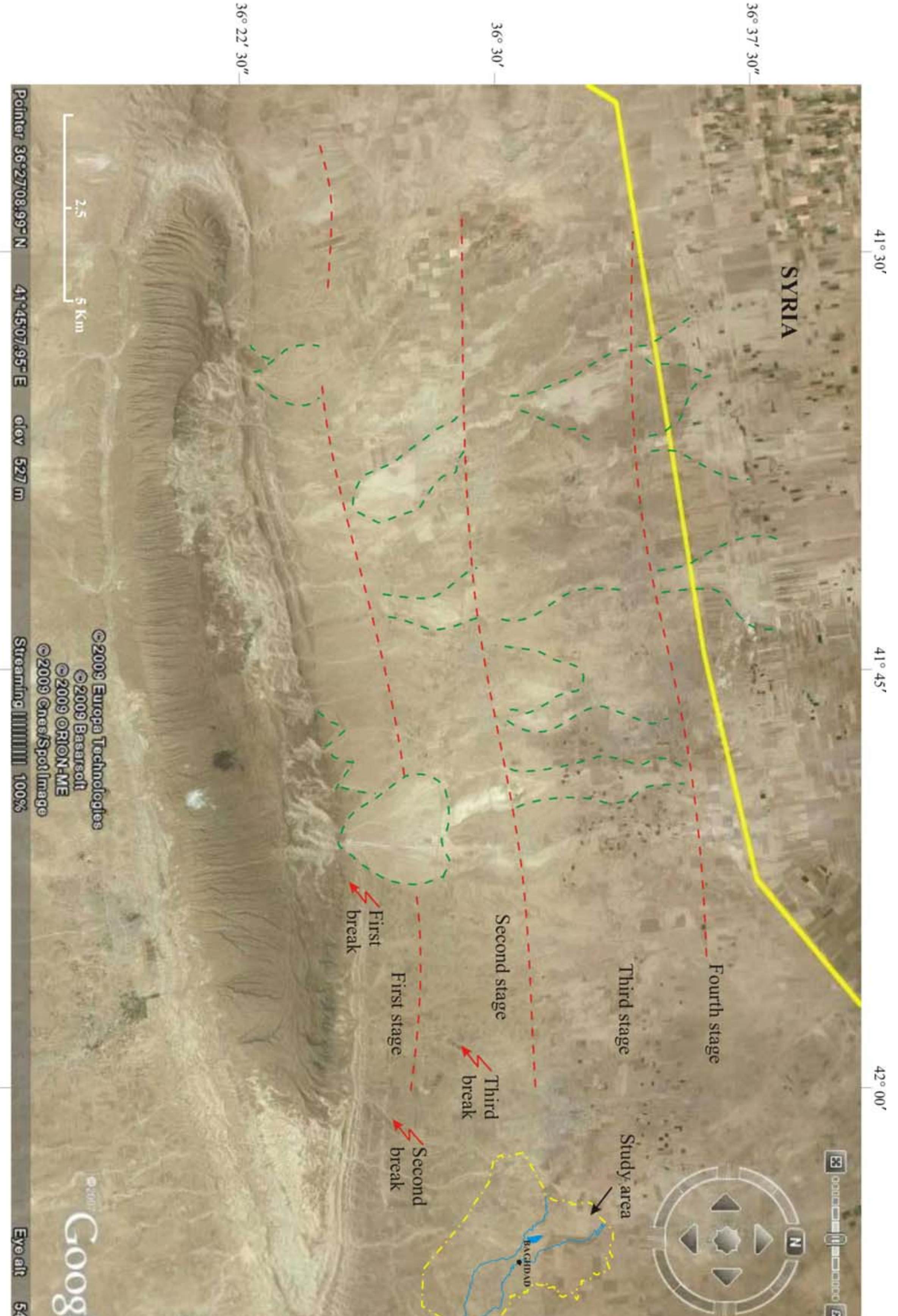


Fig.1: Google Earth image showing the location of the study area and general view of the Sinjar alluvial fans

MATERIALS USED AND METHOD OF WORK

To achieve the aim of this study, the following materials were used:

- Geological maps, scale 1: 25 000, 1: 100 000 and 1: 250 000
- Aerial photographs, scale 1: 42 000
- Google earth images
- Geological reports of the study area
- Relevant published articles

Many topographic cross sections were drawn from topographic maps, at scale of 1: 25 000, to indicate the alluvial fans morphology. GIS techniques were used to calculate the coverage area of the main large alluvial fan. Field description points (Ma'ala, 1977) were reviewed to indicate the constituents of the alluvial fans. Geological maps (Ma'ala, 1977, Hagopian *et al*., 1992 and Sissakian, 2000) were reviewed to indicate the relation between the exposed geological formations, in Sinjar anticline, and formation of the alluvial fans and their extent. Topographical maps, at scale of 1: 25 000, were used to indicate the break in slopes along the extensions of the four alluvial fan stages, and they were correlated with geological maps to indicate the type of the rocks forming the break in slopes. Many relevant published articles were reviewed to confirm certain assumptions and/ or conclusions, in this article.

GEOLOGICAL SETTING

The following geological data are quoted from Hagopian *et al*. (1992), Al-Kadhimi *et al*. (1996), Hamza (1997), Sissakian and Deikran (1998), Sissakian (2000) and Fouad (2010).

▪ Geomorphology

The study area is characterized by its flat topography, except Sinjar Mountain being the most outstanding geomorphic feature in the study area and near surroundings. The highest point is 1462 m, on top of Sinjar Mountain, whereas the lowest point is about 300 m, in the southeastern corner of the study area.

– **Geomorphological Units:** The following geomorphologic units are developed:

Units of Denudational Origin

Pediments: They are well developed on both flanks of Sinjar Mountain and along the main scarps. Their thickness mainly varies from one meter up to 5 m.

Dissected Slopes: They are developed around Sinjar Mountain**;** nearby the flanks; where the Quaternary sediments are in contact with pre-Quaternary sediments.

Polygenetic Sediments: This type of sediments, which are mainly of fine clastics, cover vast parts of the flat areas that form the Jazira and Rabee'a Plains.

Units of Structural – Denudational Origin

Hogbacks and **Cuestas:** These are developed around Sinjar anticline, within exposures of Sinjar and Serikagni – Jeribe formations. They form the first break in the slopes of the valleys that had caused the formation of the first stage alluvial fans.

Anticlinal Ridges: These are well developed around Sinjar anticline, especially within Sinjar Formation. These accelerate the flowing of rain water through the valleys.

Units of fluvial Origin

Alluvial Fans: They are well developed around Sinjar anticline; in (2 – 3) stages: The older one rests directly on Fatha and Injana formations. They cover many square kilometers (each one). They are composed of limestone gravels; up to 1 m in size, well rounded. The thickness ranges from (4 – 6) m. The second stage has more thickness and coverage area; the thickness ranges from few meters up to 20 m, whereas the coverage area reaches up to 20 Km^2, near Jaddala village and 48 Km^2 near Kersi village.

Valley Fill Sediments: They are developed in main valleys, composed of different types of sediments, depending on the source rocks; with thickness of up to 9 m.

Forms of Solution Origin: The main form of solution origin is the sinkholes, which are developed in Sinjar Mountain, within limestone and gypsum. They are of different shapes, forms and dimensions, some caves also are present.

▪ **Lithostratigraphy**

The study area is built up of sedimentary rocks ranging in age from Cretaceous to Pliocene, beside various types of Quaternary sediments (Fig.2). The stratigraphic succession is described hereinafter (from the older to the younger) briefly, depending on Ma'ala (1977), Hagopian *et al*. (1992) and Sissakian (2000).

– **Shiranish Formation** (Late Cretaceous): It is exposed in the core of Sinjar anticline only; it consists of marl and marly limestone, it is the main source for development of the alluvial fans. The thickness is 565 m.

– **Aaliji Formation** (Late Paleocene – Early Eocene): It is exposed in Sinjar anticline only; it consists of shell and marl. The thickness is about 50 m.

– **Sinjar Formation** (Late Paleocene – Early Eocene): It is exposed in Sinjar anticline only forming the bulk (carapase) of the Sinjar Mountain; it consists of well bedded and very hard limestones. The thickness is 170 m.

– **Jaddala Formation** (Middle Eocene): It is exposed in Sinjar anticline only; it consists of marl and marly limestone. The thickness is 517 m.

– **Avanah Formation** (Middle Eocene): It is exposed as a tongue within Jaddala Formation in the eastern margin of the study area, on both limbs of Sinjar anticline; it consists of marl and well bedded hard marly limestone. The thickness is 82 m.

– **Serikagni Formation** (Early Miocene): It is exposed on both limbs of Sinjar anticline and forming the bulk of the western plunge area; it consists of sandy limestone, marl and well bedded hard limestone. The thickness ranges from (65 – 305) m.

– **Dhiban Formation** (Early Miocene): It is exposed in deep cut valleys of Jeribe Mountain and the southern limb of Sinjar anticline; it consists of gypsum and limestone. The thickness ranges from (5 – 100) m.

– **Jeribe Formation** (Early – Middle Miocene): It is exposed in Sinjar anticline only; it consists of well bedded and hard limestone and dolostone. The thickness ranges from (100 – 125) m.

– **Fatha Formation** (Middle Miocene): It is exposed in both limbs of Sinjar anticline. The formation is divided into two members: **Lower Member** consists of green marl, limestone and gypsum in cyclic repetition. **Upper Member** consists of green marl, red claystone, limestone and gypsum in cyclic repetition, sandstone occurs in the uppermost parts. The thickness is 630 m.

– **Injana Formation** (Late Miocene): It is exposed in foothills of Sinjar Mountain; it consists of reddish brown sandstone, claystone and siltstone in cyclic repetition. The thickness is 1250 m.

– **Mukdadiya Formation** (Late Miocene – Pliocene): It is very rarely exposed in the Rabee'a Plain in valleys, because Quaternary sediments cover the majority of the area; it consists of grey and red dish brown sandstone, claystone and siltstone in cyclic repetition, some of the sandstone beds are pebbly. The thickness is 700 m.

– **Quaternary Sediments:** Different types of Quaternary sediments are developed in the study area; they differ in age and genesis, they are described as follow:

Alluvial Fans (Pleistocene – Holocene): They are well developed around Sinjar anticline; in three to four stages: The older one (Pleistocene) rests directly on Fatha and Injana formations covering many square kilometers (each one). They are composed of limestone boulders; up to 70 cm in size, well rounded. The thickness ranges from (4 – 6) m. The second and third stages (Holocene) have more thickness and coverage area; the thickness ranges from few meters up to 20 m, whereas the coverage area reaches up to 20 Km^2, near Jaddala village and 48 Km^2 near Kersi village. They form typical badlands due to dense cover of rock fragments on the surface of the fans.

Terraces (Pleistocene): These are developed along main valleys. The terraces consist mainly of limestone pebbles. The thickness varies within few meters.

Polygenetic Sediments (Pleistocene – Holocene): They cover the flat parts of the study area, in between the alluvial fans, and consist of sandy, silty and clayey soil, locally gypsiferous, with limestone and dolostone fragments, cemented by carbonate, gypsiferous and sandy materials. The thickness ranges from less than one meter up to few meters.

Valley fill sediments (Holocene): These are well developed in all main valleys in the study area. They consist of limestone pebbles that range in size from few centimeters up to 30 cm, sand and silt. The thickness is up to few meters.

▪ Structural Geology

The study area is located in the Unstable Shelf of the Arabian Platform, represented by the High Folded Zone (Al-Kadhimi *et al*., 1996 and Fouad, 2010). The Sinjar anticline is the only structural form in the study area. It is 80 Km long and 20 Km wide, almost E – W trending, with steeper northern limb (45 – 80)° and gentler southern limb (15 – 25)°, an E – W trending fault runs parallel to the axis along the northern limb (Fig.2). From **Neotectonic** point of view, the majority of the study area is uplifted. The uplifted amount ranges from (150 – 600) m, moreover, the calculated rate of movement ranges from (0.2 – 0.4) cm/ 100 years (Sissakian and Diekran, 1988).

ALLUVIAL FANS OF SINJAR MOUNTAIN

▪ Formation of the Fans

Alluvial fans are formed due to decrease of gradient of a stream; due to 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" (American Geological Institute, 1962). Therefore, there will be iso-trnsport 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). In the study area, valleys flow down the northern slope of Sinjar Mountain, with gradient of 1: 2, until the first slope break. Locally, along Sinjar Formation and/ or Jeribe Formation (Fig.2), the gradient drops drastically, consequently the energy decreases leading to deposition of the coarse sized materials, up to 100 cm (Ma'ala, 1977) and formation of the first stage alluvial fans. After this break in slope, the transportation and deposition of the materials continue depending on the particle size, forming concentric shape, which is very clearly expressed by the topographic maps, at scale of 1: 25 000 and even 1: 100 000 (Fig.2), in which the contour lines express iso-transport energy lines, which are very uniform, especially in the alluvial fans of the first stage.

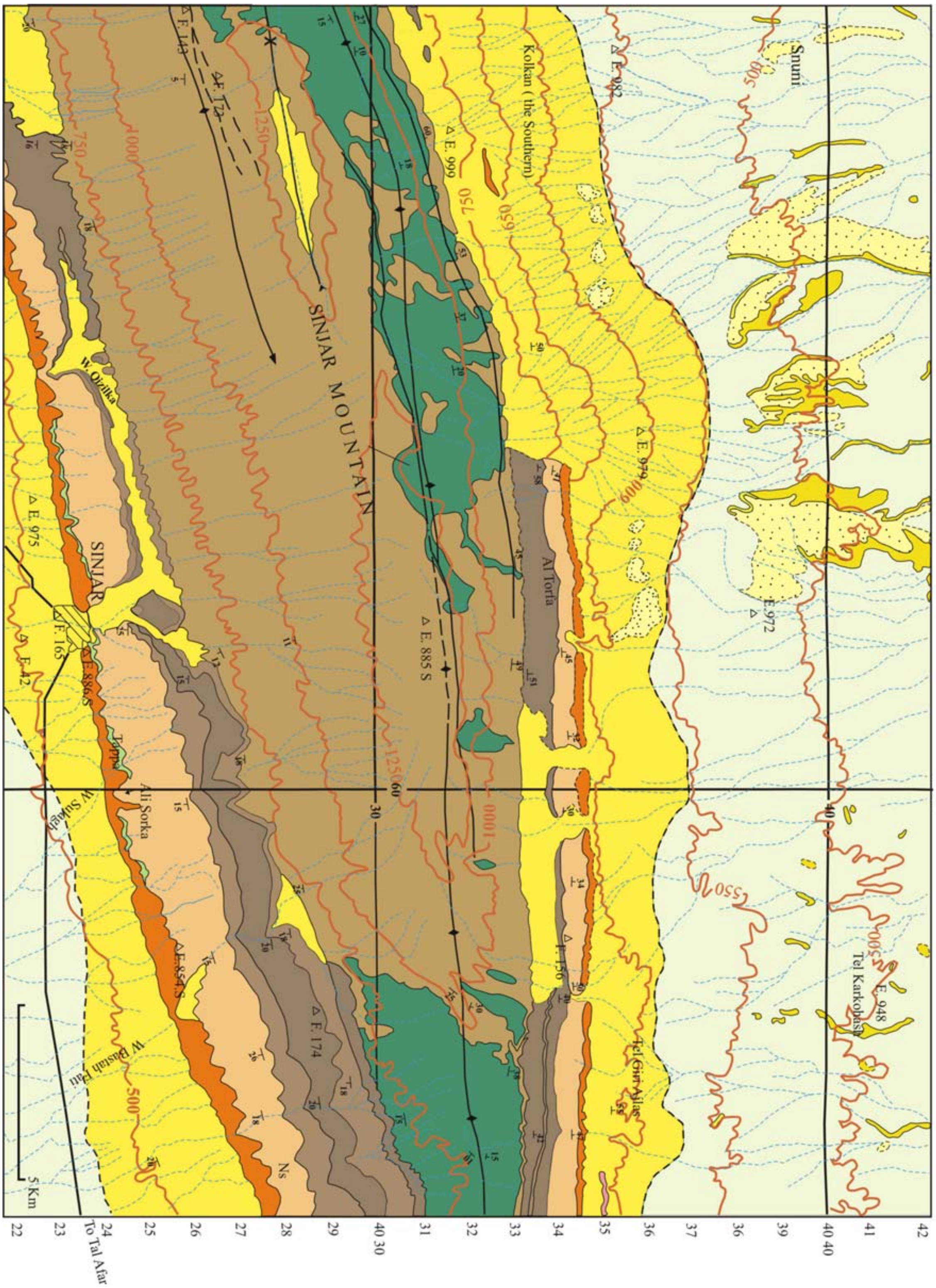
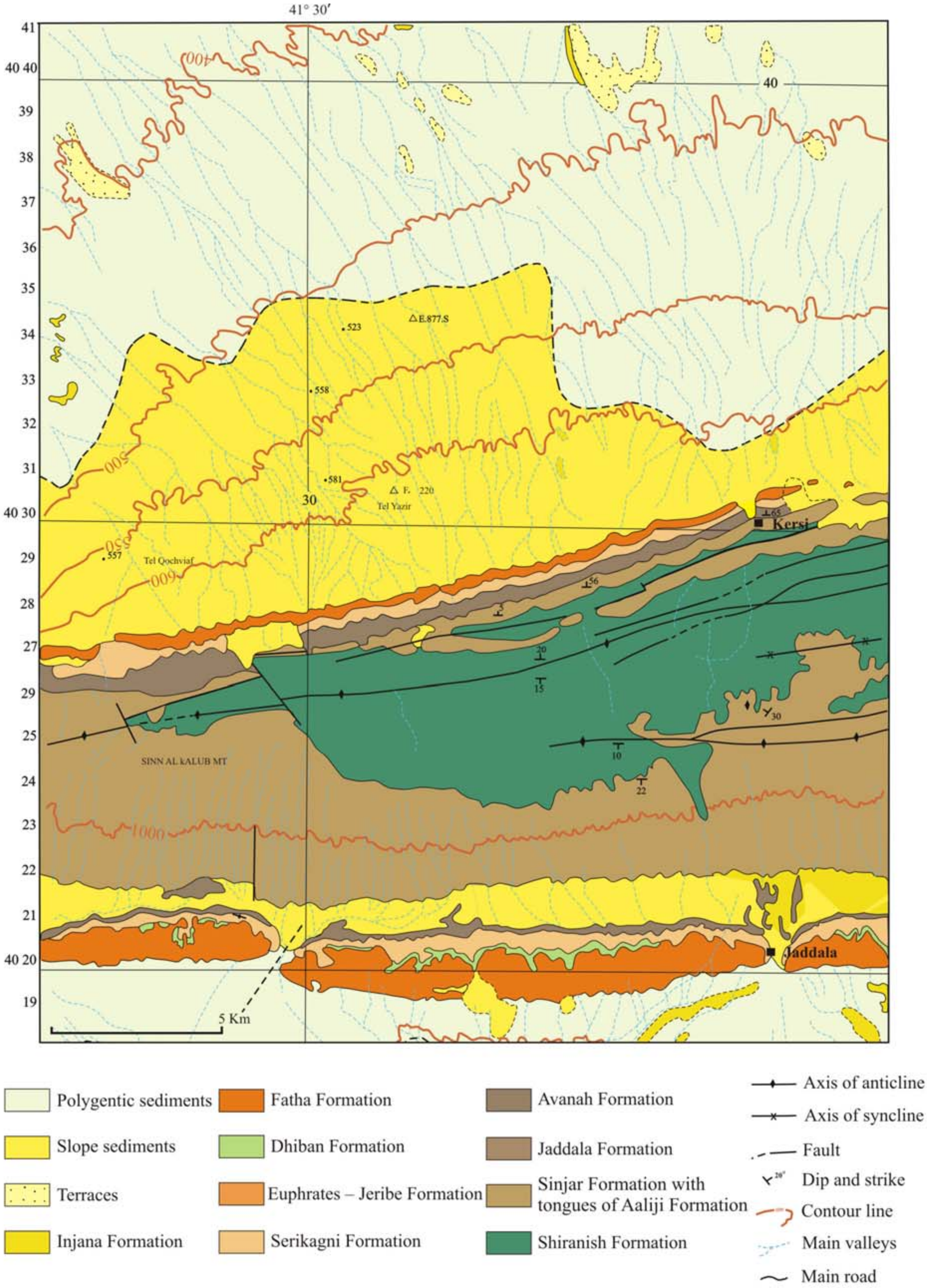


Fig.2: Geological map of the study area, scale 1:25 000 (after Hagopian *et al*., 1992)
(For legend, refer to page 16)


41° 30′
Kersi
Jaddala
Tel Yazir
Tel Qochviaf
SINN AL KALUB MT
5 Km
Polygentic sediments
Slope sediments
Terraces
Injana Formation
Fatha Formation
Dhiban Formation
Euphrates – Jeribe Formation
Serikagni Formation
Avanah Formation
Jaddala Formation
Sinjar Formation with tongues of Aaliji Formation
Shiranish Formation
Axis of anticline
Axis of syncline
Fault
Dip and strike
Contour line
Main valleys
Main road

Cont. Fig.2

Alluvial fans are apron-like deposits of granular debris that extend from the base of a mountain front to a low land below. Each fan radiates from a single source channel, and has fan-like shape in plan view. Its transverse profile is arched, and the longitudinal profile is slightly concave. Slopes are usually less than 10^o. The fans are best developed in semiarid deserts, 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). In the study area, Sinjar Mountain is the source area for formation of the alluvial fans; it forms an elongated mountain with maximum height of 1462 m, almost with poor vegetation cover, forming the range topography. In front of it, Rabee'a Plane is the depositional basin, where the alluvial fans are formed. Therefore, the "basin- and- range topography" is typically formed in the study area.

The shape of the fans is related to grain size. Fans built of boulders and cobbles have a high pronounced arch, whereas, those built of silt, sand and fine gravels have broad, flattened profiles (Bull, 1991). In the study area, boulders up to 100 cm (average of 20 – 70 cm) of limestone cover, densely, the first stage of the alluvial fans (Ma'ala, 1977). The large boulders were carried in a matrix of viscous mud; therefore have typical fan shape, whereas the finer sizes were carried to more far distances, either to form the prone parts; or to form other stages, which have longitudinal shape. Part of the sediments were also carried and transported by valleys (streams) to much far distances and deposited either as valley fill sediments or to form part of the large Rabee'a Plane.

Alluvial fans are composite structures whose units differ in surface shape and structure. "Components include: **Active stream channels** that originate in the mountains and which transport detritus to areas of deposition as well as cut into, erode, or override previous deposits. **Abandoned and locally elevated older areas** of deposition, which lie between channels. **Internally formed dendritic channels** within older deposits that erode the developed surfaces and redistribute the debris to depositional areas down slope" (Bull, 1991). In the study area, the "active stream channels" are very rare, nowadays, due to semi arid climatic conditions, as compared to prevalent wet climate during formation of the alluvial fans (during Pleistocene and early Holocene), they could be seen in Landsat and Google Earth images, and aerial photographs as light tone valleys or streams, whereas the older ones are more darker. The "abandoned elevated areas" could be seen very clearly, especially in the first stage alluvial fans (Fig.1). The "internally formed dendritic channels" also could be seen every where in the study area and along almost all stages of the fans (Fig.1). The light tone parts of alluvial fans are the younger and active parts of the fans (USGS, 2004). This criterion was used in this study to indicate the active parts of the alluvial fans, as well as the active streams and/ or valleys, along the fans.

- **Description of the Alluvial Fans**

For description of the alluvial fans of the study area, tens of field documentation points (Ma'ala, 1977) were reviewed in order to get the required data. Moreover, the geometry of the fans within each stage was determined from the topographic maps, at scale of 1: 25 000. The description is mentioned hereinafter, and the data are summarized in Table (1).

– **Shape,** only the first stage fans have ideal fan shape (Figs.1 and 3), 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 stream, because there will be iso-transport energy lines forming concentric arcs about the discharge point at the apex of the fan. These concentric arcs are represented by the topographic contour lines, which are very uniform with gradient of 1: 16 (Fig.2). However, the fans of the other three stages have longitudinal shape with broad flattened top (Figs.1

and 4). The author believes that the fans of the second, third and fourth stages have lost their shapes due to weathering, and type and size of the constituents. Because they are finer as compared to the constituents of the first stage, the insufficient renewal of the supplied materials that decrease as the fans are more far from the apex (Sinjar Mountain), and finally due to man activities, especially cultivation. Besides, the transportation energy will not be homogeneous and equally distributed along isolines, as they are in the first stage, because the energy had drastically reduced due to the gradient (Table 1).

Within the last three stages of Sinjar alluvial fans, the followings active stream channels could be clearly seen. Such channels are very clear on topographic maps at scale of 1: 25 000. They transport sediments to areas of deposition as well as cut into, erode, or override previous deposits, abandoned and locally elevated older areas of deposition that lie between channels. In the first stage alluvial fans, however, well developed dendritic channels could be seen, although partly are inactive, as indicated from their dark color, as compared to those, which are active and appear in lighter tones. The tone is used in distinguishing active channels from inactive channels (USGS, 2004).

The "feeder channel" could be seen in all stages (Fig.1), whereas only in the first stage the "intersection point" could be seen (Fig.3), where the incised channel intersects the original fan surface some where down-fan, because the slope on the fan is greater than the gradient of the incised channel. At this point, flow leaves the incised channel and spreads onto the surface of the original fan. Thus, the "active depositional lobe" could be seen only in down-fan segment, where the fan experiences aggradation. These lobes also could be seen very clearly in the first stage, but are obscured in others (Fig.4).

No filed data are available about the "**bar and swale**" micro-topography, within the alluvial fans of the study area. The author believes the range is higher in the first stage fans, as compared to those of the other three stages. This is mainly due to the grain size distribution that largely differs in the four stages. In the first stage, around (0.5 – 3) m is expected, while (0 – 0.5) m is expected within the other three stages (Table 1).

– **Constituents**, the first stage fans have different constituents as compared to remaining three stages (Table 1). The main constituents of the first stage are very hard, splintery limestone pebbles and boulders that are derived mainly from Shiranish and Sinjar formations; very poorly sorted; the size varies from (20 – 70) cm, but boulders up to 1 m are common too. The finer constituents are derived from other formations. The limestone pebbles and boulders are sub rounded to rounded, whereas those of chert are angular; now the pebbles are almost loose, partly are poorly consolidated and cemented by calcareous materials and very rarely by clastics, occasionally very coarse grained sand lenses and/ or horizons occur too. The constituents of the fans of the remaining stages are mainly of fine clastics with limestone pebbles up to 20 cm in size, usually capped by soil with loose limestone pebbles, on the top.

– **Thickness,** the thicknesses of the alluvial fans are not well documented, the reported thicknesses vary from few meters up to 30 m (Table 1), but generally few meters are mentioned. In a studied hand dug water well in a valley floor; depth to 8 m is recorded too, with boulders of 0.5 m and maximum 1 m. The thickness of the last stages is recorded to be (2 – 5) m and 8 m as maximum thickness.

Fig.3: Ideal fan of the first stage (I.P. = Intersection point)
(Dahoona alluvial fan, the name of the fan is after Al-Daghastani *et al*., 2004)

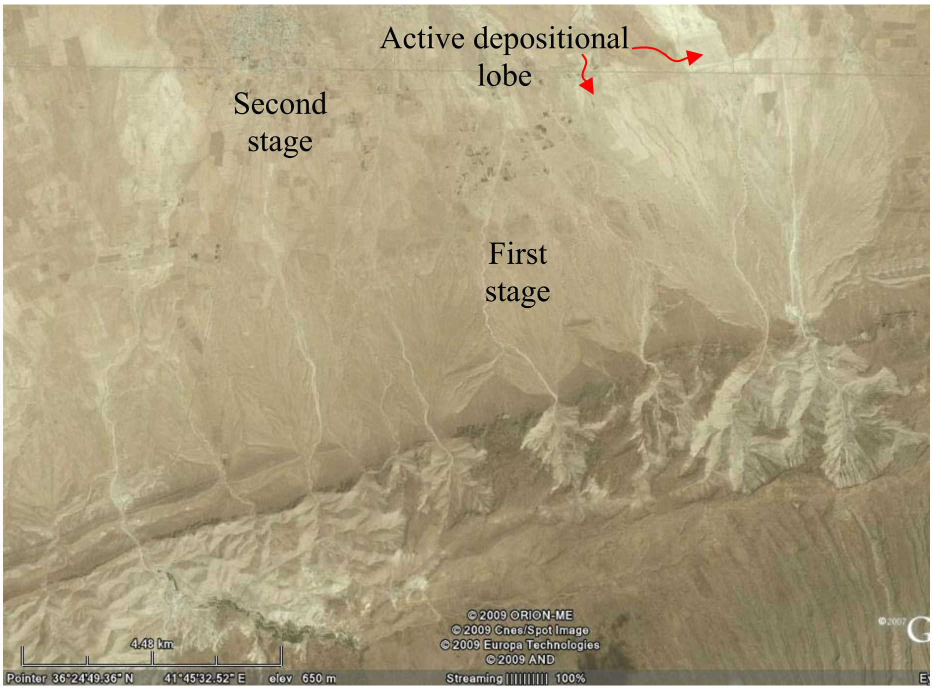


Fig.4: Fans of the first and second stages,
note the difference in the shapes of the two stages

Table 1: Characteristics of the alluvial fans in the study area

STAGE	Constituents	GEOMETRY: Length (Km)	GEOMETRY: Maximum width (Km)	GEOMETRY: Shape	GEOMETRY: Gradient (%)	GEOMETRY: Coverage area $(Km)^2$	Genetic classification	Water/ sediments ratio	Sediments size (m)	Thickness (m)	Bar and Swale (m)	Activity	Desert Varnish	Pavement	Age
First	Hard, splintery limestone, chert and clastics	2.15 – 5	1.75 – 6	Fan	5.6 – 11.6	5.25 – 16	Type I	High	0.2 – 1	Up to 30	0.5 – 3	Active	None	None	Early Pleistocene
Second	Limestone with fine clastics capped by soil with fine rock fragments	6 – 10.5	1.5 – 5.5	Longitudinal	0.9 – 2.6	7.75 – 10.2	Type II	Low	Up to 0.2	3 – 8	0 – 0.5	Dormant	None	None	Late Pleistocene – Holocene
Third		2.5 – 7.25	2 – 5		0.3 – 1.4	5.4 – 11.5	Type II	Low							
Fourth		2.3 – 3.3	1.45 – 2.5		*	4.1 – 7.4	Type II	Low							

* No topographic data

– **Coverage areas**, the fans of the four stages have different coverage areas, generally the coverage area decreases towards the flow direction (Table 1), this is attributed to the amount of the provided sediments and gradient; both decrease towards the flow direction. Although Ma'ala (1977) mentioned that the largest fan near Kersi village has coverage area of 48 Km^2, but it was found that the coverage area of the same fan is only about 16 Km^2, this was deduced using GIS technique.

▪ **Genesis**

According to the genetic sense, fans are classified by Blair and McPherson (1994) in Ritter *et al*. (2002) into two types: **Type I** and **II**. The classification depends mainly on: grain size; their shape and sorting, feeder channel length, drainage basin size, bed rock lithology and average slope. Following these parameters (Table 1), the alluvial fans of the study area could be classified as **Type I,** for the first stage and **Type II**, for the remaining three stages.

▪ **Mode of Deposition**

Following the concept of Ritter *et al*. (2002) in delineating the mode of the deposition of the four stages alluvial fans of the study area and based on the available data about the characteristics of the studied alluvial fans (Table 1), the depositional model of the alluvial fans is constructed (Fig.5). It could be seen that in the first stage alluvial fans the deposition starts with Transitional flow and continues in Debris flow then follows again by Transitional flow and terminates by stream flow, the debris flow being the dominant mode. In the last three stages alluvial fans; however, the deposition starts and terminates with the Stream flow with small time interval of Transitional flow. The last mode of deposition (stream flow) in the first stage alluvial fans is indicated by nowadays supply of the fine materials, where the valleys have no any more load carrying ability to transform boulders, due to decrease in amount of rain water precipitation. The alluvial fans of the last three stages, however, are almost dormant and rarely receive more sediments, for the same reason, and under went erosion; they almost lost their shapes due to cultivation activities (Fig.1).

▪ **Dating**

Although precise dating techniques are not available to the author, but he believes that the age of the alluvial fans are variable. Those of the first stage are most probably of Early Pleistocene and could be even? upper Late Pliocene, whereas, those of the other three stages are of Late Pleistocene – Holocene. This assumption is based mainly on the climatic changes during Pleistocene – Holocene with the related rate of sediments supply and the size of the fans. It is also believed that the fans of the last stages hardly receive any more sediments, but those of the first stage are still active and receive sediments.

RESULTS

Along the northern limb of Sinjar anticline and northwards, four stages of alluvial fans are developed; the first stage fans have typical fan shape, being genetically of Type **I**, still active, with very coarse constituents that are mainly of limestone boulders; locally covered by very thin soil veneer. The remaining three stages have longitudinal shapes; being genetically of Type **II** and are partly dormant, with fine constituents. The gradient in the first stage fans is much higher than in the fans of the other three stages. Sinjar Mountain and the developed fans form typical basin-and-range topography. No pavement and/ or desert varnish were reported in the alluvial fans of the study area. It is worth mentioning that the sediments of the third and fourth stages of the fans are believed to be as sheet run-off sediments (Khaldoun A. Ma'ala, personal communication, 2010).

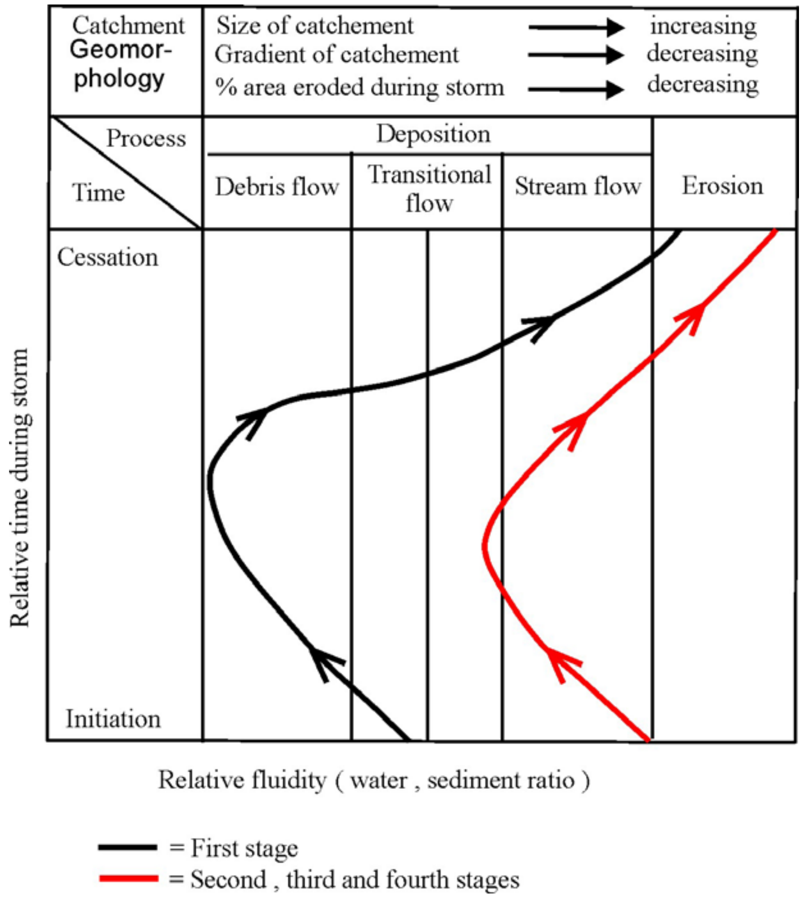


Fig.5: Conceptual model showing the change in the water/ sediments ratio, the sequence of depositional and erosional events and associated flow conditions, in the four stages alluvial fans of Sinjar Mountain (modified after Ritter *et al*., 2002)

DISCUSSION

The main source of the alluvial fans, in the study area, is the Shiranish Formations, beside Sinjar, Avanah, Serikagni and Jeribe formations, therefore, the best developed alluvial fans are along the northern limb of Sinjar anticline, especially where Shiranish Formation is exposed (Fig.2). This is the main reason why fans along the southern limb of Sinjar anticline are not well developed, as compared to those along the northern limb. Besides, the dip that is higher in the northern limb, and the presence of a long (about 25 Km) E – W trending fault, between Shiranish and Sinjar formations that probably was active and had contributed in the acceleration of fans development, and since "fans are better developed in tectonically active areas" (Bull, 1991 and Ritter *et al*., 2002).

The first break in the slope is either along the contact between Shiranish and Sinjar formations or Serikagni Formation indicating apexes of the first stage alluvial fans (Fig.2). The second break in the slope is within the Injana Formation (Fig.2); a sandstone ridge at elevation of (700 – 750) m marks the break that had caused the termination of many small fans; east of the first large fan (Dahoona Fan). This break also had caused a break along the gradient of some fans of the first stage, dividing the fan surface into two portions; active and inactive, as indicated by the tone change (Figs.1 and 3). The third break is at elevation of 550 m (a.s.l.) also within the Injana Formation (Fig.1); a sandstone ridge marks this break.

It had caused the termination of the first stage fans and initiation of the second stage fans. This ridge is only visible east of the Dahoona Fan, farther westwards it is covered by pediments and/ or fans. The breaks in gradient of the remaining two stages are gentle and almost invisible in Landsat images. This is the main reason why the fans of these stages have no typical fan shape, but are longitudinal, because the constituents are of fine size, and since "the size of the sediments is function of the shape" (Bull, 1991 and USGS, 2004).

The apexes of the last three stages are aligned in transversal? faults that are almost parallel to the axis of Sinjar anticline (Fig.1). The author believes they are attributed to the continuous up warping of Sinjar basin (upheaval), and particularly of Sinjar anticline (Ma'ala, 2009 and Al-Daghistany and Al-Dewachi, 2009) that had caused drop in the gradient, in step form and consequently caused termination of each stage and initiation of the next one. The transversal faults represent the boundaries between the blocks that exist in the northern side of Sinjar basin, which are still active, as Sinjar anticline. The whole subsiding basin was inverted after Late Cretaceous (Fouad and Nasir, 2009) and started moving up, but in different levels that caused the mentioned breaks in the gradient and consequently the four stages of alluvial fans were developed. This is another reason why along the northern side of Sinjar anticline the alluvial fans are very well developed; in contrary to the southern side, since the southern limit of Sinjar anticline forms the boundary of a tectonic block. Therefore, no break in the gradient exists in the southern side (Al-Jazira Plain), except the first break along which few fans are developed and in one stage only (Saffa Al-Dean F. Fouad, personal communication, 2010).

The low gradient also causes drop in transporting energy, consequently the iso-transport energy lines will loose their concentric shapes (American Geological Institute, 1962 and National Aeronautics and Space Administration, 2009). In the study area, transporting energy drops down continuously in the four stages; as far as the deposition place becomes more far from the source area. This is another reason that explains the longitudinal fan shapes of the last three stages.

The water/ sediments ratio also plays big role in defining the size of the transported materials, consequently defining the shape of the fan (Ritter *et al.*, 2002). In the first stage fans, because the transporting energy was very large, due to high gradient, therefore, the transported materials were large with high concentration, consequently the water/ sediments ratio was low, leading to highly viscous transporting media. This highly viscous transporting media had transported very large blocks (up to 1 m) for a distance of (2 – 6) Km in form of "Transitional flow" and very rarely in form of "Debris flow". Therefore, the first stage fans have typical fan shape. On contrary, the water/ sediments ratio in the remaining three stages was high, because the gradient was low; consequently the size and concentration of the transported materials were low. Therefore, the transportation media was as "Stream flow" and the deposited materials were of fine size; consequently the shape of the fans is not typical fan shape, but longitudinal. It is worth mentioning that all four stages of alluvial vans under went erosion now, however, they may receive sediment, especially the first stage, during heavy rain showers (as it happened in spring 2011, after completion of this article).

CONCLUSIONS

The following could be concluded from this study:

- Four stages of alluvial fans are developed.
- Only fans of the first stages have typical fan shape, others are longitudinal.
- The fans of the first stage locally are laterally over lapped, forming "Bajada".
- The size of the sediments of the first stage alluvial fans ranges between (20 – 70) cm and occasionally reaches 1 m, whereas in the other three stages ranges up to 20 cm in size.

- The thickness of the first stage fans is up to 30 m and might be more, whereas, that of the other stages have thickness of (3 – 5) m and may reaches up to 8 m.
- The fans of the first stage, genetically, are of Type I, whereas those of the other three stages are of Type II.
- The fans of the first stage are still active, whereas those of the other three stages are almost inactive (dormant), due to insufficient sediments supply.
- The apexes of the fans of the last three stages are aligned in a line that is almost parallel to the axis of the Sinjar anticline, indicating continuous upheaval of Sinjar anticline and the northern Rabee'a Plain along longitudinal blocks; the lines indicate the boundary between the blocks, and probably represent transversal faults.
- The age of the first stage alluvial fans is most probably Early Pleistocene, whereas the fans of the other three stages are of? Late Pleistocene – Holocene age.
- No pavement and/ or desert varnish exist in the alluvial fans.

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About the author

Varoujan K. Sissakian graduated from University of Baghdad in 1969 with B.Sc. degree in Geology, and M.Sc. in Engineering Geological Mapping from I.T.C., the Netherlands in 1982. Currently, he is working as the Head of Geology Department in GEOSURV and was nominated as Expert in 2005. He has 118 documented reports in GEOSURV's library and 47 published articles in different geological aspects. His major fields of interest are geological hazards, geological maps and the stratigraphy of Iraqi territory. He is the Deputy Vice President of the Middle East Subcommission of CGMW, Paris, since February 2010.

e-mail: varoujan49@yahoo.com
Mailing address: S.C. of Geological Survey and Mining,
P.O. Box 986, Baghdad, Iraq