

ALLUVIAL FANS OF THE HAB'BARIYAH DEPRESSION, IRAQI WESTERN DESERT

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Received: 17/ 06/ 2012, Accepted: 25/ 10/ 2012

Keywords: Alluvial fans, Pleistocene, Neotectonic, Graben, Karstification, Iraq

ABSTRACT

The Hab'bariyah Depression is one of the largest depressions in the Iraqi Western Desert, its length in Iraq is 230 Km; extends southwards into Saudi Arabia, whereas its width ranges from (5.1 –16.5) Km, covering an area of about 2530 Km². Its depth; on the surface ranges from (22 – 51) Km, along the eastern and western rims, respectively. The depression is filled by Quaternary sediments derived by tens of valleys that drain very large area in the Western Desert, east of longitude 40° E (east of Wadi Hauran), and some of them drain farther southern areas; in Saudi Arabia. Only two of the main valleys cross the depression, others drain in it.

The Quaternary sediments that fill the Hab'bariyah Depression include gravels; called "Hab'bariyah Gravels" (Pleistocene), alluvial fan sediments (Pleistocene – Holocene) and depression fill sediments (Holocene). The development of alluvial fans needs a drop in gradient, beside many other factors. However, the drop in the gradient of the valleys and the present gradient of the depression is not sufficient to develop the studied alluvial fans. Therefore, the development of the alluvial fans had occurred in different conditions than those are present nowadays. The Hab'bariyah Depression was developed due to a structural reason accompanied by karstification. However, neotectonic activity also has contributed in the development of the depression, consequently contributed in the development of the alluvial fans, in the depression.

المراوح الفيضية في منخفض الهبارية، الصحراء الغربية العراقية

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المستخلص

يعتبر منخفض الهبارية أحد أكبر المنخفضات في الصحراء الغربية العراقية. يبلغ طول المنخفض في العراق 230 كم ويمتد جنوباً إلى داخل المملكة العربية السعودية، بينما يترأص عرضه بين (5.1 – 16.5) كم، مغطياً مساحة تبلغ حوالي 2530 كم². أما عمقه على السطح فيتراوح بين (22 – 51) كم، على الحافتين الشرقية والغربية، على التوالي. المنخفض مملوء بترسبات العصر الرباعي التي انتقلت بواسطة العديد من الوديان التي تتحد من الصحراء الغربية العراقية، شرق خط الطول 40° E (شرق وادي حوران)، إضافة إلى بعض المناطق الواقعة في المملكة العربية السعودية. ويعبر اثنان من تلك الوديان المنخفض، أما ما تبقى من الوديان فتصب فيه.

إن الترسبات التي تملأ منخفض الهبارية تتكون من حصى الهبارية (البلايستوسين)، ترسبات المراوح الفيضية (البلايستوسين – الهولوسين) وترسبات مالئة للمنخفضات (الهولوسين). يحتاج تكون المراوح الفيضية إلى انخفاض في الانحدار، إضافة إلى عوامل أخرى. إلا أن الانخفاض الموجود في الانحدار الحالي للوديان وفي المنخفض لا يكفي لتكون المراوح، وعليه فإن المراوح الفيضية تكونت في ظروف تختلف عن تلك الموجودة حالياً. إن منخفض الهبارية قد تكون بسبب بنيوي إضافة إلى عملية التخسف، إلا أن النشاط البنيوي الحديث قد ساهم أيضاً في تكون المنخفض، وهذا بدوره ساهم في تكون المراوح الفيضية في المنخفض.

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INTRODUCTION

The central part of the Iraqi Western Desert is characterized by development of dense drainage system, which drains very large part of the desert by numerous valleys that extend in W – E direction and drain the whole area towards the Hab'bariyah Depression. Among the valleys only two; Ubayidh and Ghadaf cross the depression, others terminate and drain in it. The depression, which is almost in N – S direction, covers an area of about 2530 Km². The length of the depression, in Iraq is about 230 Km, and extends southwards inside Saudi Arabia. The width of the depression is irregular, it ranges from (5.1 – 16.5) Km, the maximum width being in its central part. The surface depth of the depression ranges from (43 – 90) m, along the eastern and western rims, respectively, the deepest part being in the central part of the depression, along its length.

▪ Location

The Hab'bariyah Depression is located in the eastern part of the Iraqi Western Desert (Fig.1). Al-Nukhaib town is the main administrative center in the depression, beside many other small settlements, like Qatari, Shabwan, Al-Awaj and Al-Bireet (Fig.2). The studied area is approximately limited by the following coordinates.

Longitude	41° 58' 00"	42° 14' 30"
Latitude	30° 58' 00"	32° 59' 00"

▪ Aim

The aim of this study is to discuss the origin and mode of deposition of the alluvial fans system, which is developed in the Hab'bariyah Depression. This aim was achieved by using different geological data, with interpretation of aerial photographs and Google Earth and satellite images.

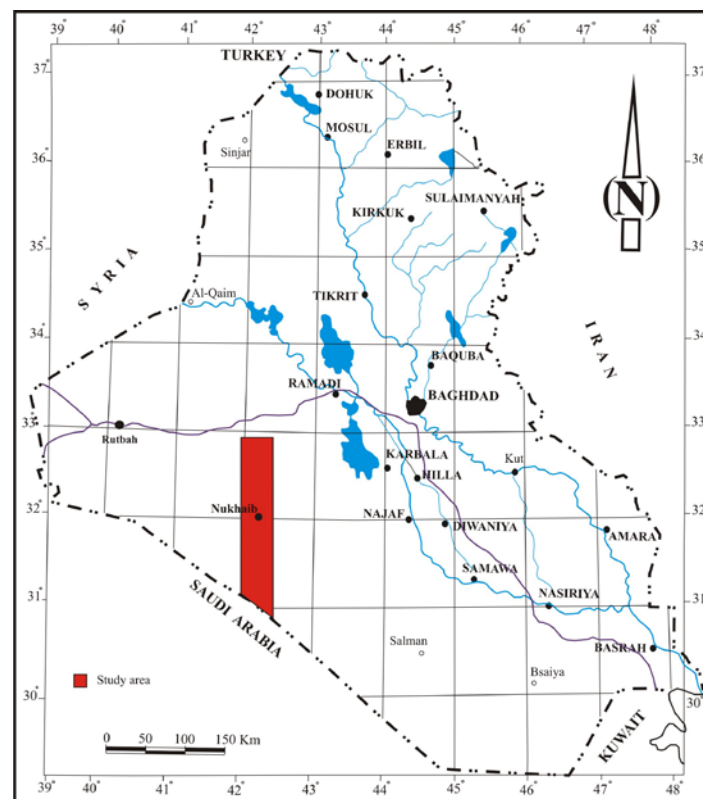


Fig.1: Location map of the studied area

▪ Previous Works

Many workers reported about the Hab'baryah Depression, among them are:

- Al-Mubarak and Amin (1983) described the gravels accumulation in the Hab'baryah Depression and called them "Hab'baryah Gravels" and considered the depression as a graben and called it "Hab'baryah Graben", but they did not mention any thing about the alluvial fans. However, they recognized two levels of gravels, and described them as higher and lower levels.
- Al-Bassam *et al.* (1995) reported about the Hab'baryah Depression in details, and considered its origin to be a graben, but they did not mention about the alluvial fans.
- Hamza (1997) presented the alluvial fans of the Hab'baryah Depression on the Geomorphological Map of Iraq, at a scale of 1: 1000 000, but did not mention their details.
- Abdul Jabbar and Zaini (2009) reported about the origin of the Hab'baryah Depression, using GIS and remote sensing technique, they concluded that the depression is a graben.
- Sissakian and Deikran (2009) reported about the activity of the Hab'baryah Depression, and considered it as an active neotectonic area. They also considered that the alluvial fans are still active.
- Al-Shaikh and Al-Mashhadani (2012) studied the Hab'baryah Depression, using geophysical data and concluded that the origin of the depression is related to karstification. They did not mention any thing about the alluvial fans.

▪ Materials Used and Methodology

In order to achieve the aim of this study, the following materials were used:

- Topographical maps at scale of 1: 25 000, 1: 100 000 and 1: 250 000
- Geological maps at different scales.
- Landsat images, DEM, Google Earth images, and aerial photographs.
- ArcGIS technique and relevant extensions.

The aforementioned data were used as an integrated study to achieve the required data about the development of the alluvial fans of the Hab'baryah Depression and their characteristics. Topographical maps were used to indicate the dimensions of the depression. To deduce the type of the exposed rocks and Quaternary sediments, geological maps and reports were also used. Aerial photographs, Landsat images, and Google Earth images were interpreted to indicate the parameters of the alluvial fans and their shapes and stages. ArcGIS technique and extensions were used to deduce the gradient of the fans and main valleys, coverage areas of many fans and the topographic map of the depression with cross section.

GEOLOGICAL SETTING

The geology of the studied area is briefly mentioned hereinafter, depending on the best available data:

▪ Geomorphology

The studied area is a wide depression, trending N – S, however north of Wadi Ghadif changes to NW – SE. Numerous valleys drop their sediments in the depression. A complex drainage system had developed alluvial fans system, which have W – E trend; the same trend of the main valleys. The fans have almost typical fan shape, with concave to flatten surfaces and radiating isolines. The depression also is locally filled by depression sediments and has valley fill sediments; both are typical for desert areas. All geomorphological units in the depression are mainly of fluvial origin, however, some aeolian sand accumulations occur too.

▪ **Stratigraphy**

The exposed formations and Quaternary sediments in the Hab'bariyah Depression are briefly described hereinafter. The geological map of the studied area is presented in Fig. (2).

— **Umm Er Radhuma Formation (Paleocene):** Al-Mubarak and Amin (1983) divided the Umm Er Radhuma Formation in the eastern part of the Iraqi Western Desert into two members, however, in the studied area only the Upper Member is exposed. It is divided into three units: **a) Shelly – Chalky Unit** (42 – 45 m), consists of dolostone with chert lenses and nodules, followed by interbedding of shelly calcareous dolostone and chalky limestone, with chert layers, overlain by chalky dolostone. **b) Upper Chalky Unit** (13 – 35 m) consists of alternation of thick horizons of marly and chalky limestones with shelly dolostone, overlain by chalky limestone. **c) Upper Shelly Unit** (30 – 45) consists of dolomitic limestone, overlain by shelly limestone, followed upwards by dolomitic limestone. The thickness of the Umm Er Radhuma Formation in the supplementary type section is 458 m (Bellen *et al.*, 1959). The Upper Member in the studied area ranges from (85 – 115) m (Al-Mubarak and Amin, 1983).

— **Dammam Formation (Eocene):** Only the Lower Member is exposed in the studied area; it includes only Ubaiyidh Unit, which consists in Wadi Ubaiyidh vicinity of basal conglomerate, overlain by nummulitic limestone. In Nukhaib vicinity, the lower part consists of quartzitic sandstone, with the same lithology of the upper part. The thickness in the studied area and near surroundings ranges from (32 – 99) m (Al-Mubarak and Amin, 1983).

— **Zahra Formation (Pliocene – Pleistocene):** According to Al-Mubarak and Amin (1983) the Zahra Formation in the northern part of Nukhaib Graben area, consists of (3 – 5) cycles. Each cycle consists of light brown, reddish brown and white, partly pebbly, calcareous sandstone, overlain by red and reddish brown, slightly sandy claystone, which is followed by greenish grey, slightly sandy and gypsious marl, which is capped by whitish grey and brownish grey, slightly sandy, fossiliferous and burrowed limestone. In the southern part of Nukhaib Graben area, it consists of 26 cycles. Each cycle consists of greenish grey, slightly calcareous and pebbly sandstone, in the upper parts, reddish brown sandy claystone lenses occur. The sandstone is overlain by pink, burrowed slightly sandy limestone.

— **Hab'bariyah Gravels (Pleistocene):** Al-Mubarak and Amin (1983) introduced the Hab'bariyah Gravels for the first time. These are well developed in the eastern part of the Iraqi Western Desert, and extend northwest wards (Fig.2). They consist of two layers: The first one (lower) is composed of loose, rounded to subrounded limestone pebbles with few chert pebbles, the size of the pebbles range from (12 – 20) cm. The thickness of this level ranges from (5 – 6) m, exceptionally reaches (8 – 12) m, in the northern bank of Wadi Ghadaf. This horizon is capped by calcrete layer, semi bedded, with few pebbles and a thickness of (0.5 – 1.5) m. The second (higher) gravelly layer is composed of loose, rounded to subrounded dolostone, limestone and chert pebbles. The size of the pebbles ranges from (0.5 – 3) cm, with a thickness of (1 – 3) m, but occasionally may reach (4 – 5) m. The source and origin of the pebbles are obscure. The authors have considered these gravels as the alluvial fans of Al-Hab'bariyah.

— **Valley Fill Sediments (Holocene):** The main valleys are filled by different clastic sediments. The main composition of the pebbles is carbonates with silicates; the pebbles are rounded to subrounded, with an average size of (1 – 10) cm, but may reach to 25 cm. The thickness ranges from (0.5 – 2.5) m, but locally may exceed 5 m, or even more.

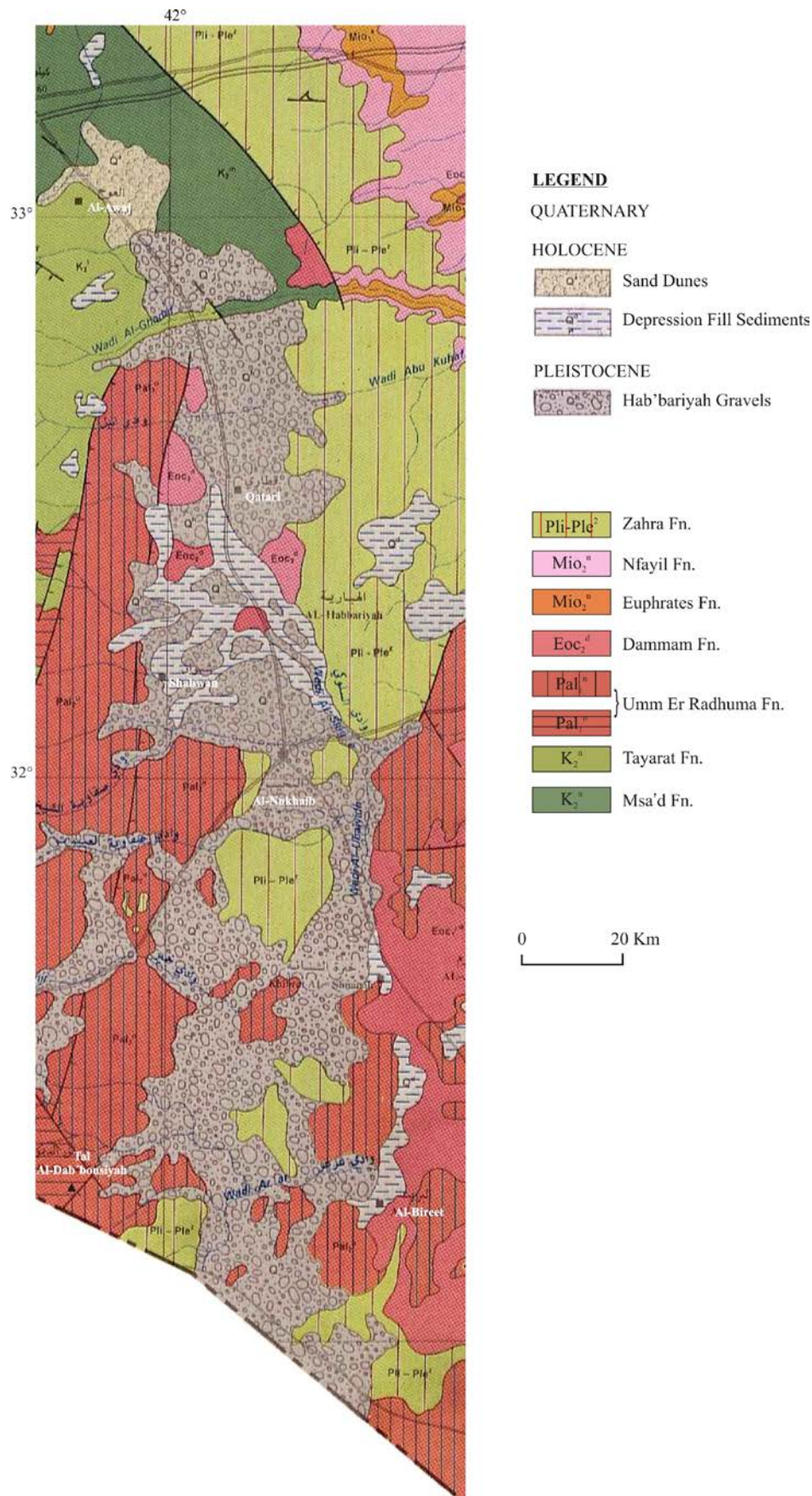


Fig.2: Geological map of the studied area (after Sissakian, 2000)

— **Depression Fill Sediments (Holocene):** The sediments are mainly of clay and silt, locally chert pebbles may occur in the surrounding of the small depression, within the main Hab'bariyah Depression. The thickness is (0.5 – 1.5) m, and rarely may exceed.

▪ **Structural Geology**

The studied area is located within the Stable Shelf of the Arabian Plate (Buday and Jassim, 1984; Al-Kadhimi *et al.*, 1996 and Jassim and Goff, 2006). Whereas according to Fouad (2012), it is located within the Inner Platform of the Arabian Plate. From the Neotectonic point of view, the studied area is uplifted. The amount of the uplift ranges from (325 – 400) m, whereas the rate of the uplift is about 0.2 cm/ 100 year (Sissakian and Deikran, 1998).

Many workers have studied the Hab'bariyah Depression and reported that it is formed due to tectonic effect, where both sides of the depression are limited by normal faults; forming a large graben (Al-Mubarak and Amin, 1983; Al-Bassam *et al.*, 1995; Sissakian and Deikran, 2009 and Abdul Jabbar and Zaini, 2009).

THE HAB'BARIYAH ALLUVIAL FANS

▪ **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 (1991) 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 local 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 a role in their formation. In the studied area, although recently the dry climate prevails, especially during the last decade, but during Pleistocene and Early Holocene, successive wet and dry phases were witnessed, as indicated from the presence of two stages of the alluvial fans, and the developed gypcrete layer in between them.

▪ **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 (Sissakian, 2011). 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-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). In the studied area, valleys flow from the plateau of the Western Desert that is highly dissected by dense valleys (Fig.3). The gradient drops gently along the western rim of the Hab'bariyah Depression (Fig.4) accompanied by widening of the feeding channels, consequently the energy decreases leading to deposition of the coarse sized materials and formation of the first stage alluvial fans. After this break in the slope, the transportation and deposition of the materials continue depending on the particle size, either to form the second stage fans or to be deposited as depression and/ or valley fill sediments (Fig.3).

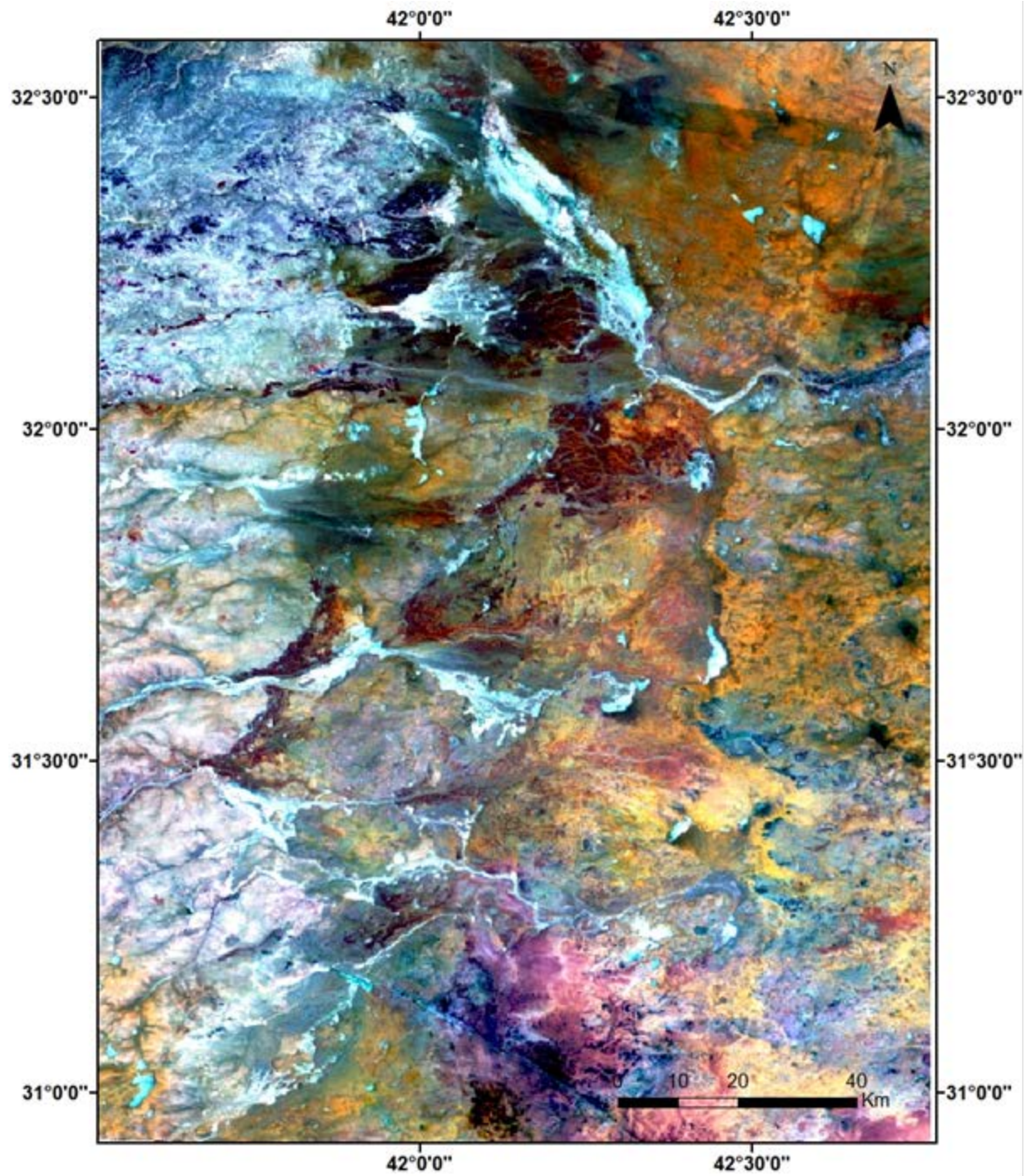


Fig.3: Landsat image, in Hab'bariyah vicinity, showing dense drainage system and two stages of alluvial fans (as indicated by the difference in the tones)

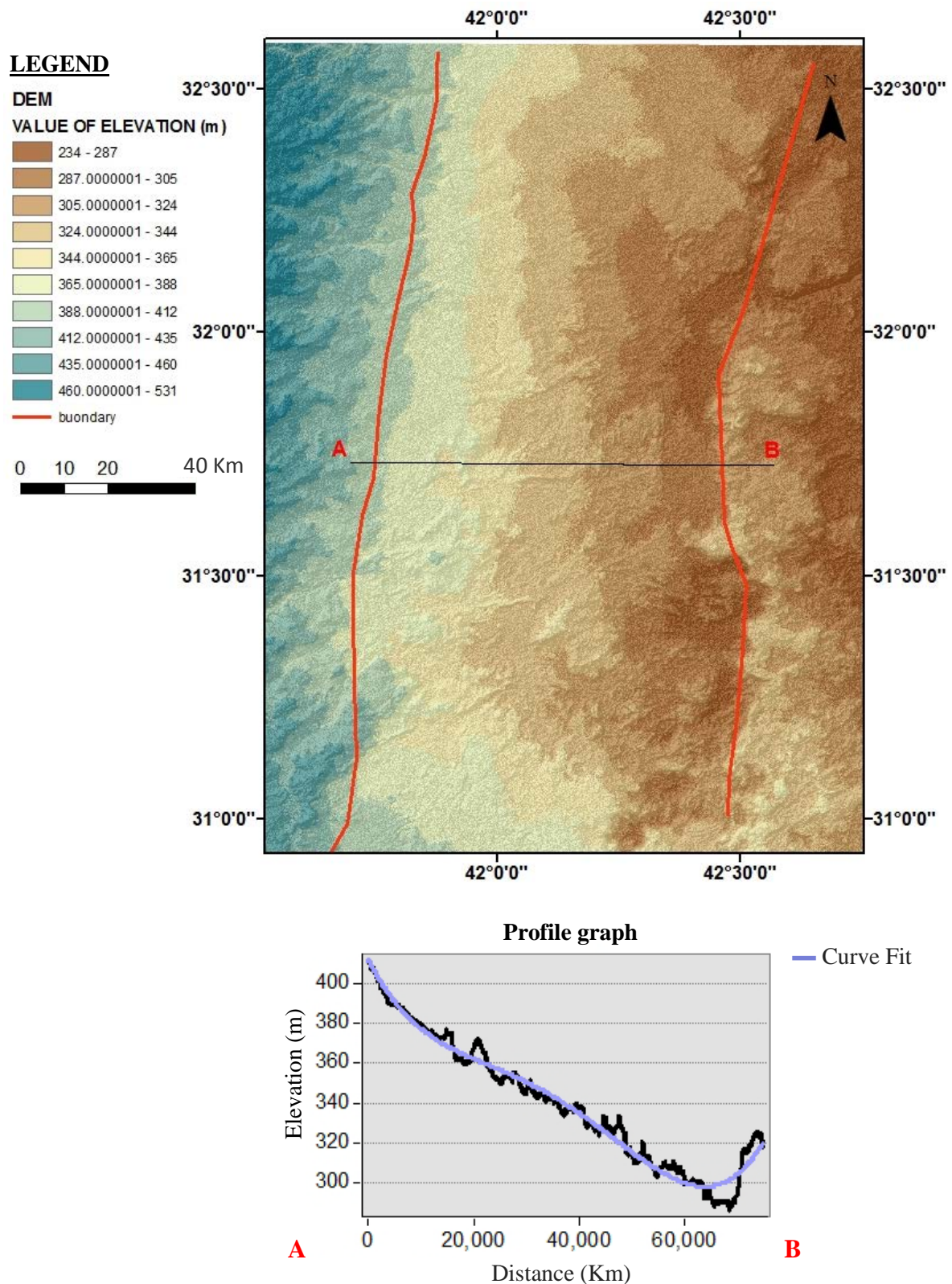


Fig.4: Topographic map of the Hab'bariyah Depression with a cross section (AB) (deduced from DEM, SRTM data)

■ Mode of Deposition

Alluvial fans are apron-like deposits of granular debris that extend from a high front to a low land below. Each fan radiates from a single source channel, and has fan-like shape in plain view. Its transverse profile is arched, the longitudinal profile is slightly concave, and slopes are usually less than 4° . 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 studied area, the Western Desert is the source area for the sediments of the alluvial fans; it forms a wide plateau covered by Cretaceous rocks, with height range of (400 – 550) m, almost with no vegetation cover, forming the range topography. In front of it, the Hab'bariyah Depression is the depositional basin, where the alluvial fans are formed. Therefore, the "basin-and-range topography" is not typically formed in the study area. This is attributed to the slight height difference between the basin and the range (about 180 – 200 m, along 175 Km) (Fig.4). Moreover, the range area is a plateau, not mountainous; consequently the gradient of the valleys, which dissect the range, is not high.

Following the concept of Ritter *et al.* (2002) in delineating the mode of the deposition of the alluvial fans of the studied area and based on the available data about the characteristics of the studied alluvial fans, the depositional model of the alluvial fans is constructed (Fig.5). The deposition starts and terminates almost with the "Stream Flow" with small time interval of "Transitional Flow" and for erosion, especially for the first stage alluvial fans, which did not receive any more sediments. In the last mode of deposition (stream flow), the alluvial fans are almost dormant and rarely receive more sediments, and underwent erosion (Fig.5), this is the case for the first stage alluvial fans. They can easily be recognized by their dark tones (Figs.3 and 6).

■ Shape and Size

Unfortunately, no detail descriptions for the constituents of the alluvial fans; of the studied area are available. However, the description of Al-Mubarak and Amin (1983) for the Hab'bariyah Gravels is considered. 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 studied area, the average size of the pebbles ranges from (12 – 20) cm, for the first stage (older) and (0.5 – 3) cm for the second stage. The pebbles are composed mainly of limestone, dolostone and chert. The thickness of the first stage ranges from (5 – 6) m, and may reach (8 – 12) m, whereas the thickness of the second stage ranges from (1 – 5) m (Al-Mubarak and Amin, 1983). The large pebbles were carried in a matrix of semi-fluid mud; therefore, they have typical fan shape, whereas the finer sizes were carried to more far distances, to form the prone parts. Part of the sediments was also carried and transported by valleys (streams) and deposited as either valley fills sediments or to form depression fill sediments of the Hab'bariyah Depression.

The first stage fans have ideal fan shape (Fig.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 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 (Fig.3). Because they are finer as compared to the constituents of the first stage, the insufficient renewal of the supplied materials that decrease as the climate changes 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.

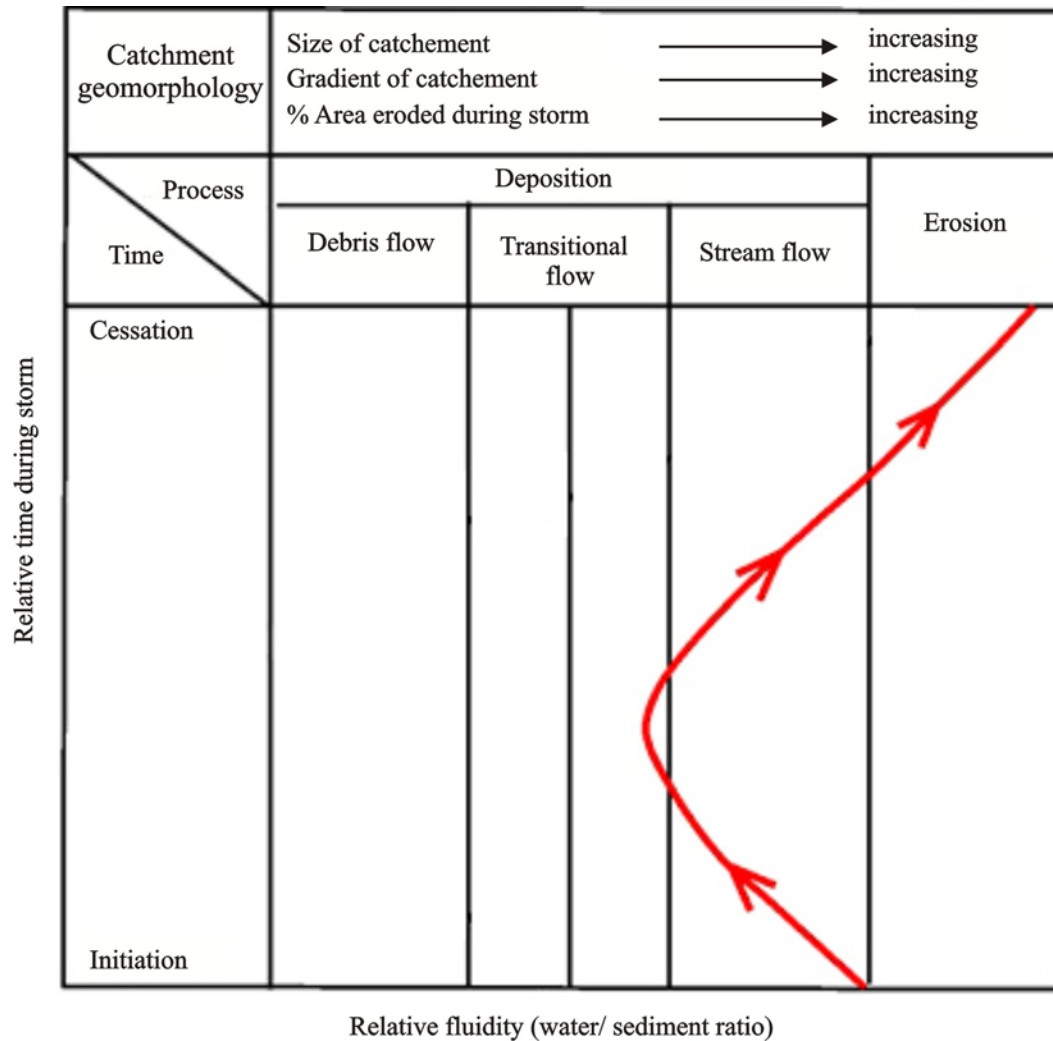


Fig.5: Conceptual model showing the change in the water/ sediments ratio, the sequence of depositional and erosional events and associated flow conditions, in alluvial fans of Hab'bariyah Depression (modified after Ritter *et al.*, 2002)

Alluvial fans are composite structures whose units differ in surface shape and structure. "Components of the fans include: **Active stream channels** that originate in the high lands 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 (Fig.3). The "internally formed dendritic channels" also could be seen everywhere in the fans of the studied area (Fig.3). 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 (Figs.3 and 6).

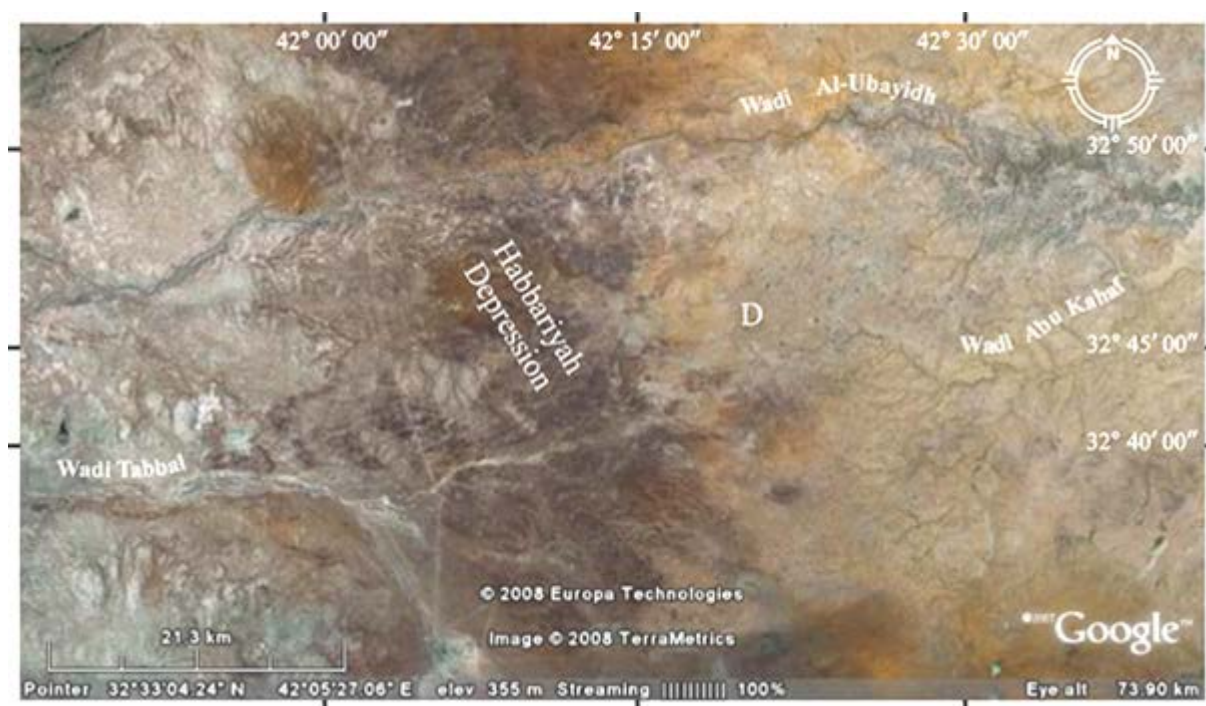


Fig.6: Google Earth image, in Hab'bariyah vicinity, note the divide area between wadi Tabbal and wadi Abu Kahaf (marked as D), also the complex alluvial fans system

▪ Water/ Sediments Ratio

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 fans of the studied area, because the transporting energy was not large, due to low gradient, therefore, the transported materials were small to medium sized, with (medium – low) concentration, consequently the water/ sediments ratio was high, leading to medium to low viscous transporting media (Fig.5). This (medium – low) viscous transporting media had transported (medium – low) sized materials (up to 20 cm) for a distance of (20 – 38) Km in form of "Stream Flow" and the deposited materials were of medium to fine sized. It is worth mentioning that the alluvial fans underwent erosion now, however, they may receive sediments, during heavy rain showers.

▪ 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 **Type II**. The classification depends mainly on: grain size; their shape and sorting, feeder channel length, drainage basin size, bed rock lithology and average slope, accordingly the studied alluvial fans could be classified as **Type II**.

▪ Coverage Area

The coverage area of the Hab'bariyah Depression is about 2530 Km², whereas the three fans (Fig.7) have the following coverage areas for the first and second stages, from north to south: 116.791, 226.696, 387.155, and 43.388, 106.653, 120.363 Km², respectively. The areas were measured using ArcGIS technique.

■ Gradient

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 studied area, transporting energy drops down continuously in the two stages. This is another reason that explains the deposition of the sediments, after the fans as normal valley and/ or depression fill sediments. The first break in the gradient is along the western rim of Hab'bariyah Depression (Figs.3 and 7), it is deduced using ArcGIS technique. The second break is in the depression, which had caused the development of the second stage fans (Fig.7). Such breaks indicate neotectonic activity (Sissakian and Deikran, 2009).

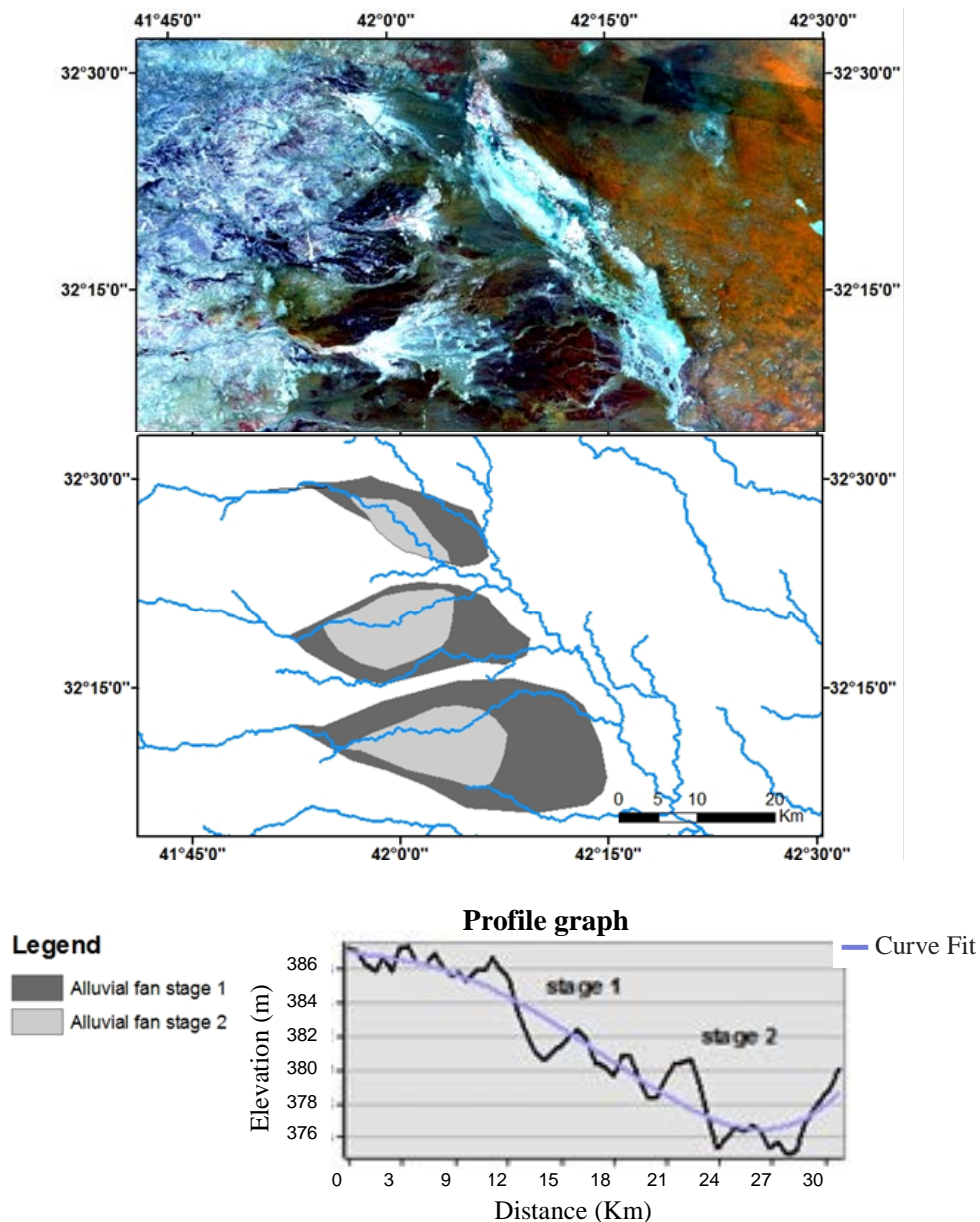


Fig.7: Three alluvial fans in Hab'bariyah Depression, showing two stages of alluvial fans and their gradient drop in the largest fan (deduced by ArcGIS technique) (Stage 1; older and Stage 2; younger)

▪ Streams and Channels

Within the alluvial fans of the studied area, the flowing active streams and/ or channels could be clearly seen in Google Earth and Landsat images (Figs.3, 4 and 8). 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. Also well developed dendritic and semi-radial 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 between active and inactive channels (USGS, 2004).

The "**feeder channel**" and "**intersection point**" could be seen also (Fig.8), where the incised channel intersects the original fan surface somewhere 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, but not so clearly (Fig.8). No filed data are available about the "**bar and swale**" micro-topography, within the alluvial fans of the studied area. The authors believe that their range is very low, due to the small – medium grain size distribution, it is expected to be (0 – 0.5) m.

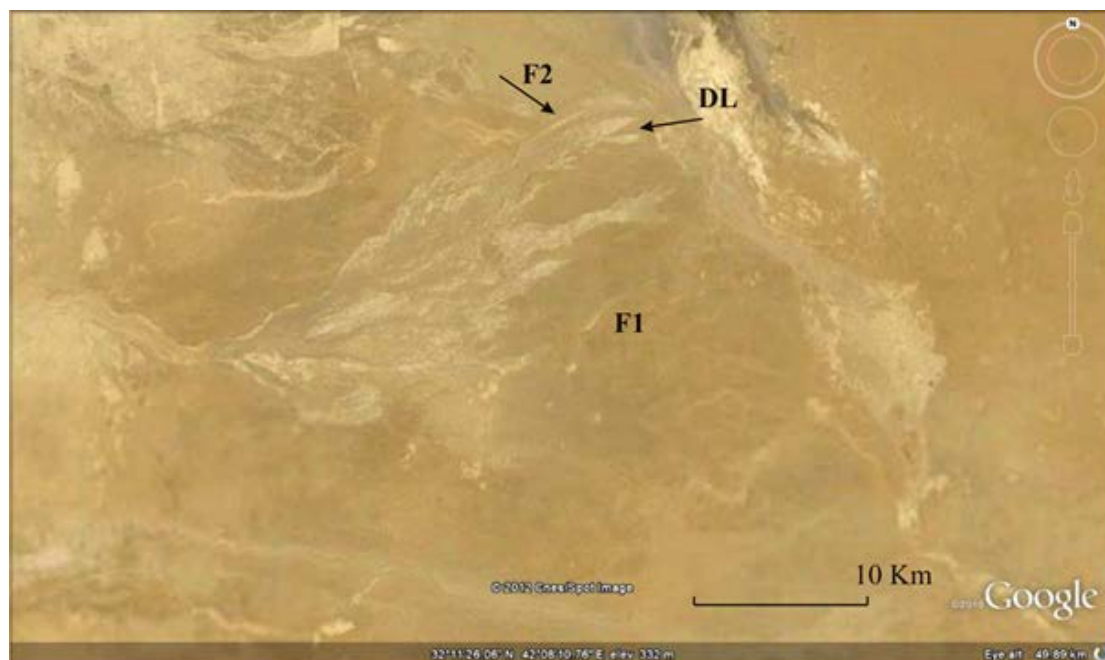


Fig.8: Alluvial fan of the younger (second) stage, overlapping an older (first stage) stage.
Note two main feeder channels (**F1** and **F2**), and active depositional lobe (**DL**)

▪ Source of the Fan's Materials

The main source of the alluvial fans is the Cretaceous and Paleogene formations that are exposed in the central part of the Western Desert. The exposed formations are Hartha, Tayarat, Digma, Umm Er Radhuma and Dammam (Fig.2). These formations contain considerable amount of soft rocks interbedded with hard rocks. Therefore, they are easily eroded, transported and deposited in the active Hab'bariyah Depression, as alluvial fans since "fans are better developed in tectonically active areas" (Bull, 1991 and Ritter *et al.*, 2002).

▪ **Dating**

Although precise dating techniques are not available to the authors, but they believe that the alluvial fans have variable ages. The age of the first stage fans is probably Early Pleistocene; whereas, that of the second stage fans is Late Pleistocene – Holocene or Early Holocene. This assumption is based mainly on the climatic changes during Pleistocene – Holocene with the related rate of sediments supply, beside the tone differences in the fans (USGS, 2004). It is also believed that the fans of the last stage still receive sediments, but not those of the first stage.

RESULTS

The Hab'bariyah Depression is tectonically an active depression, which receives the sediments of numerous valleys that drain the central part of the Western Desert. These valleys drop their sediments in the depression forming alluvial fans, due to drop in the gradient. Although the drop in the gradient is not high, still two stages of alluvial fans are developed, indicating neotectonic activity. The fans are composed of medium to fine sized materials, because the gradient difference between the source and depositional area is not high, therefore, the developed fans have not typical concave fan shape, but they are of flat surface.

DISCUSSION

Two stages of alluvial fans are developed in the Hab'bariyah Depression. The first stage is the older with more coarse sediments and more concave shape, as compared with the second (younger) stage (Figs.3, 8 and 9). The coarse size of the first stage indicates wet climate, as compared with the second stage, with more transportation ability. The presence of a gypcrete horizon between the two stages of alluvial fans (Al-Mubarak and Amin, 1983) indicates a dry phase (Pluvial) in between the two wet phases in which the two stages of fans were developed. The gypcrete horizon may indicate a Late Pleistocene – Early Holocene age, therefore, the second stage will have Early Holocene age, and they are still active, especially during heavy floods in the valleys of the Western Desert. These are also indicated by the light tone surface of the fans, as well the light tone valleys, which are good indication for their activity (USGS, 2004).

The development of the two stages of alluvial fans indicates a break in the gradient of the Hab'bariyah Depression; otherwise only one stage would be developed. However, the break in the gradient inside the depression should be accompanied by a subsidence in the depression, which means neotectonic activity. This is clearly visible in the discontinuity of majority of the valleys (Fig.5, point D), except Wadi Ghadaf and Wadi Ubaiyidh. Such activity is proved by Sissakian and Deikran (2009). The active graben origin of the depression is also proved by Al-Mubarak and Amin (1983); Al-Bassam *et al.* (1995) and Abdul Jabbar and Zaini (2009).

Although the studied area is located in the Inner Platform of the Arabian Plate, but it suffers from tectonic unrest. The active Abu Jir Fault Zone and its extension the Euphrates Fault Zone (east of the studied area) are good examples (Fouad, 2007). The continuous changes of valley trends and abnormal terrace accumulation along them, the dislocated valleys and controlling of their courses (Sissakian and Deikran, 2009), are good indications for Neotectonic movements in the vicinity. Such activities are attributed to Neotectonic movements by different researchers (Markovic *et al.*, 1996; Kumanan, 2001; Cohen *et al.*, 2002; Mello *et al.*, 1999; Bhattacharya *et al.*, 2005; Jones and Arzani, 2005; Philip and Vidri, 2007; Woldai and Dorjsuren, 2008 and Pavlides, 1989). Moreover, such intraplate regions, which were believed to be seismotectonically inactive, indicate, by new observations and

concepts of present-day deformation in intraplate regions, a significant level of Neotectonic activity, both seismic and unseismic; leading to significant deformation of the Earth's crust (Cloetingh, 2002).

Another prove for the neotectonic activity of the studied area and near surroundings is the regional trend of the valleys, which is eastwards, where almost all valleys discharge in the main Hab'bariyah Depression, except Wadi Al-Ubayidh and Wadi Al-Ghadaf (Figs.3, 5 and 7), these two valleys cross the depression and continue their courses eastwards. A good example is Wadi Tabbal and its continuation, east of Hab'bariyah Depression, Wadi Abu Kahaf; originally these two valleys were one, but due to subsidence of the depression, the main valley is divided into two valleys (Sissakian and Deikran, 2009) (Fig.5). The authors believe that previously the valleys were continuously flowing eastwards and discharging either to Razzaza Depression or the Euphrates River. However, due to subsidence of the Hab'bariyah Depression the valleys are terminated in the depression. The subsidence of the depression is also indicated by thick accumulation of gravels, called Hab'bariyah Gravels (Al-Mubarak and Amin, 1983 and Sissakian, 2000). Actually, these two stages of gravels are the two stages of alluvial fans, which are developed in areas where the valleys merge to Hab'bariyah Depression, many of the fans are still active, as indicated by their tones (Figs.3, 5, 7, 8 and 9). Such active fans may indicate active subsidence, indicating Neotectonic movements (Mello, 1999; Jones and Arzani, 2005; Philip and Virdi, 2007 in Woldai and Dorjsuren, 2008)

Figure (9) shows clearly the two stages of alluvial fans, the lighter in tone are the younger (second stage). It is also very clearly visible the overlapping of the second stage over the first stage, which is inactive. This is attributed to continuous subsidence, either to tectonic effect (Al-Bassm *et al.*, 1995 and Abdul Jabbar and Zaini, 2009) or due to karstification (Al-Sheikh and Al-Mashhadani, 2012). It is also possible that both factors have contributed in the subsidence, such combination effects to form large depressions are well known worldwide (White and White, 2006).



Fig.9: Two stages of alluvial fans, note the dark and light tones (first and second stages, respectively)

Figure (9) also shows that the second stage alluvial fans are concave – longitudinal in shape with flat top; rather than concave cone shape, indicating fine sediments, with high water/ sediments ratio and medium to low viscous transporting media (Fig.5). This medium to low viscous transporting media had transported medium to low sized materials (up to 20 cm) for a distance of (20 – 38) Km in form of "**Stream Flow**" and the deposited materials were of medium to fine sized, with very small mode of "**Transitional Flow**" (Fig.5).

Figure (9) also shows the overlapping of the fans of the two stages (Point **A**) and the erosion of the marginal parts of the fans by means of the flooded water in the Hab'bariyah Depression, points **E1** and **E2**, for the first and second stages of alluvial fans. The overlapping of the fans is another indication for continuous subsidence; consequently change in the gradient, which had caused the development of the second stage fans.

Figure (10) shows an alluvial fan of the second stage with active and dormant (inactive) parts, as indicated by light and dark tones, respectively. The tone difference is used in detecting of the activity of the fans by USGS (2004). The "feeder channel" (Point **F**) and the "intersection point" (Point **I**) are also clearly visible. Moreover, the erosion of the distal part of the fan by means of the flowing water inside the depression (Point **E**). Within the inactive part, however, the abandoned "feeder channel" is also clearly visible (Point **AF**). These features are good indications for the neotectonic activity of the area, and confirm the continuous subsidence of the Hab'bariyah Depression.



Fig.10: Alluvial fan of the second stage, note the active and still (dormant) parts (light and dark tones, respectively)

A big alluvial fan of the second stage is overlapping the first stage inactive fan (Fig.8) as indicated by the light and dark tones, respectively. Note that the "Feeder channel" terminates at the end of the active second stage; in the middle part of the fan (Point **F1**), whereas in the northern half part of the fan, which is still active, the "**Feeder channel**" extends to the end of

the fan (Point **F2**, Fig.8). The "**Active Depositional Lobe**" (Point **DL**) could be seen only in down-fan segment, where the fan experiences aggradation, in the northern active part, at the marginal part (Fig.8). There, the erosion cuts the marginal parts of the fan by means of the flooded water in the Hab'bariyah Depression, during heavy showers, which are almost extremely rare in the last decade.

CONCLUSIONS

This study has the following conclusions:

- Two stages of alluvial fans are developed in the Hab'bariyah Depression. The first stage is inactive (dormant), whereas the second stage is active.
- The two stages of alluvial fans are separated by a horizon of gypcrete, indicating a break in sedimentation due to dry climate.
- The two stages of the alluvial fans are developed due to break in the gradient within the Hab'bariyah Depression. The break of the gradient is attributed to continuous subsidence of the depression. The subsidence of the depression, most probably is due to tectonic effect (a graben), or due to karstification. However, the effect of both factors could not be ignored.
- The overlapping of the alluvial fans, presence of two stages of fans, and more than one feeder channel are indications for neotectonic activity in the studied area.
- The age of the alluvial fans is most probably Early Pleistocene, for the first stage and Late Pleistocene – Holocene or Early Holocene for the second stage, parts of which are still active, although the present day climate witnesses a dry condition.

ACKNOWLEDGEMENT

The crucial comments of Mr. Sabah Y. Yacoub amended this article, he is gratefully thanked. The authors also highly acknowledge Mr. Hayder H. Taha for his skill work in presentation of the figures and arranging the text.

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