GEOMORPHOLOGY OF THE HIGH FOLDED ZONE

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ABSTRACT

The geomorphology of the Iraqi High Folded Zone (HFZ) is reviewed in the present article. The High Folded Zone is characterized mainly by mountainous topographic nature. The nature of the topography reflects the type of the exposed rocks and the structural effect. Generally, two main different topographical parts could be recognized, this is attributed to the presence of longitudinal and narrow anticlines and shallow synclines, locally faulted. Moreover, the surface of the HFZ area is dissected by complicated drainage patterns with variable density; they drain the area towards the main streams and rivers, and then toward the Tigris, Greater Zab, Lower Zab and Sirwan rivers. The chemical and mechanical weathering are active, the water is the main erosional agent being also an active process.

A generalized geomorphologic map of the HFZ is compiled, at scale of 1: 1000 000. The map elucidates the spatial distribution of the main geomorphologic units and the related morphologic features. The geomorphologic units are classified genetically into six classes, which include different landforms. The recognized genetic units are: **Structural – Denudational, Denudational, Fluvial, Solution, and Man-made origins,** and possible **Glacial moraine.** Each of these units includes different lithomorphologic landforms, which were developed due to weathering, erosion and depositional processes, in conjunction with tectonic, structural, lithological, and climatic factors.

The present study revealed that the geomorphologic evolution of the HFZ was greatly influenced by the last phase of intensive orogenic movement that took place during Late Miocene – Pliocene, and continued during the Quaternary Period with less intensity. During the Quaternary Period, the climate became a leading factor in controlling the majority of geomorphologic processes, particularly the fluvial. The Quaternary long-term climatic changes are deduced by well-developed river terrace stages along the main rivers and their tributaries, and some large streams and valleys, beside numerous alluvial fans and calcrete.

جيومورفولوجية نطاق الطيات العالية

فاروجان خاجيك سيساكيان، طلال حسن كاظم ومواهب فاضل عبد الجبار

المستخلص

شملت هذه الدراسة مراجعة جيومورفولوجية منطقة نطاق الطيات العالية في شمال وشمال شرق العراق. وأهم الظواهر السطحية الرئيسية في هذه المنطقة تتمثل بكونها منطقة جبلية ذات تضاريس عالية وتتميز بوعورتها، بشكل عام وتتخللها بعض السهول المنبسطة أو قليلة التموج، خاصة عندما تتكشف فيها صخور ذات صلادة واطئة، والتي تكون مغطاة بشكل عام بترسبات العصر الرباعي. إضافة إلى ذلك، فإن سطح المنطقة مقطع بواسطة شبكات التصريف السطحي المعقدة ذات الكثافات العالية، وفي مناطق عديدة تكون على شكل مضايق مختلفة الاحجام والأصل، حيث تقوم شبكات التصريف بصرف مياه المنطقة باتجاه الأنهار والجداول الرئيسية وبالتالي تصب في حوض نهر دجلة، اضافة الى انهار الزاب ألأعلى والزاب ألأسفل وسيروان والتي بدورها تصب في نهر دجلة خارج المنطقة.

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تم توليف خريطة جيومورفولوجية مبسطة لمنطقة نطاق الطيات العالية من مقياس 1: 000 1000، وقد وضحت هذه الخريطة التوزيع المكاني للوحدات الجيومورفولوجية الرئيسية، إضافة إلى بعض الأشكال السطحية الأخرى. وتم تصنيف الوحدات الجيومورفولوجية اعتمادا على المنشأ إلى ستة أصناف وهي الوحدات ذات الأصول، **التركيبية – التعروية**، **التعروية، النهرية، الإذابية**، وتلك **الناتجة عن فعل الإنسان**، وقد توجد **ترسبات الثلاجات** أيضا، وتشمل كل من هذه الوحدات الجيومورفولوجية على عدة أشكال أرضية ذات صخارية مختلفة. وقد تكونت هذه الأشكال نتيجة لفعل عمليات التجوية والتعرية والترسيب المقرونة بالعوامل البنيوية والتركيبية والصخارية والمناخية.

وقد توصلت هذه الدراسة إلى أن نشوء جيومورفولوجية منطقة الطيات العالية قد تأثر بشكل كبير بالمرحلة الأخيرة من الحركة ألأوروجينية البانية للجبال (Alpine Orogeny) التي حدثت خلال عصر المايوسين المتأخر وعصر البلايوسين واستمرت خلال العصر الرباعي ولكن بشدة أقل. خلال العصر الرباعي، أصبح للمناخ دورا متصدرا في السيطرة على غالبية العمليات الجيومورفولوجية. وقد شهد العصر الرباعي عدة تغيرات مناخية طويلة الأمد تم استنتاجها من خلال تكون عدة مناسيب للمدرجات (المصاطب) النهرية على امتداد الأنهار والجداول الموسمية وبعض ألوديان الرئيسية، وكذلك عشران المراوح الغرينية وترسبات الكالكريت.

INTRODUCTION

The geomorphological units, features and historical development of the High Folded Zone (HFZ) are quite similar to those of the Low Folded Zone, because geomorphologically the two zones form extension and continuation to each other. Therefore, the authors followed same manner used by Yacoub *et al*. (2011) in writing the geomorphology of the Low Folded Zone to keep the harmony in between the two zones. Moreover, the presented geomorphological map was matched with that of the Low Folded Zone in devoting the geomorphological units, as much as possible.

The present study is an attempt to review the geomorphology of the Iraqi High Folded Zone (HFZ), depending, basically on the data achieved through the comprehensive regional geological survey (1970 – 1982) and subsequent geological compilation of the Geological Maps at scale of 1: 250 000 (GEOSURV, 1992 – 1998), which were conducted by GEOSURV's geological staff. The regional geological survey introduced a brief description of the geomorphologic landforms and poor evaluation of the geomorphic processes acted in the HFZ. However, the authors used the geological maps and the detailed description of lithology, stratigraphy and structural geology of the exposed formations to elucidate the geomorphologic featured of the HFZ area. Moreover, further useful geomorphologic information is acquired by the field checking carried out during 2006 – 2013, which was forwarded to update the Geological Map of Iraq (Sissakian and Fouad, 2012).

GEOSURV has introduced two geomorphologic maps of Iraq at scale of 1: 1000 000. The first is a reconnaissance Geomorphologic Map (Witold and Hassan, 1986) and the second is the Geomorphologic Map (Hamza, 1997). Al-Ma'amar *et al*. (2009 and 2011), and Al-Jaf and Kadhim (2010) conducted geomorphological mapping at scale of 1: 250 000 in restricted parts of the HFZ, using remote sensing and GIS techniques.

The authors compiled and presented a geomorphological map of the HFZ, using GIS technique. The base map, upon which the geomorphological map depends is the geological map (Sissakian and Fouad, 2012), with some modifications to the geological units to be in accordance with the geomorphological units. Moreover, the authors have also presented a slope map of the HFZ.

Moreover, significant data concerning geomorphological aspects are mentioned in many geological maps at scale of 1: 250 000, among them are Kirkuk (Sissakian, 1993), Mosul (Sissakian, 1995), Khanaqeen (Barwari and Slewa, 1995), Zakho (Al-Mousawi *et al*., 2007) and Kani Rash (Fouad, 2007). The authors updated the geomorphologic evaluation of the HFZ using visual interpretations of Landsat (TM and ETM) and Quickbird images, supported by field observations. Moreover, the authors used the updated geological maps at scale of 1: 250 000, Erbil and Mahabad, and Sulaimaniyah Quadrangles (Sissakian and Fouad, 2014a and b, respectively). Those maps with their attached reports include significant data concerning different geomorphological aspects in the studied areas, which are part of the HFZ.

The present article includes tens of illustrations the majority of which are field photos, and few are Google Earth and Landsat images. Some of these photos are hazy, because they were taken during winter season.

- **Location**

The High Folded Zone, from physiographical point of view, includes the **High Amplitude Mountainous Province** (Sissakian and Fouad, 2012), which is situated between the Extremely Rugged Mountainous Province, to the north and the Low Mountainous Provinces, in the south. Both the northeastern and southwestern boundaries are not marked by distinct and sharp morphologic features; however, they almost coincide with the tectonic zones of Iraq (Fouad, 2012). The HFZ covers about 15827 Km^2, with width range of (32 – 71) Km and length of about 400 Km (Fig.1).

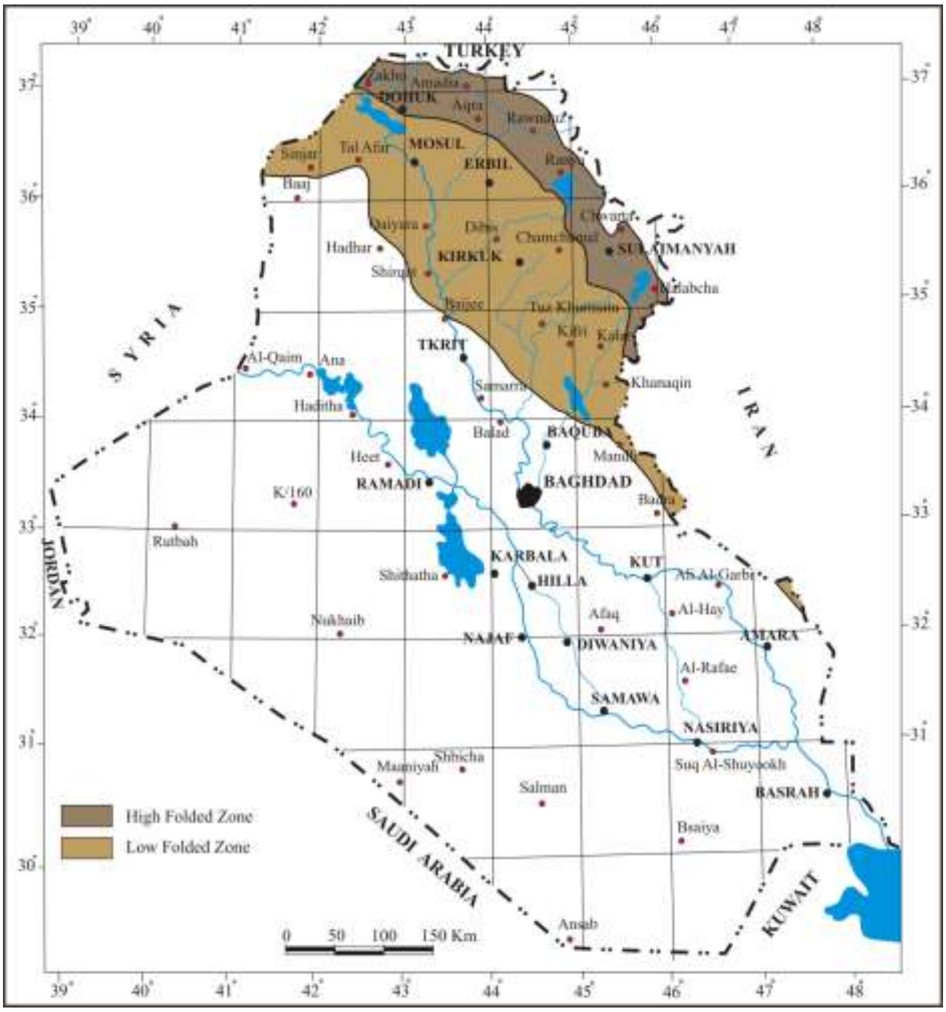


Fig.1: Location map of the High Folded Zone (after Fouad, 2012a)

▪ **Climate**

According to the updated World Map of the "Koppen – Geiger Climate Classification" (Kottek *et al*., 2006), the majority of the High Folded Zone lies within the region of the main semiarid climate, with steppe precipitation and hot arid temperature conditions. This global classification depends on the temperature and precipitation data for the period 2002 – 2009; except of Sulaimaniyah station, which is for the period 2001 – 2007, on regular 0.5-degree latitude/ longitude grid. The HFZ lies between the arid to the savannah climate morphogenetic regions according to the Peltier diagram (Peltier, 1950 in Fookes *et al*., 1971). Nevertheless, during the last decades, significant changes have occurred concerning decrease in rainfall and increase in dust storms (Sissakian *et al*., 2013).

The climatic data used to identify the climatic zone of the HFZ area, are acquired from the climatic records of three meteorological stations located within the HFZ area (Table 1 and Fig.2), although the first station is just on the borders of the HFZ. From reviewing the meteorological data, there are some variations in recorded values of the main climatic elements between the southeastern part towards north and northeastern parts of the HFZ. It seems that there is gradual decrease in mean values of the temperature from 20.2 °C, in Sulaimaniyah station to 17.7 °C, in Salah Al-Deen station; on the contrary, there is a considerable increase in the mean annual rainfall from 428 mm, in Erbil station to 688 mm, in Sulaimaniyah station. These variations are mainly attributed to the difference in elevation of the ground level, which is generally increasing towards the north and northeast (Fig.3).

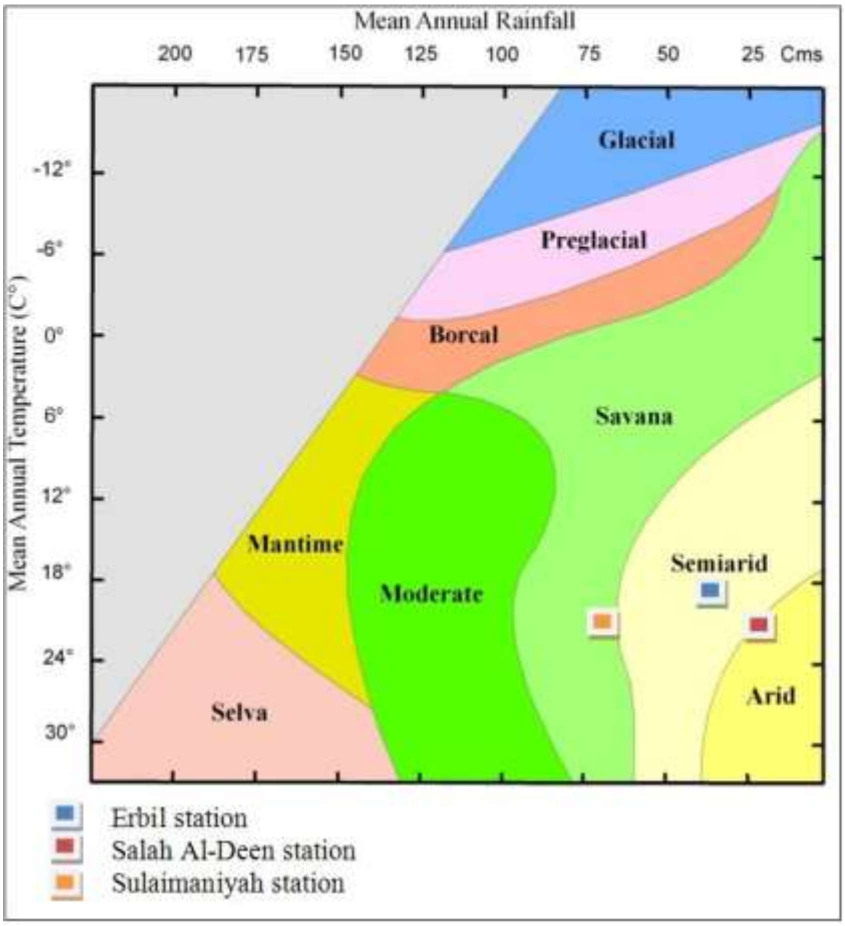


Fig.2: Climatic boundaries of the morphogenetic regions of the HFZ
(After Peltier, 1950 in Fookes *et al*., 1971)

Table 1: Climatic data of the High folded Zone area for the period
(Obtained from Iraqi metrological stations, 2001 – 2009)

	Months / Monthly Total of	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	Total Annual
Periods (2001–2007) Sulaimaniyah station	Rainfall (mm)	142	123	84.3	92.3	45.3	0.0	0.0	0.0	0.5	24.3	60.2	116	688
	Evaporation (mm)	1.7	2.5	3.4	4.7	7.2	10.9	12.4	11.2	8.5	4.9	2.4	3.0	73.2
	Temperature (°C)	6.3	8.1	12.9	18.5	23.3	29.7	32.8	33.0	28.3	25.2	13.7	9.9	20.2
	Humidity (%)	68.2	69.9	53.8	58.4	41.0	27.9	25.3	24.7	24.3	37.6	52.5	69.7	46.1
Periods (2002 – 2009) Erbil station	Rainfall (mm)	72.1	68.4	65.4	48.7	16.0	3.3	1.9	3.9	9.9	28.0	46.2	64.4	428
	Evaporation (mm)	1.6	2.4	4.0	5.4	8.8	12.3	13.5	12.7	9.9	6.3	3.0	1.7	81.6
	Temperature (°C)	7.8	9.0	12.8	18.3	26.3	30.9	34.2	33.8	29.1	23.6	15.3	9.9	20.9
	Humidity (%)	68.2	69.9	53.8	58.4	41.0	27.9	25.3	24.7	24.3	37.6	52.5	69.7	46.1
Periods (2002 – 2009) Salah Al-Deen station	Rainfall (mm)	116	114	88.3	63.5	23.9	2.3	4.2	0.2	9.4	40.9	58.4	82.9	601
	Evaporation (mm)	1.2	1.5	3.0	3.9	6.7	9.8	10.3	9.4	7.0	4.6	2.1	1.4	60.9
	Temperature (°C)	5.1	6.0	10.1	15.3	21.4	26.9	30.9	30.8	26.3	20.1	11.7	7.4	17.7
	Humidity (%)	68.2	69.9	53.8	58.4	41.0	27.9	25.3	24.7	24.3	37.6	52.5	69.7	46.1
Temperature (°C) is the mean of max. and min. temperatures Rainfall is total														

GENERAL TOPOGRAPHY

The topographic surface of the HFZ generally rises in elevation towards north and northeast. The lowest areas range in height from (215 – 230) m (a.s.l.) to the highest elevated areas, which range from (2000 – 2500) m (a.s.l.) with some exceptionally high peaks of the mountains that reach 2763 m (Fig.3), as in Pera Magroon Mountain. The main structural pattern, lithology and geomorphologic processes affect the topography, all the factors played important roles in the development of the surface features. The main topographic features are the elongated and elevated mountainous chains reflecting the anticlinal structures, which are separated by synclinal troughs forming flat plains with local slight undulations.

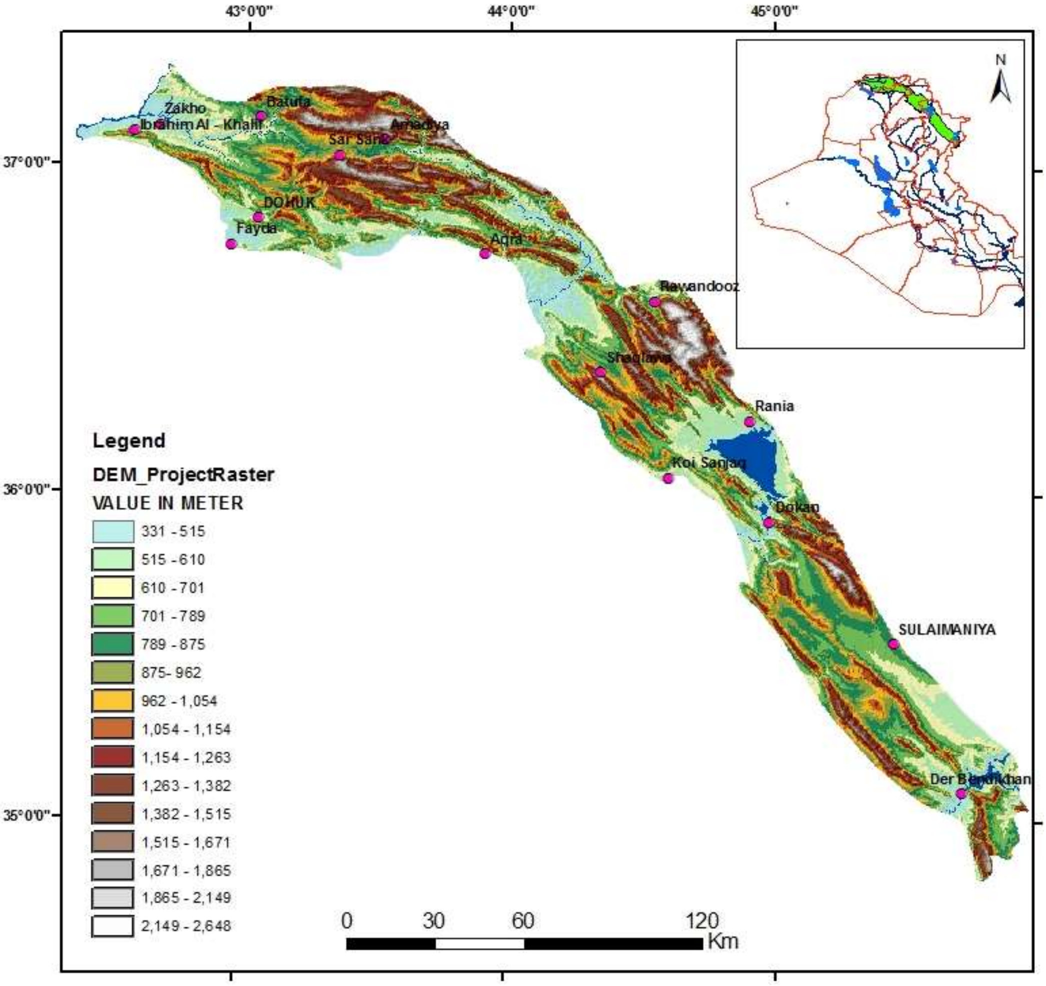


Fig.3: Elevation map of the HFZ, expressed in different heights (m, a.s.l.)
(extracted from DEM, 30 m)

- **The Mountainous Part**

The highly rugged and rocky terrain dissected by dense V- and U-shaped valleys and deeply cut rivers and streams, which locally form gorges and canyons characterize the mountainous part. The height of the mountains is greatly variable, ranging from (1000 – 1750) m above the surrounding areas, which represent the local relief of the mountains. The highest peak is in Pera Magroon Mountain; attaining (2763) m, whereas others, such as Safeen, Korak, Peris, Gara, Surdash, Khali Kan, Qara Dagh, range from (1000 – 2200) m (Fig.3).

- **The Flat and Undulated Plains Part**

These plains represent gently sloping lands combined with low relief. Different types of Quaternary sediments cover the plains; fine clastics dominate the surface sediments, especially the residual soil, which is brown in color, mainly clayey; rich in lime, due to the abundance of the carbonate rocks in the area. The plains often cover wide areas that reach several hundred square kilometers (Fig.3), mostly cultivated. The surface of the plains is dissected by widely spaced shallow drainage system, forming low relief. These systems are restricted to the surroundings of Dokan, Darbandi Khan, Mosul and Dohuk lakes (Fig.3), beside the troughs of some wide synclines and/ or undulatory plains that are built up by soft rocks, such as Tanjero, Kolosh and Gercus formations.

▪ **Slopes**

The slope is one of the most important topographic attribute used in geomorphologic evaluation and modeling of areas of variable relief (Huggett, 2007). The Digital Elevation Model (DEM) provides good opportunity to classify the slopes of the HFZ area that is characterized by variable relief ranging from flat to steep. The slopes are expressed in degrees and classified into six classes (Fig.4). The zonation of these classes are suggested by the authors depending on the topographic nature of the HFZ, taking into consideration the resolution of the available DEM (30 m) data and the scale of the final layout. The **first class** is (0 – 1)° represents the flat plains and the flood plains of the main rivers and the surroundings of the lakes. The **second class** is (1.01 – 3)° represents the foothills' slopes and the upper parts of the pediment plains. The **third class** is (3.01 – 5)° represents the margins of the main mountains, which are characterized by undulated terrain, and low tilted and moderately dissected strata. The **fourth class** is (5.01 – 15)°, it is developed in rugged and highly dissected and moderately tilted strata (dip slopes of cuestas and hogbacks) along the flanks of the main anticlinal structures. The **fifth class** is (15.01 – 30)° and **sixth class is** (> 30.01)°, both are restricted in the cores of the high anticlines, such as Safeen, Khalikan, Pera Magroon, Gara, Matin, Korak, Peris, where steep structural slopes, erosional cliffs, and structural scarps are well developed. Moreover, these slopes occur along the deeply cut valleys, gorges and canyons. The statistical analysis shows that the second class prevails; as compared with the others.

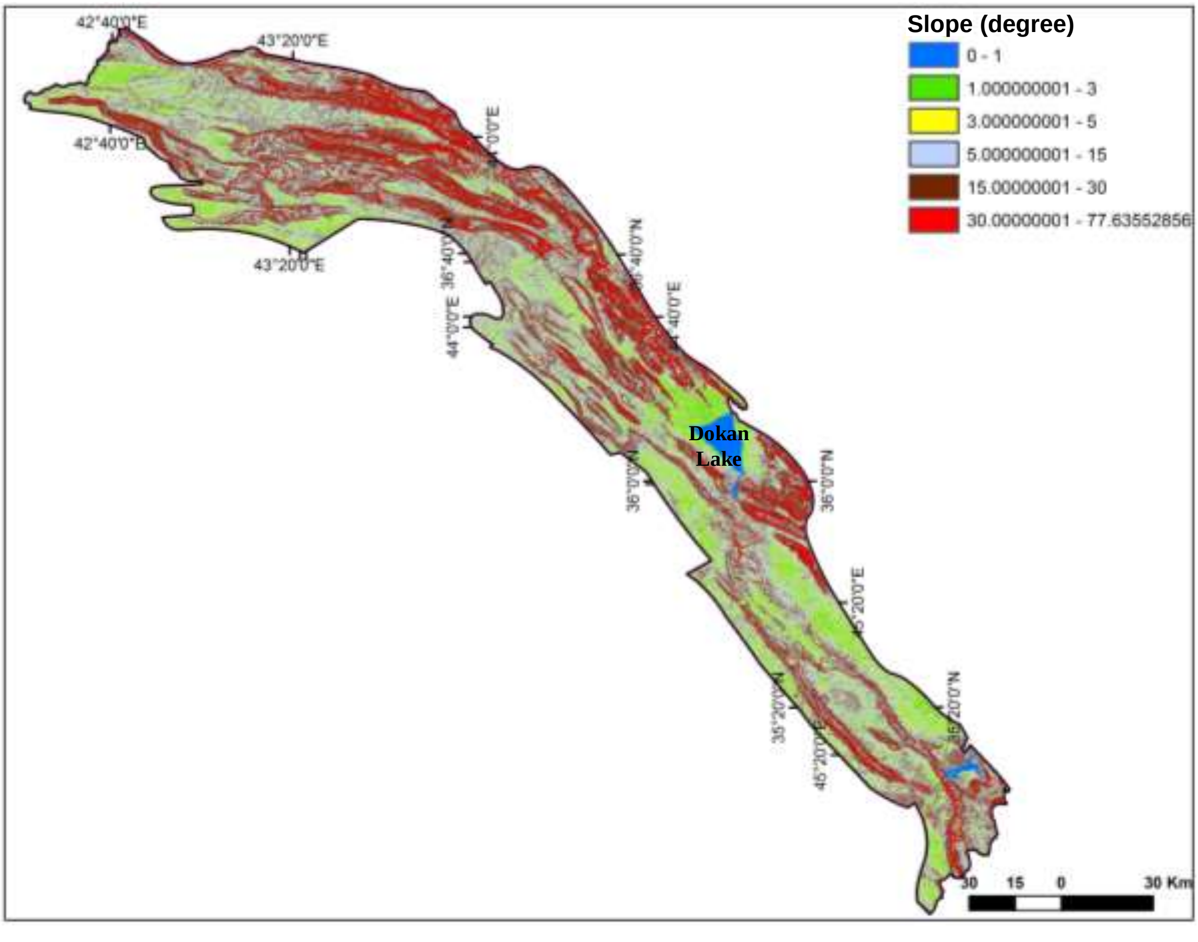


Fig.4: Slope Map of the HFZ (Compiled from DEM, 30 m)

Moreover, the authors compiled the hill-shade (Fig.5) and the paint map (Fig.6) using Arcmap GIS. In both maps, the elevated and flat and undulatory areas are clearly visible. The dark grey tone in the Hill-shade map differentiates the elevated areas, which are dissected by dense drainage, whereas, the smooth grey tone characterizes the flat and undulatory areas (Fig.5). Moreover, the wide very smooth grey tone characterizes the lakes and their near surroundings; very clearly; as it is in Dokan lake and less clearly in Darbandi Khan lake, besides, the repetition of light and dark parallel grey lines, which reflect the dense drainage. The former's represent the valleys, whereas the latter's represent the erosional cliffs.

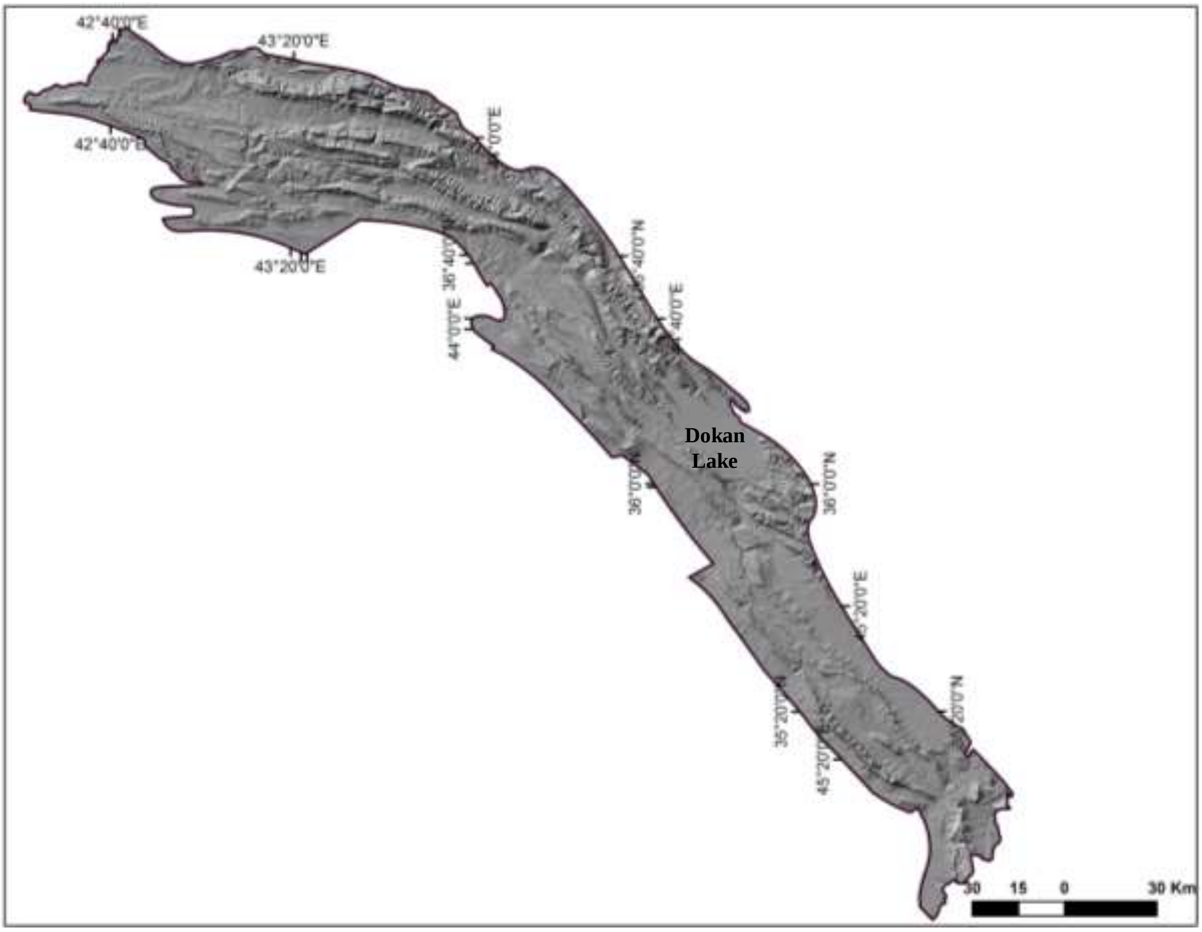


Fig.5: Hill-shade map of the HFZ (Compiled from DEM, 30 m)

The Paint map of the HFZ (Fig.6) differentiates the elevated areas from the flat and undulatory plains by different colors and their tones. The blue and violet colors characterize the elevated areas, whereas the grey and greenish grey colors characterize the flat and undulatory plains. However, the green color characterizes the lakes and their near surroundings (Fig.6).

The dens drainage is even clearly visible in the repetition of parallel lines of blue and light blue colors. The former's represent the valleys, whereas the latter's represent the erosional cliffs (Fig.6).

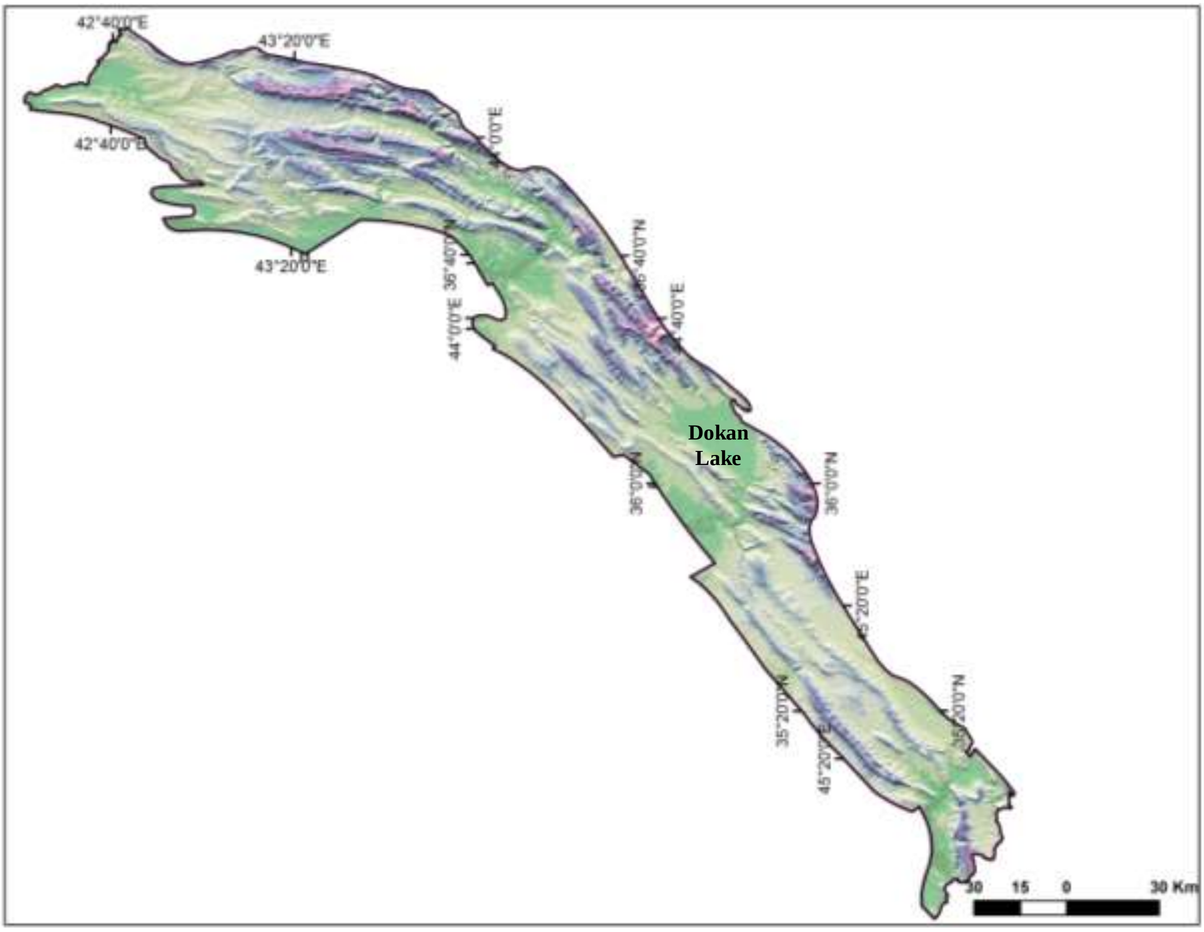


Fig.6: Paint map of the HFZ (Compiled from DEM, 30 m)

- **Drainage**

The HFZ is well drained by the Greater Zab, Lesser Zab, and Sirwan rivers, and some other streams such as Rawandooz, Haji Beg, Amadiya, Dohuk, and related drainage patterns. Numerous ephemeral steams and valleys drain the HFZ; all of them flow towards the Tigris River off the involved area. The ephemeral streams and dry valleys of the HFZ are often flooded quickly after heavy rain showers, because they run down from wide catchment's areas in the adjacent mountains, inside and off the Iraqi territory.

The shape of the valleys is widely variable, in the HFZ, depending mainly on the type of rock. Usually, they are U- and V-shaped, in addition to many other types; like gorges and canyons. Narrow V-shaped valleys are developed in the higher altitude of the stream basins, where the erosive activity is stronger vertically than horizontally (Pavlopoulos *et al*., 2009). In the lower altitudes and especially in loose material, the U-shape is wide and broad, like in Shiranish, Tanjero, Kolosh, and Gercus formations and terrace sediments.

Figure (7) shows a generalized drainage network of the HFZ, compiled from DEM using Arcmap GIS. The authors believe that the pre folding drainage system in the HFZ is likely to have been a dendritic system with the dominant direction of the flow to be approximately from NE to SW. The development of NW – SE trending folds has caused the present drainage pattern to deviate significantly from the original pattern producing drainage basins that mimic the fold trends. The dip valleys usually flow on the bedding planes of the hard rocks. These dip valleys transect a considerable part of the structure forming a series of gorges Fig. (7).

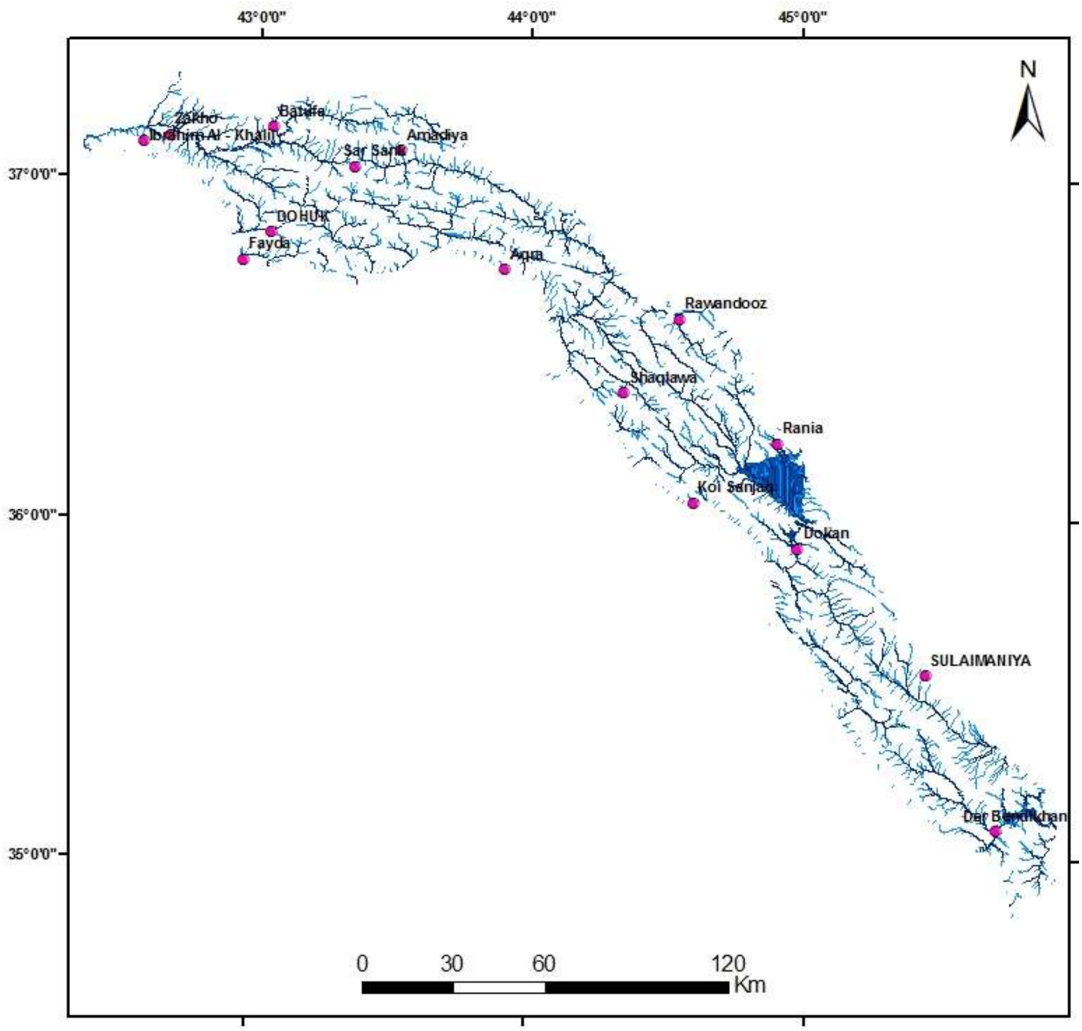


Fig.7: Drainage map of the HFZ (Compiled from DEM, 30 m)

The types of the drainage patterns are also variable, reflecting the lithological and climatic conditions prevailing in the area, beside the tectonic activity and more precisely the Neotectonic activity. The major types of drainage patterns are shown in Fig. (8) and described hereinafter.

─ **Dendritic Pattern:** This type is often developed in homogenous and uniformly resistant strata and unconsolidated sediments, where the structural control has less effect, such as in Shiranish, Tanjero, Kolosh, Gercus, and Bai Hassan Formations. Dense branching of tributaries occurs on steep slopes and in impervious rock types, whereas, in clastic sediments and gentle slopes, the wide spaced drainage network is developed (Fig.8A). It is also developed in active crown areas of landslides and on upper reaches of galleys and large valleys.

─ **Parallel Pattern:** The main valleys, which usually flow in the synclines and very locally in cores of eroded anticlines (such as Gara and Qara Dagh), and those developed along dip slopes of hard rocks have parallel drainage patterns, locally regularly spaced, especially in jointed and well bedded hard rocks. This type is structurally controlled and commonly developed on the limbs of the main structures (Fig.8B). Those parallel valleys, which are developed on slopes of hard rocks, and locally even soft rocks, but not on high slopes, represent the majority of the drainage pattern in the HFZ.

Gorges and canyons are usually developed in the mountainous parts, especially when crossing massive rocks (Fig.8D and E). Sissakian and Abdul Jab'bar (2010) studied assorted gorges and canyons from the northern and northeastern parts of Iraq, the majority of them lie within the HFZ. They concluded that the main reasons for the development of the canyons and gorges are: **1)** Tectonic influence, **2)** Neotectonic influence, **3)** and Geomorphological aspects and features. The length of the gorges attains up to 11 Km, whereas their depths range from (100 – 500) m.

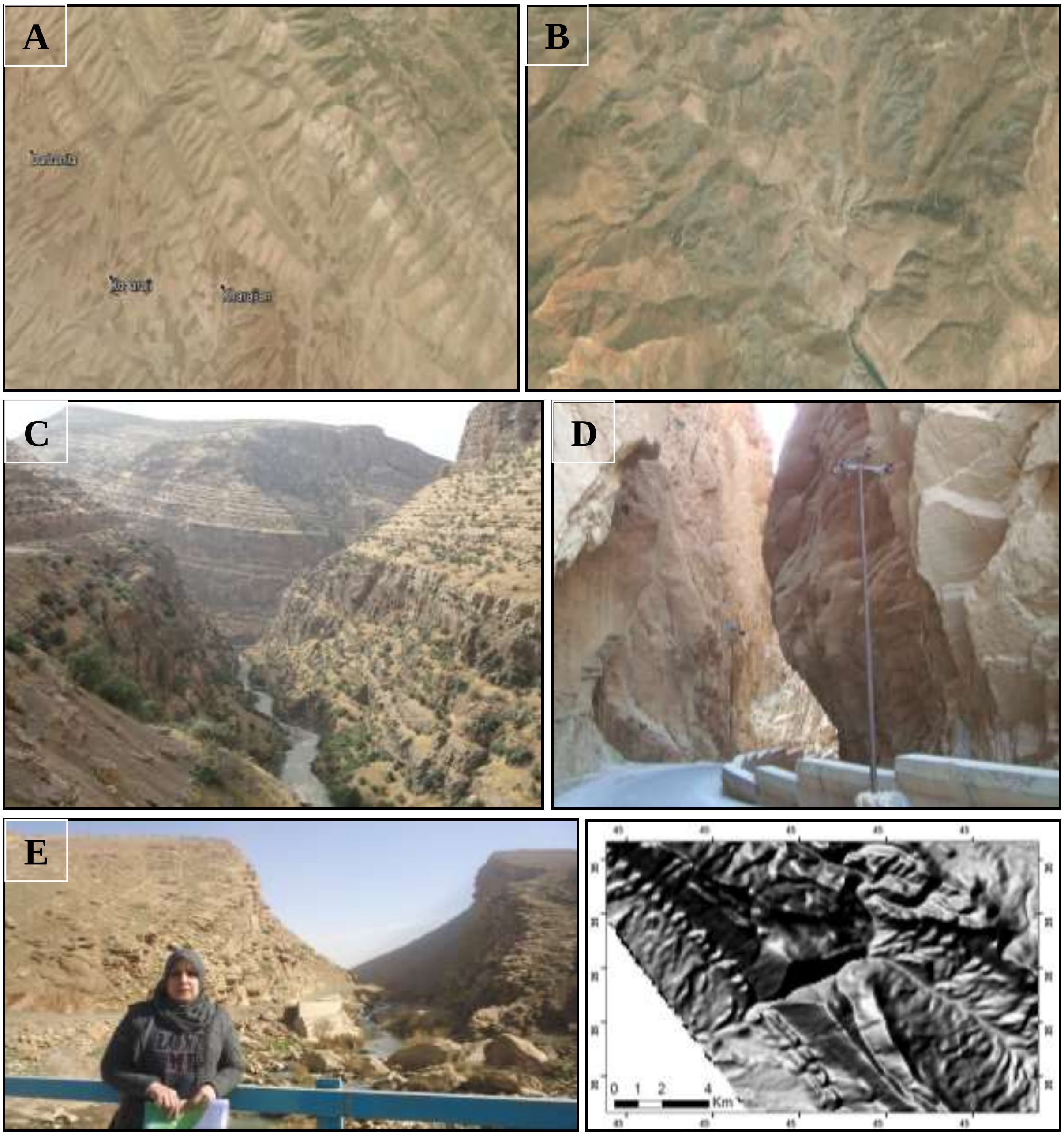


Fig.8: Major types of drainage patterns in the High Folded Zone,
A) Dendritic (Gercus and Kolosh formations, north of Dohuk city, **B)** Parallel (Azmir Mountain) (**A** and **B** are Google Earth images), **C)** Canyon, V-shaped (Galley Ali Beg), **D)** Gorge (Sartaq Bammu, southeast of Darbandi Khan town), and **E)** Bassara gorge (Left field photo, and Right DEM)

GEOLOGICAL SETTING

The HFZ is an integral part of the Western Zagros Fold – Thrust Belt (Fouad, 2012a and b). Therefore, the tectonic and structural effects, beside the type of the exposed rocks and climatic conditions have controlled the main geomorphologic units and the geodynamic processes. The HFZ is built-up of sedimentary rocks ranging in age from Triassic to Pliocene, beside various types of Quaternary sediments (Sissakian and Fouad, 2012 and Sissakian and Al-Jibouri, 2014). The oldest exposed rocks belong to the Bedu Formation, which is exposed in the core of Gara anticline. The Cretaceous and Jurassic rocks are the most widely exposed rocks in the area, forming the carapaces of all mountains. The Paleogene and Neogene (Oligocene) rocks are mainly of marine carbonate with clastics; they usually form the limbs of the high anticlines, and locally they occupy the trough of synclines. The Early and Middle Miocene rocks are of lagoonal carbonates and evaporate, respectively. The Miocene – Pliocene rocks are exposed only in restricted areas, represented by marine (Early Miocene) clastics and rare gypsum and limestone (Middle Miocene), whereas the remaining are clastic sediments (Late Miocene – Pliocene, and Early Pleistocene); mainly fluvial and lacustrine sediments, which mark the beginning of the continental environment, deposited in strongly sinking foredeep, due to the Late Alpine Orogeny. The Quaternary sediments are not well developed due to active erosion, which washes out the weathered sediments; however, the Pleistocene river terraces and alluvial fans of different stages, calcrete and residual soil are developed in different parts, covering restricted areas (Sissakian and Al-Jibouri, 2014).

It is worth to mention that during Early Pleistocene, the Alpine Orogeny reached its climax; and the last tilted formation involved was Bai Hassan Formation, as evidenced by the highly dipping strata of the formation. During the Pleistocene, the intensity of the orogenic movement has continuously decreased and new cycles of denudation and aggradation have started, accompanied by considerable climatic changes. These processes have controlled the development of different geomorphologic units and landforms in the HFZ.

GEOMORPHOLOGIC PROCESSES

Weathering, erosion, mass movements, transportation and deposition are the essential geomorphic processes in the HFZ. In conjunction with geological structures, tectonic processes, climate and living things, they fashioned landforms and landscapes (Huggett, 2007). However, in the HFZ the activity of these processes and their impact on the exposed rocks and soil vary in different geomorphic units and they are greatly influenced by the climatic changes with time, particularly during the Quaternary Period. Human activities have also a significant impact on the modification of landforms, through different land uses.

- **Weathering**

The HFZ lies within the zones of weak chemical weathering and insignificant mechanical weathering, according to the mean rates of temperature and rainfall (Peltier, 1950 in Fookes *et al.*, 1971). Consequently, the weathering mantle (regolith) lying above the bed rocks is often thin and generally not well developed, except in some large plains, like Shahrizoor in Sulaimaniyah vicinity. The main reason for that is the intensive erosion, which continuously removes the weathered material; this is attributed to high rainfall and snow cover, especially in the extreme parts of the HFZ. However, the activities of the weathering processes vary from place to another, which are influenced by local variations in rock types, climate, topography, vegetation cover and age of the weathering surface, and the structural control.

The main active mechanical processes in the area of the HFZ are the unloading, alternate heating and cooling (day and night, and seasonal cycles), and repeated wetting and drying, whereas, the main chemical weathering process is the solution (Fig.9); this is attributed to the predominance of the carbonate rocks in the area of the HFZ. These processes are more active in limestone bearing formations, such as Qamchuqa, Bekhme, and Pila Spi formations, which often form the carapace of the mountains, except the last formation.

Fig.9: Solution effect in limestone, **Left)** Shnider cave (Large scale) in Bradost Mountain, **Right)** Solution holes (Small scale, compare with the size of the optics) in limestone of the Pila Spi Formation, Bammu Mountain

- **Erosion and Mass Wasting**

The fluvial erosion is the most prevailing and active processes in the HFZ, beside the snow action, which has less effect on the rocks and sediments. Therefore, the land surface is almost barren of soil cover (Fig.10). Rill, gully, and sheet erosion are the main fluvial erosion types (Fig.11), which are very active in the mountainous and hilly areas, whereas the sheet erosion, which represents un-concentrated surface water flow, acts almost on the flat and gently sloping terrains. However, the streams are practically effective landform-makers (Huggett, 2007). Moreover, the streams and rivers are powerful transport agents in the HFZ area. They carry and transport the weathered and eroded materials from the high altitudes, depositing them in form of different fluvial sediments, downstream; such as terraces, alluvial fans, flood plains… etc.

The wind erosion includes two main processes, the deflation and abrasion. These processes are more effective during dry seasons, especially on the Quaternary sediments. However, it decreases northwards in the HFZ, in accordance with the increase of the vegetation cover.

- **Aggradation**

The alluviation is the most dominant aggradational process, which leads to level up the topographically low surfaces in the HFZ, which cover very restricted and small parts within the area involved. This large-scale depositional processes took place in broad synclines, and flat and undulatory plains, since the beginning of the Quaternary Period and most possibly even earlier, and are still active. The recent fluvial depositional processes are restricted to narrow belts along the floors of the valleys and within the meandering belts of the rivers and streams. The colluvial depositional process has also contributed to smoothening the surface of the slopes along the margins of the intermountain depressions, and other types of slopes (Fig.11, Right).


Fig.10: **Left)** Typical landscape of bare rocks, note the thickness of the soil cover is almost nil (Barzanja area), **Right)** Bare rocks, under active erosion, the weathered materials are accumulated down slope, as depositional glacis (Bammu Mountain)


Fig.11: **Left)** Rill erosion within the Pila Spi Formation, top of Bammu Mountain, **Right)** Gulley erosion in Jurassic formations, Barzanja Mountain, East of Sulaimaniyah

- **Mass Movements**

The mass movements are very active processes within the HFZ. This is attributed to the existence of: **1)** High relief differences, **2)** Existing of soft rocks capped by hard rocks, **3)** Existing of steep slopes, **4)** The influence of the active erosion, **5)** Predominance of wet rainy seasons, although not so long, and **6)** Man-effect through engineering constructions.

The main types of mass movements are landslide, toppling, rock fall, mudflow, and soil creep (Sissakian, 1993 and 1995, Sissakian and Ibrahim, 2004 and 2005, and Sissakian *et al*., 2007). They are developed in the mountainous and undulated areas of the HFZ, especially along the river and stream valleys. Most types of these mass movements are related to gravity action or combined actions of gravity and water; however, man effect is an important role, especially in landslides (Fig.12). Water saturation accelerates and increases the possibility and rate of mass movements down slopes by weight, such as landslides, mudflows and earth flows.

Fig.12: **Left)** Landslide in bedded limestone of the Kometan Formation, along the eastern bank of Dokan Lake (compare the size of the landslide with the size of the car in the lower left corner), **Right)** Toppled blocks of sandstone within Injana Formation in Diwana stream (south of Darbandi Khan)

Several landslides have occurred in different parts of the HFZ, among which is the landslide of Dokan Lake (Fig.12). It is within the Kometan Formation (well bedded limestone beds), due to un-estimated road cut. In addition to the landslides, rock falls and mudflows have been recorded in different parts of the HFZ (Sissakian and Youkhanna, 1979 and Sissakian and Fouad, 2014a and b). The rock falls, toppling, soil creep (Fig.13) and rock debris are more common, especially in the landscapes with high cliffs and steep slopes along the anticlinal ridges and banks of rivers and streams, and very rarely along banks of the main valleys.

It is believed that there are many mass movement events, which have occurred in different parts of the HFZ, but they have not been well documented and recorded during the regional geological mapping of Iraq.

Fig.13: **Left)** Soil creep, along Ranya Mountain (compare the size with the size of the truck in the middle left side), **Right)** Rock fall and rock debris within Balambo Formation, near Barzanja (compare the size of the fallen blocks with the size of the mud hut)

GEOMORPHOLOGIC UNITS

The geomorphological map of the HFZ at scale of 1: 1000 000 (Fig.14) is compiled by the authors, depending on the available information from the previous works and partly updated, by using remote sensing data. The map elucidates the geographic distribution of the main geomorphologic units in the studied area, only those, which the scale of the map permits to present them on the map. The authors used the geological map (Sissakian and Fouad, 2012) as a base map for defining the geomorphological units, which have direct relation with the geological units (Fig.14). The authors used GIS techniques for compilation of the geomorphological map, they have enhanced the map; depending on geomorphological field work, field check and using published articles and some postgraduate theses. The authors have classified the units into five genetic classes in addition to a possible Moraine unit; each class includes different lithomorphologic units. The units are described hereinafter.

- **Units of Structural – Denudational Origin**

These geomorphologic units are basically developed by combined action of tectonic and erosion processes, with their impact on different types of the exposed bed rocks. The following units and landforms are recognized in the HFZ area.

─ **Structural Ridges (Anticlinal Ridges):** These ridges represent the narrow and convex crests of the tight anticlines in the HFZ (Fig.14). They are well developed on the limbs and/ or cores of the most anticlines of the HFZ, especially when hard limestone and dolomite are exposed, such as in Safeen, Hareer, Korak, Pera Magroon, Gara, Peris anticlines. The ridges generally have asymmetrical slopes, trending NW – SE, in the central and southeastern parts of the HFZ, then gradually change westwards to almost E – W; their surfaces are semi-barren, uneven and dissected by net of rills, galleys and streams (Fig.15). The height of the ridges differ widely in different parts of the HFZ, usually increasing north and northeastwards, as the relief of the mountains increases in the same direction. The heights range from (100 – 500) m, and exceptionally may reach 1000 m, as in Pera Magroon anticline, which includes the highest peak in the HFZ (2763 m).

─ **Homoclinal Ridges (Cuestas and Hogbacks):** These ridges are well developed over broad areas along the strike in many anticlines in the HFZ (Fig.14). These types of ridges are differentiated according to the dip amount of the beds. **Cuestas** form in beds dipping gently perhaps up to (5 – 15)°. **Homoclinal ridges** are just asymmetrical and develop in more steeply tilted beds with a dip of (10 – 30)°. **Hogbacks** are symmetrical forms; developed where the strata dip very steeply at 40° plus (Huggett, 2007) (Fig.16A). Cuestas are well developed in broad low anticlines and/ or synclines, especially in Injana, Mukdadiya and Bai Hassan Formations, which comprise an alternation of soft and hard rocks. Homocline and hogback ridges are well developed on the inner limbs and near cores of many anticlines, where the strata are more steeply dipping. The dipping rocks either form continuous ridges or dissected by streams that cross the strike of the beds. When the steeply dipping beds are deeply cut by streams, **flatirons** morphology is formed with apices pointing up dip (Fig.16B). Flatirons are well developed in many anticlines, especially in formations, which bear well bedded limestones, such as Pila Spi, Shiranish, Kometan, Qamchuqa and Sarmord Formations. Their heights depend mainly on the thickness of the beds. The thicker the beds the higher the flatirons.

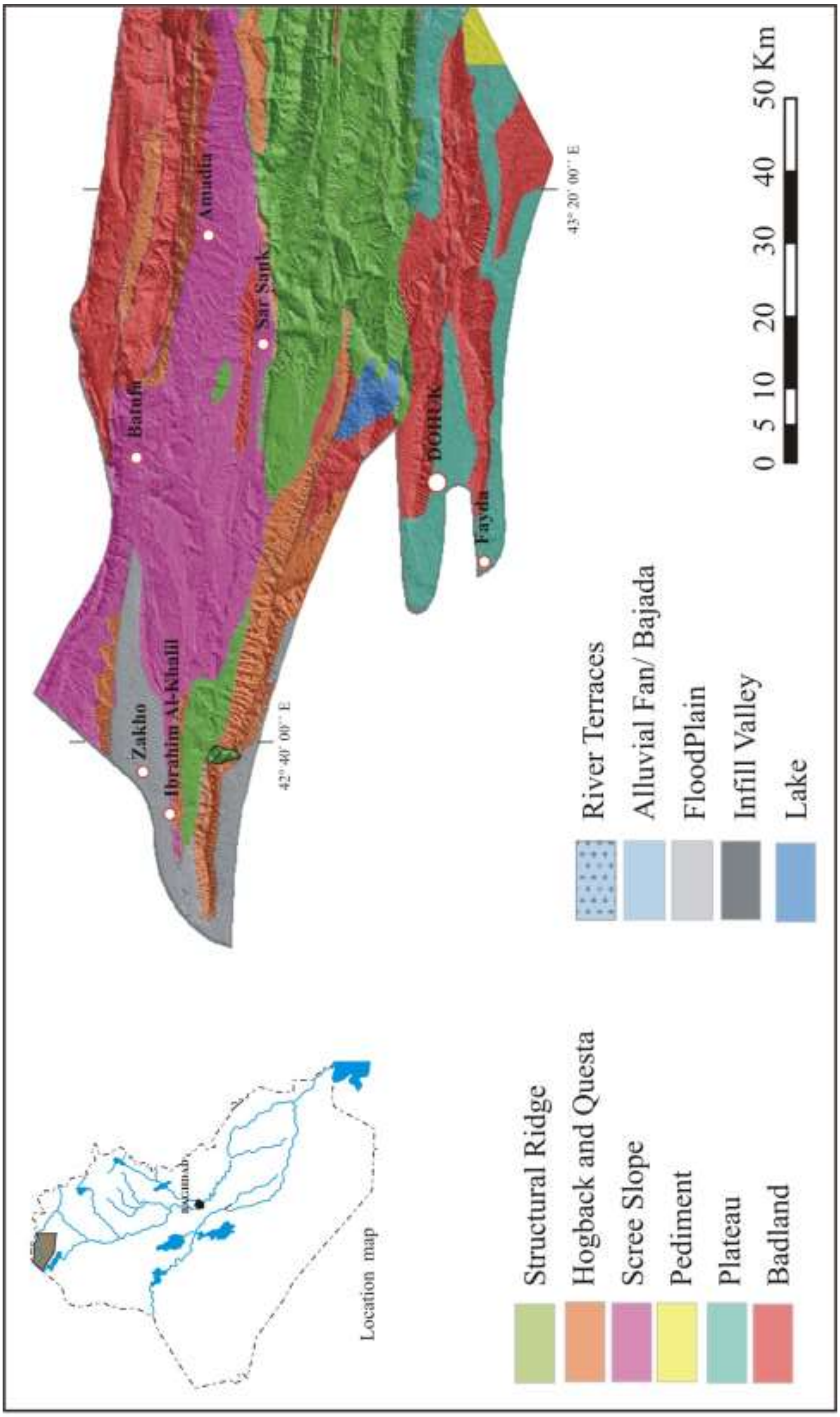
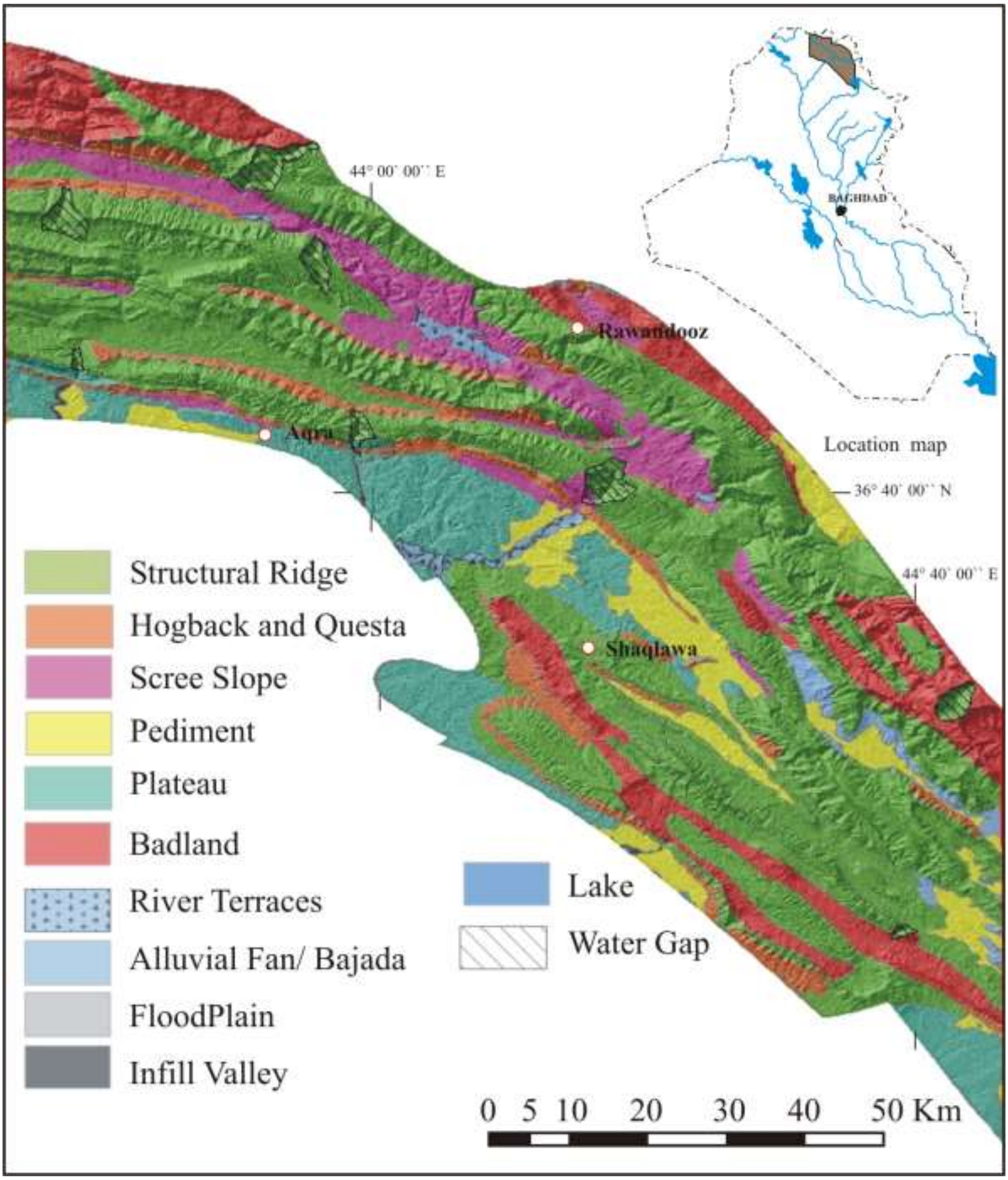
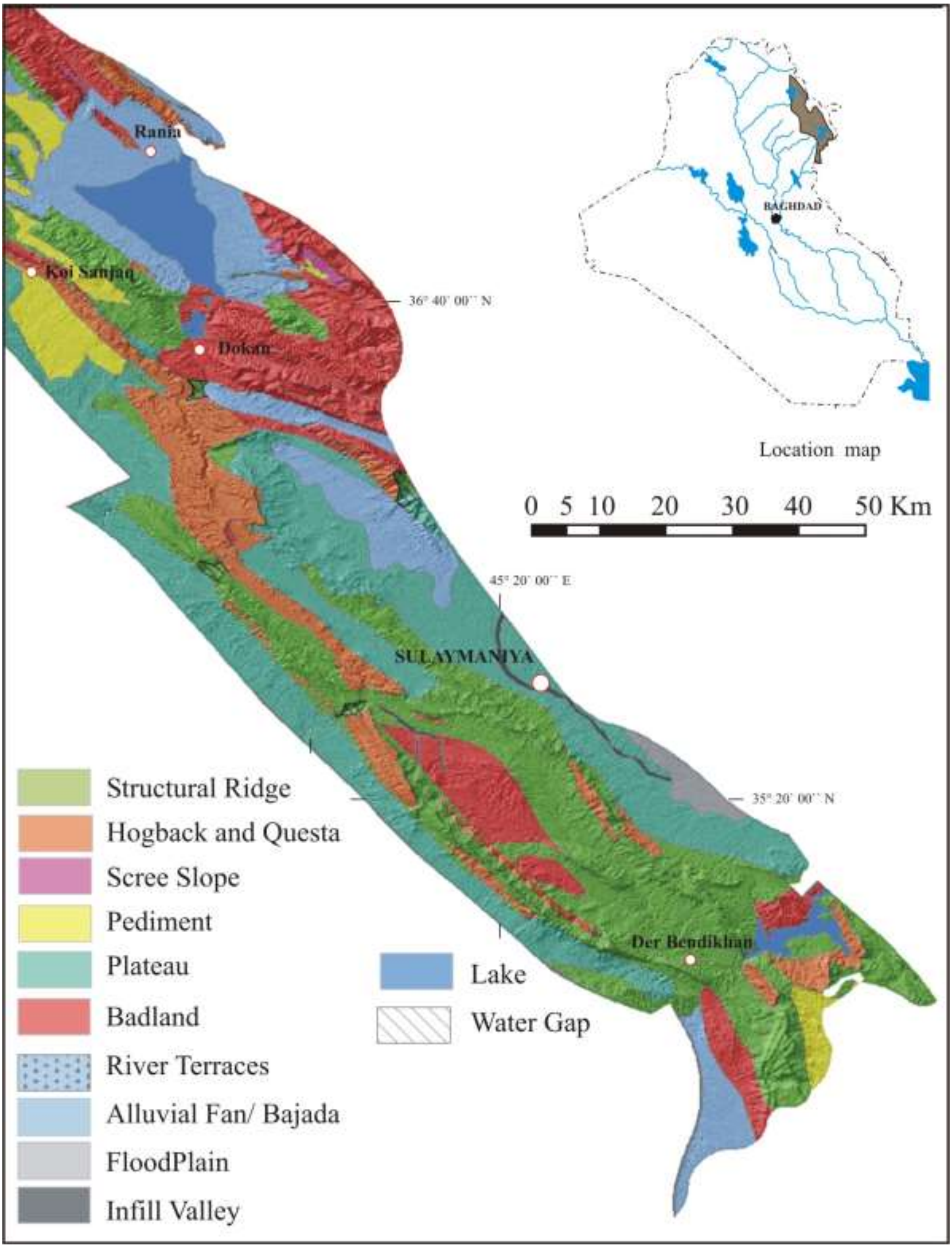


Fig.14: Geomorphological map of the High Folded Zone (Part 1)



cont. Fig.14: Geomorphological map of the High Folded Zone (Part 2)



Cont. Fig.14: Geomorphological map of the High Folded Zone (Part 3)

Fig.15: Anticlinal ridges, **Left)** Bammu anticline, **Right)** Surdash anticline

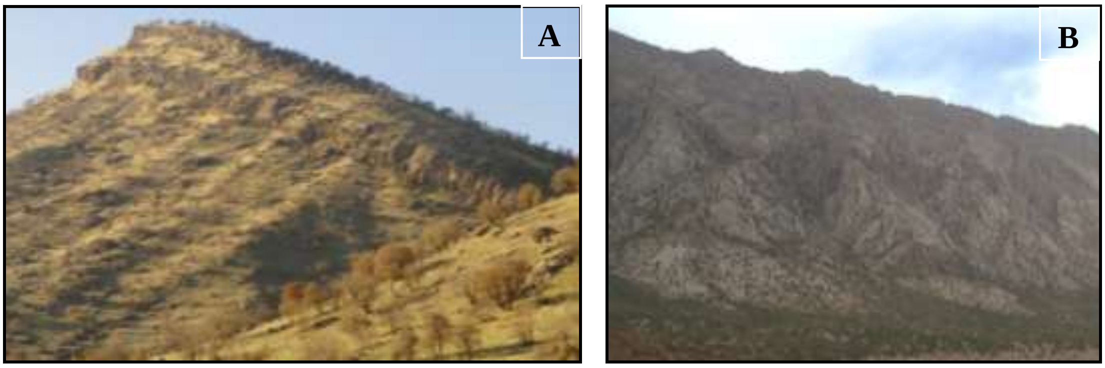


Fig.16: **A)** Hogback within Tanjero Formation overlain by a lens of Aqra Formation, NE of Rawandooz town, **B)** Flat irons in Kometan Formation, NE limb of Pera Magroon anticline

― **Flat Lying Highland Forms (Plateaus):** These landforms resemble plateaus in unfolded area; they are developed on top of semi horizontal beds, usually dissected. They are found on the top of many anticlines; such as Hareer and Permam (Fig.17), which have broad hinge zones that attain up to few kilometers in width. Korak anticline, also exhibits many flat lying highland forms near Rawandooz town. In addition, some small isolated plateaus are present, like Amadiya Plateau (Sissakian and Fouad, 2011).

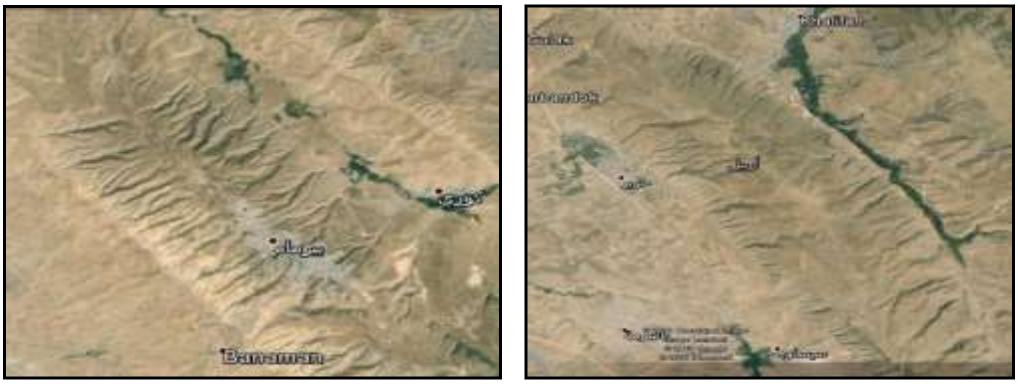


Fig.17: Google Earth images of flat lying highland forms, **Left)** Permam and **Right)** Hareer

– **Other Geomorphological Forms:** Many geomorphological forms are developed in the HFZ, of Structural – Denudational origin, among them are:

Fault Scarp: Many structures in the HFZ are affected by different faults (Sissakian and Fouad, 2012 and 2014a and b, and Sissakian, 2013). The front of the faults form scarps, following the fault lines (Fig.18). The height of these scarps varies from few meters up to few hundred meters; anti-dip valleys and streams usually dissect their slopes.

Fig.18: **Left)** Fault escarpment between Gercus and Pila Spi formations, along Sulaimaniyah – Dokan road, **Right)** Thrust fault escarpment in Aqra anticline, Bekhme and Shiranish formations are thrusted over Tertiary formations (up to Injana Formation)

Hoodoos: These are very special geomorphological forms; formed in hard well bedded and/ or massive, horizontally lying carbonate rocks. Their uppermost part forms sharp arrow-shaped forms, which range in height from (10 – 50) m, and exceptionally more. Good examples are developed in Gulley Ali Beg (Fig.19 Left) and Pera Magroon Mountain.

Fig.19: **Left)** Hoodoos in well bedded horizontally lying limestone of the Bekhme Formation, in Gulley Ali Beg gorge, **Right)** Water Gap along Gulley Zanta in Aqra anticline (photographed from the middle part of the gorge, facing north)

Water Gaps: These are developed when a stream or even a dry valley crosses an anticline or syncline. Tens of water gaps are developed in the HFZ. Sissakian and Abdul Jabbar (2010), Abdul Jabbar (2012) Sissakian (2013) and Al-Kubaisi and Abdul Jab'bar (2014) studied many of the existing water gaps in the HFZ and gave examples and explanation for their development. Good examples are Bassara, Gulley Ali Beg (Fig.20), across Safeen anticline, near Sama Quli village, Bekhme gorge, and Gulley Zanta gorge (Fig.19). The water gap in Gulley Ali Beg is a very special and complex one, since the water flows in the gorge from two opposite directions, then the two valleys meet in the middle of the gorge, and then cross the anticline parallel to the anticlinal axis (Fig.20) (Sissakian and Abdul Jab'bar, 2014b).

Fig.20: Google Earth images of water gaps. **Left)** Basara, along Qara Dagh Mountain, and **Right)** Gulley Ali Beg (Note: Both images are facing south)

It is worth to mention that water gaps are also developed by lateral propagation of folds and their vertical growth (Keller and Pinter, 2002). Sissakian and Abdul Jab'bar (2013) and Sissakian (2013), however gave different explanations for forming the water and wing gaps. Nevertheless, the water gap of Gulley Ali Beg is quite different from normal water gaps, and form very complex system (Sissakian and Abdul Jab'bar, 2014b).

Wind Gaps: These are developed when a stream or valley crosses an anticline or syncline, abandons the course, due to tectonic effect. Abdul Jab'bar (2012), Sissakian (2013) and Sissakian and Abdul Jab'bar (2013) noticed and studied many wind gaps in the HFZ. A good example is the Darbandi Bazian gorge (Fig.21) Sissakian (2010) attributed the development of the wind gap to a local neotectonic activity.

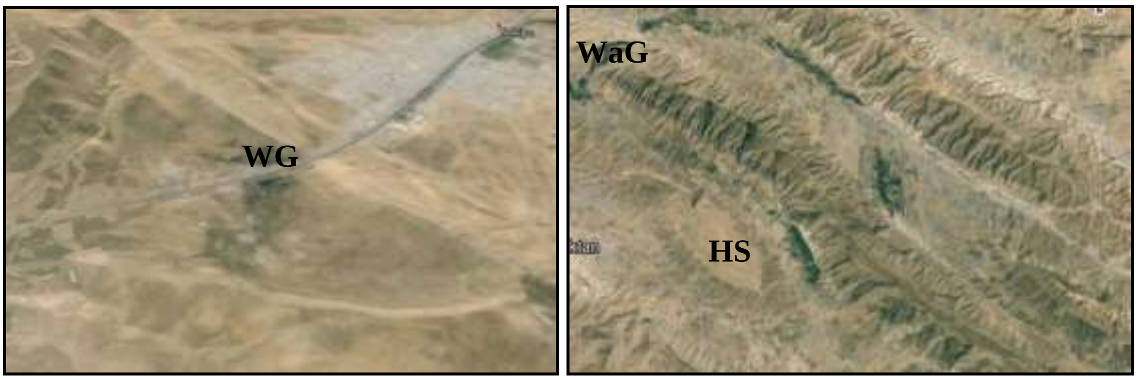


Fig.21: Google Earth images. **Left)** Wind gap (**WG**) in Darbandi Bazian, and **Right)** Hanging syncline (**HS**), between Safeen and Mirawa anticline. Also, note a water gap (**WaG**) in Sama Quli village (both images are facing south)

Hanging Syncline: Synclines usually form the main valleys in the HFZ. However, synclines rarely form elevated areas and hence hanging synclines. Good examples occur between Safeen and Miraw Anticlines, near Shaqlawa town (Fig.21) (Sissakian and Youkhanna, 1979).

Wine Glasses: Another significant geomorphic form is the Wine glasses, which have formed in different parts of the HFZ. These started developing in the early Pleistocene, and may be even in the Late Pliocene. Enormous amounts of rocks were weathered and eroded to develop the Wine glass forms, indicating very wet periods. The water transfers the sediments through one outlet, which usually forms typical V-shape; its size depends on the thickness and bedding of the outer hard rocks and the size of the cirque. The washed sediments are deposited by the flowing water; out of the cirque mainly as alluvial fans and/ or as depositional glacis. A good example is the Ziwi cirque in Pera Magroon Mountain, and the developed large alluvial fan (Fig.22). Tens of such Wine glass forms are developed by water erosion in the HFZ.

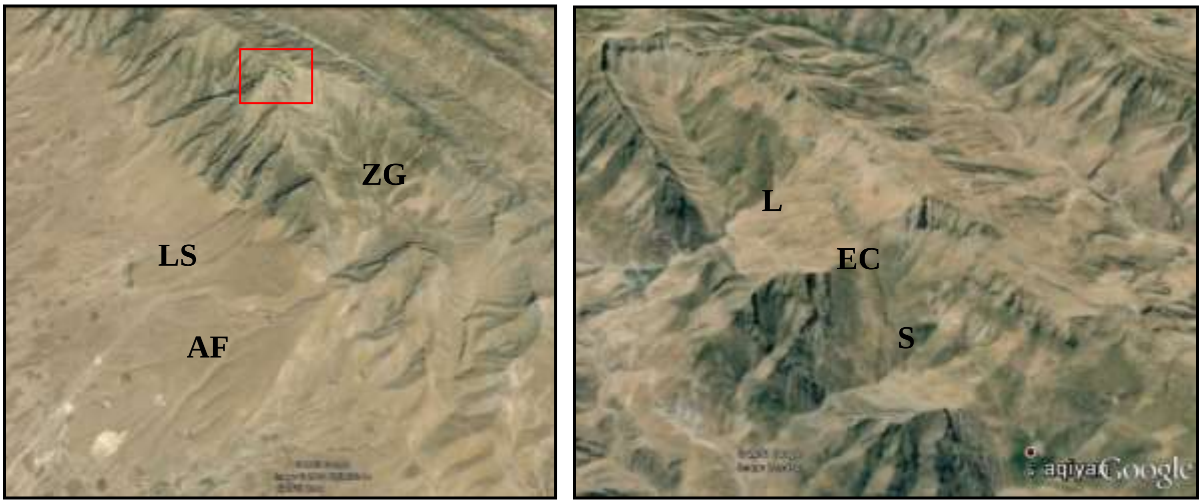


Fig.22: Google Earth images, showing Wine glass features in different locations: **Left)** Ziwi (**ZG**) and the related large alluvial fan (**AF**) in Pera Magroon Mountain. Note a large landslide (**LS**) west of the fan (**AF**), and the developed Bajada on both sides of the large fan (the green triangle marks the highest peak, 2763 m), and **Right)** Rawandooz, in Korak anticline, the large Wine glass (**L**) will conjugate with the small one (**S**), in between is an erosional cliff (**EC**).

Erosional Cliffs (Escarpments): These are developed in different parts of the HFZ, with different lengths and heights (Figs.20, 21 and 22). They are usually formed in hard carbonate rocks, either in almost parallel lines, which have the same alignment of the strike of the beds (Fig.20), or have irregular forms, as in Wine glass forms (Fig.22).

- **Units of Denudational Origin**

Two major units of denudational origin are developed in the HFZ; glacis (pediments) and badlands. They cover vast areas; reaching many hundred square kilometers, distributed on different parts throughout the HFZ area (Fig.14).

— Glacis (Pediments): In the HFZ, pediments are well developed on both sides of majority of the anticlines, with variable extensions, which range from few hundred meters up to few kilometers. This is attributed to small separating distances between the anticlines, because the synclines are tight and shallow (Fig.23). Two types of glacis are differentiated in the HFZ area; these are: **1) Depositional Glacis**, and **2) Erosional Glacis** (Fig.14). However, mixed glacis also exist in the HFZ, but they are not differentiated on the attached map, because they cover small and narrow areas. These landforms are represented on the GEOSURV's geological maps as slope sediments, polygenetic and sheet run-off sediments.

Depositional Glacis: These form broad gentle slopes with smooth or low relief (Fig.24); they are formed by running water, mainly as sheet. They are built of alluvial sediments derived from the upland masses, generally loamy soil with admixture of rock fragments and/ or pebbles. Their thickness may exceed 15 m, but ranges mainly from (2 – 8) m, locally; areas of these glacis are occupied by agricultural fields.

Erosional Glacis: These form gently sloping rock-floored erosion; commonly of low relief or slightly undulated surface; they are developed by running water, mainly rill erosion. They are commonly mantled by thin discontinuous veneer of alluvial sediments, residual soils may also occur mixed with the glacis, which are underlain by bedrocks (occasionally tilted beds) (Fig.24).

Fig.23: Narrow syncline, near Dokan Lake, note the depositional glacis are almost absent, due to steep limbs of a tight and narrow syncline

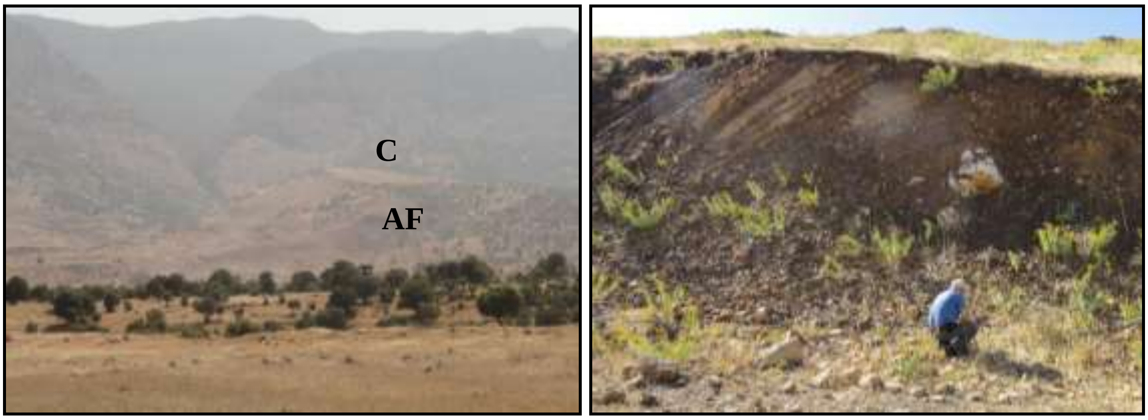


Fig.24: **Left)** Depositional glacis, north of Qara Dagh Mountain, note the alluvial fan (**AF**), capped by calcrete (**C**), and **Right)** A mixture of residual soil and erosional glacis, on the top of tilted Jurassic beds, within Matin anticline, near Amadiya town

─ **Badlands:** Badlands are developed in mountainous areas and distributed in different parts of the HFZ (Fig.14). They are well developed in areas built up of soft rocks, such as Tanjero, Kolosh, Gercus, Fatha, Injana, Mukdadiya and Bai Hassan Formations (Fig.25). The badland areas are characterized by very dense drainage network separated by narrow water divides, with either flat or rounded crests. The valleys of the first orders are V-shaped, whereas the valleys of higher orders are flat-floored. Sheet, rill, gully and stream erosions, beside rock falls, toppling and creep are very effective geomorphic processes in the formation of badland; these are still active, especially during heavy rain.

It is worth mentioning that badlands in the present study are genetically, considered as one of the denudational units, depending on the major factor, which is denudational processes, due to the dominance of soft rocks in the involved areas. However, in all badland areas, within the HFZ, dipping strata are also present, which reflect existence of structural influence.

Fig.25: Google Earth images, Badland morphology, **Left)** West of Darbandi Khan lake, and **Right)** North of Qara Dagh Mountain. In both areas, Fatha, Injana, Mukdadiya and Bai Hassan formations are exposed

▪ **Units of Fluvial Origin**

Many depositional landforms of fluvial origin are developed in different parts in the HFZ (Fig.14). They are greatly variable in size; some of them have small extensions; such as the channel fills of small valleys and streams, which form very narrow strips along the valley floors. Larger forms are the alluvial fans, especially around Darbandi Kham and Dokan lakes. Flood plains, Dokan Conglomerate, calcrete and terraces occur to a lesser extent. The following fluvial landforms are well developed in the HFZ area.

─ **River Terraces:** Alluvial terraces are well developed on both sides of the main rivers and streams' valleys. They are either found as paired or unpaired terraces, in different localities along the river valley, depending on variation in rates of vertical incision and lateral migration of the river channel. They are composed of rounded to sub-rounded gravels and sands with variable gravel sizes. All main rivers, in the HFZ, form alluvial terraces, which are developed in different levels above the present river level. Generally, (2 – 4) terrace levels are recorded along the main rivers, during geological mapping, which has been conducted by GEOSURV in different parts of the HFZ.

The main rivers and streams; flowing within the HFZ area have the same histories concerning complication and incision and consequently have the same terrace stages. From the authors' field observations, only two river terrace stages have been recognized along the Lesser Zab River, northeast of Ranya town (Fig.26), which is the usual number of the developed stages. However, only one stage of terraces is developed along the Rawandooz River (Fig.26). In all cases, the pebbles are mainly of carbonates and silicates, with fewer amounts of igneous and metamorphic rocks. The size of the pebbles varies between (1 – 25) cm, but exceptionally exceed 50 cm. The pebbles are sub rounded, rounded and well rounded, mainly of spheroidal shape; some are rode and disk shaped. The thickness of each level varies from (3 – 5) m. Their height difference between the levels and from the recent valley level range from (3 – 12) m. Generally, river terraces are not well developed in the HFZ, especially in rugged terrains. This is attributed to steep gradients and high energy of flowing water.

Fig.26: River terraces: **Left)** Lesser Zab River, northeast of Ranya town, and **Right)** Rawandooz River, near Barsarin village

— **Alluvial Fans:** Alluvial fans are developed in different parts of the HFZ (Fig.14), although not all of them are presented in the compiled geomorphological map (Fig.14) due to the scale limitations. Special cases occur around Dokan and Darbandi Khan Lakes, where their coverage areas range from few hundred square meters to about 15 Km^2. In both areas, the fans are covered by thick soil mantle, with thickness ranging from (2 – 5) m. The extensions of the large alluvial fans reach up to 17 Km; such as Ranya fans (Fig.27).

Ephemeral streams and valleys, in different parts of the HFZ, have deposited many small alluvial fans. The alluvial fans are either found as individual fans with clearly visible fanlike shape on plan view (Fig.27), or laterally coalescent forming Bajadas (Figs.28 and 29). The Bajadas often form narrow belts, with (2 – 3) Km width, along the foothill slopes. The composition, stages and size of the fans are highly variable in the HFZ, usually more than one stage is developed, especially in small fans.

It is worth to mention that Sissakian and Abdul Jab'bar (2013) have introduced a new classification for the alluvial fans in Iraq, including alluvial fans of the HFZ. The main types are: **1)** Single Stage fans, and **2)** Multi Stages fans. Furthermore, the types are divided into sub-types; including: **1)** Fans covered by calcrete (Examples are in Qara Dagh Mountain), **2**) Fans covered by soil (Examples are Ranya and Qalat Diza Fans), **3)** Fans originated from landslides (Examples are in Qara Dagh Mountain), **4)** Rock fans (Examples are along ridges where the Pila Spi, Bekhme and Kometan Formations are exposed) (Fig.29).

Fig.27: Google Earth image showing alluvial fans complex; near Qalat Diza (Off the HFZ) and Ranya, beside the alluvial plain of the Lesser Zab River.

Fig.28: **Left)** Google Earth image of a typical large single stage alluvial fan (**LAF**), with small coalescent fans; west of Darbandi Khan Lake. Note that the main stream (**MS**) had moved eastwards, and abandoned the original feeder channel, due to climatic changes and/ or tectonic activity, and **Right)** Coalescent alluvial fans forming Bajada, along the northeastern flank of Qara Dagh Mountain. Also note a single terrace level (**TL**) of a small valley

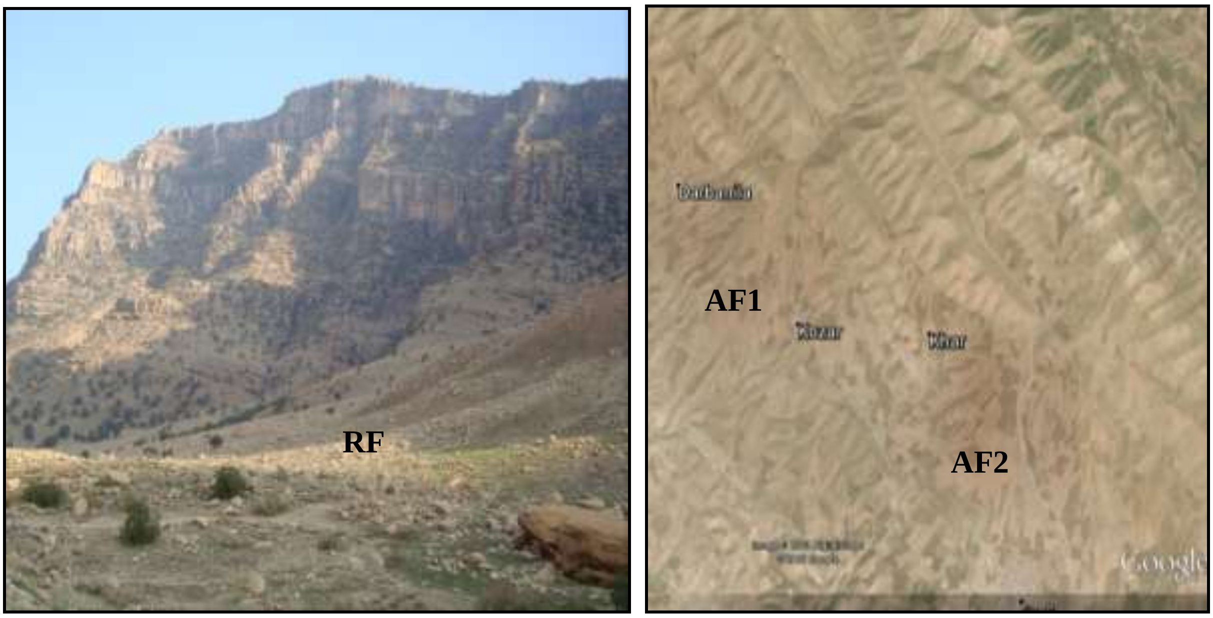


Fig.29: **Left)** Two small rock fans (**RF**) derived from the Pila Spi Formation, Sartaq Bammu area, and **Right)** Google Earth image showing two single alluvial fans (**AF1** and **AF2**); southeast of Sulaimaniyah; near Said Sadaq town

In very restricted areas, rock fans are developed along the flanks of some mountains, especially when the exposed rocks are hard, thinly well bedded, like the Pila Spi, Bekhme and Kometan formations, good examples are in Ranya area. The accumulated rock blocks have fan shapes, but not cemented, the size of the rock blocks ranges from (15 – 100) cm.

─ **Flood Plains:** The flood plain sediments form irregular strips along the rivers and large streams in the HFZ; their stretches are limited within the extent of meandering belts of the river channels (Fig.27). The channels are often bounded either by high cliffs built up by the river terraces or by bedrocks. The morphology of the flood plains is also influenced with different types of river channels; such as straight, meandering and braided channels. The width of the flood plains is greatly variable within the same river or stream, as well as from one river to another; it ranges from few tens of meters in small branches, (1 – 2) Km in Greater Zab and Lesser Zab rivers. The flood plain sediments are usually built of fairly cemented fine clastics, mainly sand silt and clay; with sparse lenses of disseminated fine pebbles; they often form discontinuous sheet overlying the valley terrace gravely sediments, with clayey top cover; therefore, are occupied as agricultural lands (Fig.30).

The flood plains are developed in different stages of different levels above the river. Generally, (1 – 2) levels; separated by low cliffs of (1 – 3) m height are often visible in many places along the main rivers; such as Greater Zab, Lesser Zab and Sirwan rivers. On contrary, many rivers and streams have almost no flood plains, due to the very narrow courses and steep slopes, which accelerate the erosion (Fig.30, Right). It is worth to mention that the same river may have developed its flood plain in a certain area and in other areas has no flood plains, depending on the maturity of the river and/ or stream.

Fig.30: **Left)** Flood plain of the Lesser Zab River, with two stages of terraces, northeast of Ranya town, and **Right)** Rawandooz River, note absence of the flood plain (compare the width of the river with the size of the two cars, north of the bridge)

– **Infilled Valleys:** These are developed in valleys; almost everywhere in the HFZ area. The valleys are created mainly by fluvial processes, and rarely in conjunction with tectonic processes. The composition of the sediments, their width and thickness are greatly variable, depending on the source rocks, geomorphic position and size of the valley. Those in the northern part of the HFZ include mainly carbonates and silicates, whereas in the northeastern parts, igneous and metamorphic rocks are also included. Valleys in the mountainous parts are filled by boulders (Fig.31); with sands and gravels, whereas in the undulatory areas they are filled by relatively finer clastics and are better sorted (Fig.31). The width of the valleys ranges from few meters in the young streams' orders to few tens of meters in the mature orders, and very rarely exceeds few hundred meters. Locally two-cycle valleys are developed, indicating climatic changes.

Fig.31: Valley fill sediments: **Left)** Course of a stream, north of Barsarin village, a tributary of Rawandooz River, and **Right)** Diwana stream, south of Darbandi Khan town. Note the difference in the type and size of the infilled sediments

─ **Dokan Conglomerate:** This is a special lithostratigraphic unit deposited along the southern and eastern margins of Dokan Lake and the top of Khalikan Mountain. Karim and Taha (2012) called it as "Dokan Conglomerate", Sissakian and Fouad (2012) adopted this term. The Dokan Conglomerate is very hard and weather resistant, consists mostly of blocks, boulders and gravels (Fig.32) derived from Qamchuqa Formation, with some clasts from the Kometan Formation, and at the upper part, rare clasts from the Pila Spi Formation occur too. The conglomerate is folded, in some places, the dip is more than 30°, and angularly overlies the Kolosh, Shiranish, and Kometan formations with more than 20° difference in the dip amount. In other areas, the conglomerate shows, equal dip with the aforementioned formations, on the top of Khalikan Mountain it is almost horizontally lying, with a thickness of about 300 m (Karim and Taha, 2012).

Fig.32: Dokan Conglomerate (**DC**), northeast of Dokan lake, along the road to Ranya. Note the details in the foreground block

─**Calcrete:** The calcrete commonly caps different Pleistocene clastic sediments in the HFZ area, usually caps alluvial fan sediments. It is also developed on the top of the pediments (glacis) (Fig.29) and slopes along the limbs of many anticlines. The thickness of the calcrete commonly ranges from (< 1 – 5) m and occasionally reaches 15 m, as in Amadiya Plateau (Sissakian and Fouad, 2011) (Fig.34). Calcrete is formed by cementation of rock fragments of different sizes, which range from (< 0.1 – 1) m, but occasionally may reach 3 m, and even more. The surface and ground water play the main role in the development of the calcrete; therefore, its presence indicates wet climatic period. The calcrete is developed during prevailing warm and wet climate phases; during the Pleistocene. It is very similar to the Pleistocene terraces, which are well developed in different parts of the HFZ, but with main differences in the shape and type of the constituents (Figs.33 and 34).

Fig.33: **Left)** Calcrete (**C**) capping the depositional glacis; forming flat top surface, northeastern flank of Qara Dagh Mountain, and **Right)** Details of a calcrete in Bammu Mountain

Fig.34: **A)** Well developed calcrete, upon which Amadiya town is built
B) A cave in Kometan Formation, Barzanja Mountain, with accumulation of rock debris in a steep valley, downstream a typical rock fan (RF) is developed

- **Units of Solution Origin**

The solution landforms are developed in areas where carbonate rocks are exposed within the HFZ. Caves are the most common solution landform found in limestones, which are well exposed as in Qara Dagh, Barzanja (Fig.34A), Safeen, Bradost (Fig.35) mountains. The entrance of the caves varies from less than one meter to several tens of meters wide (Sissakian and Ibrahim, 2004 and 2005, Sissakian and Al-Mousawi, 2007, and Sissakian *et al*., 2007). In some of these large caves, stalagmites and stalactites are developed; in others old human remains were found, as in Shnider cave in Bradost Mountain (Fig.35), northwest of Rawandooz town.

Sinkholes are very rarely developed, in limestones of different formations and gypsum beds of the Fatha Formation; formed due to solution of limestone and gypsum beds. The shape of the sinkholes is usually concave, irregular shapes are common in gypsum beds.

Another type of solution forms is the "Karren", which is in form of channels or furrows, caused by solution on massive bare limestone surfaces; they vary in depth from, a few millimeters to more than one meter and are separated by ridges. Good example is near Rwandooz town on top of Korak Mountain (Fig.35).

Fig.35: **Left)** The entrance of the Shnider cave in Bradost Mountain, and **Right)** Google Earth image, "Karren" a solution form on top of Handreen Mountain (The image is facing east)

- **Units of Man-Made Origin**

The HFZ area is not rich in anthropogenic landforms; although some of them are related to historical sites and others are related to the recent human activities. Over the last two centuries or so, human activities have had an increasingly significant impact on the transfer of Earth materials and modification on the landforms, chiefly through agricultural practices, mining and quarrying, and the construction of roads and cities (Huggett, 2007), in addition to construction of dams. In the HFZ, these man activities have produced different landforms; such as dams, which are located in the HFZ area namely, Dokan, Darbandi Khan, and Dohuk dams with related wide lakes. Other small dams, however, are under constructions, like Diwana dam (south of Darbandi Khan town), and a large dam; named Bekhme dam was under construction along the Great Zab River, but the construction is terminated hitherto.

Many gravels and sand, and limestone quarries, which form large and irregular pits have modified the natural landscape, and are still in progress. The cutting of many roads especially across the mountains impose many changes in slope gradients and natural relief from place to another by removing or adding earth material along the path of the roads.

- **Unit of Moraine Origin**

Wright (1986) reported about Moraine sediments in Rawandooz, Diyana, Seeda Kan, Galala, Barsarine areas. He mentioned that the sediments could be seen above (40 – 150) m of the existing riverbeds, and extends for few kilometers. The size of the cobbles attain more than one meter, consisting of silicates, igneous and metamorphic rocks and quartz, cemented by carbonate materials. The estimated age is Early Pleistocene. Moreover, he attributed many meanderings in the rivers and streams to the action of the moraine.

DISCUSSION

- **Historical Geomorphology**

The geomorphologic evolution of the HFZ was greatly influenced by the last phase of intensive orogenic movements that took place during Late Miocene – Pliocene, and reached its climax during Early Pleistocene. The last tilted beds involved in this intensive movement belong to Bai Hassan Formation (Pliocene – Early Pleistocene); with an exceptional case concerning the inclination of the calcrete masses, which coincides with the paleo-slopes and tilted beds of the Dokan Conglomerate. However, the effect of the Neotectonic activity continued during Quaternary Period, which started during Late Pliocene.

Starting from the Quaternary Period, especially from Pleistocene, the existing landforms started to have their shapes to form the main landscapes. Water was the main agent in developing the landforms, with less effect the snow and wind. The rocks were subjected to weathering in different degrees; depending on their resistance to weathering, which in turn depends on their strength. The water being as the main erosional agent washed out the weathered materials and deposited them as glacis, alluvial fans, terraces, calcrete, flood plains, and infill valley sediments.

Starting from the Late Pliocene, the Neotectonic activity played a major role in modifying the landforms, especially growing of the anticlines and sinking of synclines. This is attributed to the major thrusting, which occurred during the collision of the Sanandaj – Sirjan Zone of the Eurasian Plate with the Arabian Plate, causing the end of the marine phase and beginning of the continental phase. Meanwhile, tens of streams and the main rivers have carved their courses, especially in the mountainous regions. Some of them followed the general gradient by gravity; others have dissected anticlines either due to the lateral propagation of the folds or due to local Neotectonic activity, forming water gaps. However, upon abandoning the streams their courses along water gaps, due to many reasons, the remaining gaps formed wind gaps. In the HFZ are, Abdul Jab'bar (2012), Sissakian and Abdul Jab'bar (2013) and Sissakian (2013) recognized tens of water gaps and wind gaps. Moreover, they attributed the studied water gaps and wind gaps to different reasons, some of them are related to tectonic and Neotectonic activities, others are related to different geomorphological features; like alluvial fans, mass movements, and to climatic changes.

The tectonic and Neotectonic movements took their role too in forming and defining the landforms. The main rivers and streams, and even the large valleys started to incise their courses; forming the terrace levels. Further, more have carved in hard rocks to initiate their courses, locally dissecting anticlines and/ or synclines directly across them forming water gaps, others followed the regional gradient and initiated their courses parallel to the anticlines.

These movements; however, have continuously changed their intensity and propagation directions; consequently, some of the rivers and streams have abandoned their courses in water gaps due to lateral growth of the anticlines and/ or local Neotectonic movements; therefore, wind gaps were formed.

The continuous collision of the Arabian and Iranian Plates, have caused folding of the beds and increase dipping of the already dipping beds. Some of the beds were faulted; in different forms due to these continuous compressional forces, which in turn developed different joint systems in the hard rocks.

From all the aforementioned processes, different geomorphological units were developed to shape the existing landforms, consequently the present landscapes. The geomorphological units belong to five different origins, these are: Structural – Denudational, Denudational, Fluvial, Solution, and Man-made units. Each of these five genetic forms has many units.

- **Neotectonics**

The Neotectonic activity and the related structures played an important role in development of the major geomorphologic units and the surface relief of the involved area. Consequently, the spatial distribution of denudation (degradation) and aggradation (accumulation) areas were clearly defined at the end of the Pliocene and the beginning of the Pleistocene. The denudational processes were dominating in the structurally elevated areas, where the downward erosion was activated, whereas the agradational processes were prevailing in the structurally low troughs; and they tended to level the surface up. The flowing water was a dominant geomorphologic agent, which led to the formation of many erosional and depositional landforms in the studied area, like erosional glacis and calcrete.

It is worth mentioning that Sissakian and Deikran (1998) presented the Neotectonic map of Iraq, in which they have considered that the majority of the HFZ area was and is still an up lifting area. The upward movement is more than 1000 m, since the Late Miocene, which represent the beginning of the Neotectonic movements. Moreover, they calculated the upward movements' rate to be about 0.8 cm/ 100 year, in the HFZ area.

- **Wine Glasses**

The authors have recognized that those anticlines in which rocks older and/ or younger than Cretaceous Period are exposed, exhibit Wine glasses more than those in which only Cretaceous rocks are exposed. Moreover, those anticlines in which only Cretaceous rocks are exposed; beside that they did not exhibit Wine glasses, with some very rare exceptions. They have whale back-shape structures, due to the exposed very hard and thick Cretaceous rocks. This assumption is attributed to the fact that those anticlines in which rocks older than

Cretaceous Period are exposed are wide and shallow anticlines, like Gara and Pera Magroon anticlines. Moreover, the Early Cretaceous succession includes very thick hard rocks, which are not easily eroded to exhibit Wine glasses. On the contrary, the Jurassic and even the Triassic successions include soft rocks in their upper parts (Sissakian and Saeed, 2012), which were easily eroded to form the Wine glasses; exposing younger erosional surfaces (Jurassic and Triassic rocks); rather than those which show older erosional surfaces (Cretaceous and younger rocks). Good example is Gara anticline in which rocks of the Triassic age are exposed, the whole anticline exhibits extremely large Wine glass with many outlets, which, have opposite directions (Fig.36). Another example is Bana Bawi anticline with its large Wine glass including three outlets through Degala gorge, Kom Isban and Sama Quli (Fig.37); in this anticline the presence of thick and soft Late Cretaceous and Early Tertiary rocks; Shiranish, Tanjero, Kolosh and Gercus formations are the reason for forming the Wine glass. On the contrary, in Hareer (Fig.38) and Aqra (Fig.39) anticlines, for example, where the Bekhme Formation forms the carapace of the mountains, no Wine glass is developed yet, although both are dissected by dense and deeply cut valleys, which exhibit active gulley erosion. The authors attributed this to the presence of thick and hard rocks of the Bekhme and Qamchuqa formations, beside the tight form of the anticlines, and comparative low relief.

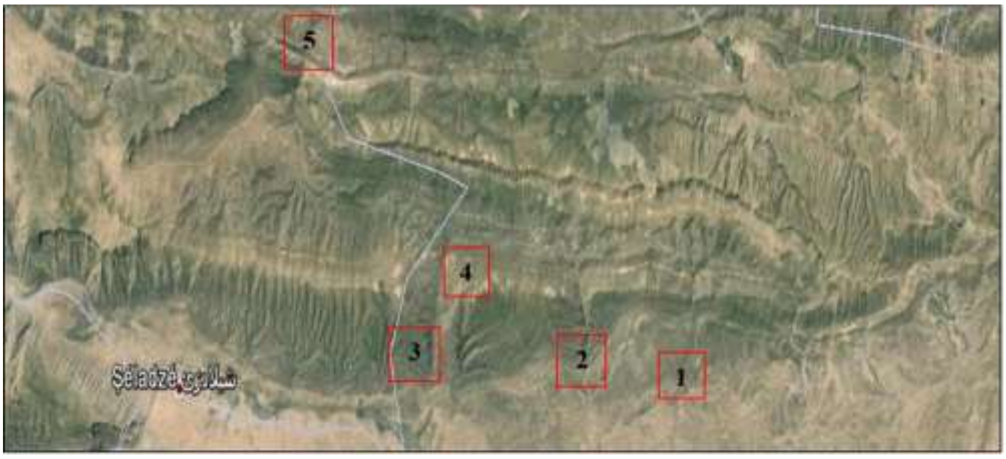


Fig.36: Google Earth image of Gara anticline. Note the whole anticline exhibits one extremely large Wine glass feature, with three outlets (**1**, **2**, and **3**, whereas no **4** is not fully developed) towards the north and one outlet (**5**) towards the south (The image is facing south)

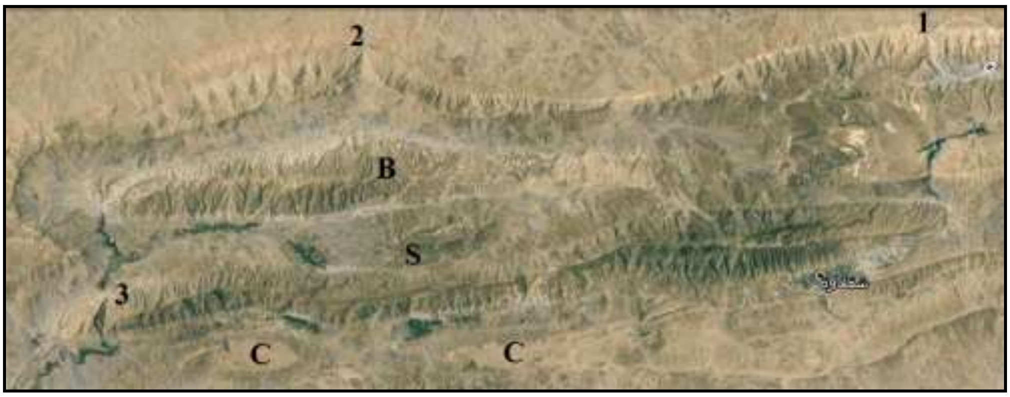


Fig.37: Google Earth image showing: **B)** Bana Bawi anticline exhibiting extremely large Wine glass feature, with three outlets: **1)** Kom Isban, **2)** Degala, and **3)** Sama Quli Galley (Through Safeen anticline). **S)** Safeen anticline, note the whole anticline does not exhibit any erosional cirque. **C)** Two hanging synclines (The image is facing N135° E)

Fig.38: Google Earth image of Hareer anticline. Note the absence of Wine glass feature, although tens of deeply cut valleys dissect each limb, also not a water gap (**WG**) and a wind gap (**AG**) (The image is facing N135° E)

Fig.39: Google Earth image (facing south) of Aqra anticline. Note the absence of Wine glass feature and presence of two water gaps, Bekhme (**Be**) and Gulley Zanta (**GZ**)

▪ **Development of Water Gaps and Wind Gaps**

Water gaps and wind gaps are very common phenomenon in the HFZ; almost the majority of the anticlines and even locally synclines exhibit both types of gaps. If a fold starts to propagate laterally and the incision rate of the river is higher than the uplift rate of the fold, then a gorge, called "water gap", will be established. If the incision rate of the river becomes lower than the uplift rate of the folds during further growth of the anticline, the river gets defeated and diverted leaving behind a dry valley called wind gap (Burbank *et al*., 1999; Burbank and Pinter, 1999). Moreover, different geomorphological processes may contribute, accelerate or even forms water gaps and may change them to wind gaps (Sisskian and Abdul Jab'bar, 2010).

Elevations of wind gaps along the crest of the fold may reveal the direction of the folds plunge and hence the direction of the lateral propagation. Drainage parallel to a fold axis will likely be diverted in the direction of propagation. As diversions develop, tributary streams are captured and the size of the upstream drainage basin increases until there is sufficient stream power to maintain a channel temporarily at the nose of the fold where propagation has not yet occurred (Fig.40) (Keller and Pinter, 2002). This area becomes a water gap and eventually defeated by uplift and/ or stream capture. If defeat occurs, the channel may be diverted again in the direction of lateral propagation, and in the course of a fold development, the channel may make several passes around the fold as the drainage develops. For some folds, there may be several wind gaps produced in this manner, and the drainage will be repeatedly diverted around the nose of the fold. Good examples are Gara (Fig.36), Safeen (Fig.37), Hareer (Fig.38), and Aqra (Fig.39), anticlines.

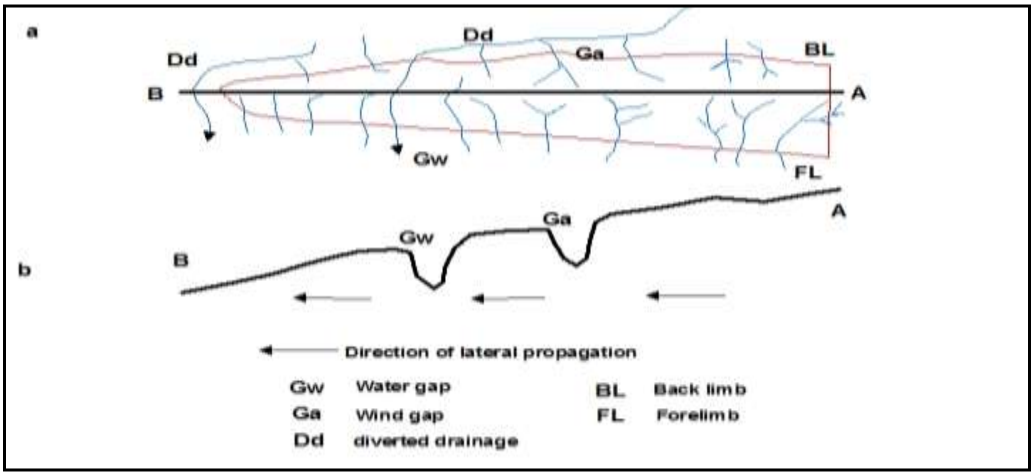


Fig.40: Idealized diagram showing the tectonic geomorphology of a fold that is propagating laterally (Keller and Pinter, 2002)

Evaluation of drainage patterns for specific folds may suggest that some folds are propagating in two directions as that adjacent folds are propagating toward each other or that younger folds are propagating parallel towards or against older fold in a fold belt. Good example in the HFZ is Galley Ali Beg Gorge, which exhibits a special water gap that have two opposite flowing direction, where two streams valleys met together in the middle of the gorge, and then cross the anticlines (Korak, Peris and Bradost) almost parallel to their axes (Sissakian and Abdul Jab'bar, 2014b).

The processes that transform water gaps into wind gaps are generally complex, and at least two hypotheses are possible.

- Uplift of the fold may block the channel in the water gap, forcing a diversion in the direction of the lower topography, which is likely to be in the same direction in which the fold is propagating.
- A channel crossing the nose of the fold has a tributary on the mountain side of the fold that erodes headward, parallel to the axis of the fold, toward the water gap (Keller and Pinter, 2002).

In many cases, a wind gap probably forms by a combination of both tectonic and fluvial processes (uplift diversion and capture of drainage). Good example in the HFZ are Darbandi Bazian wind gap (Sissakian, 2010), and wind gaps within Bradost and Pera Magroon anticlines (Sissakian and Abdul Jab'bar, 2010 and Abdul Jab'bar, 2012). The involved fluvial processes may include rapid deposition of pediments and/ or alluvial fans, beside mass movement phenomena, such as large landslides, rock debris slide, soil flow,

In a whaleback fold with an elliptical base, it can be figured out that the streams curve to maintain flow perpendicular to each contour line (Fig.41). The curvature of the stream depends on the elliptisity of the fold; but changes in the amplitude of the fold have no influence on the curvature of the rivers courses (Ramsey *et al*., 2008).

If the fold propagates laterally, an asymmetrically forked drainage network starts to form. These drainage patterns develop by the inheritance of older tributary patterns in areas with less curvature around the top of folds and therefore, may contain information about earlier stages of folding. This first generation of tributaries, are more or less parallel to the fold axis, links with a second generation tributary pattern perpendicular to the folds limbs, always using the steepest available slope. These distinctive asymmetrically forked tributaries and radial drainage can show lateral propagation directions similar to the flow direction of the older part of the linked tributaries, which show growth directions. With growing distance to the center of the fold; the asymmetry of the tributary increases, finally resulting in curved tributaries at the nose of the fold, which only preserve the latest stages of the folding (Ramsey *et al*., 2008) (Fig.41). A good example is the northwestern plunge of Handreen anticline (Fig.42).

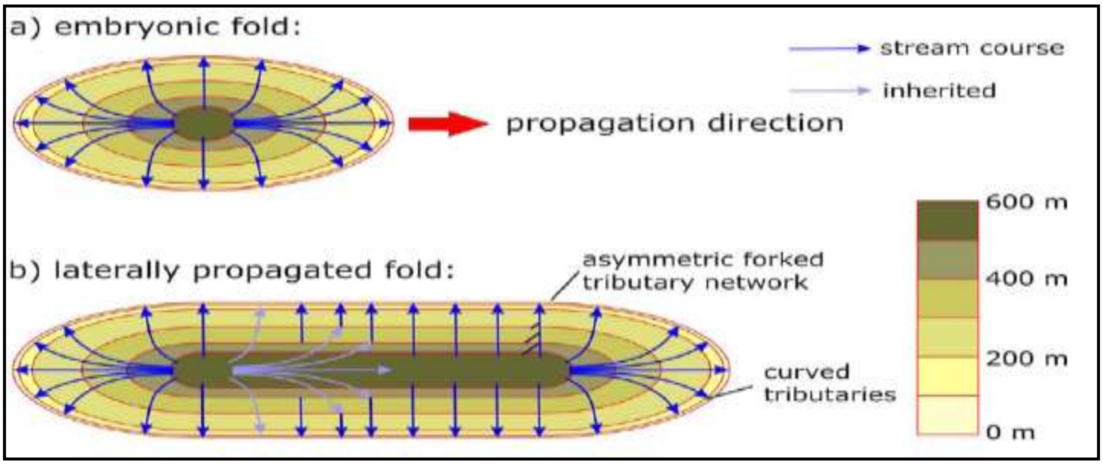


Fig.41: **a)** Map view with contour lines of an idealized embryonic cylindrical fold with its theoretical tributary pattern for an idealized fold with elliptical base and convex-up limbs. **b)** Tributary pattern for the same fold as above that has grown in length (after Ramsey *et al*., 2008)

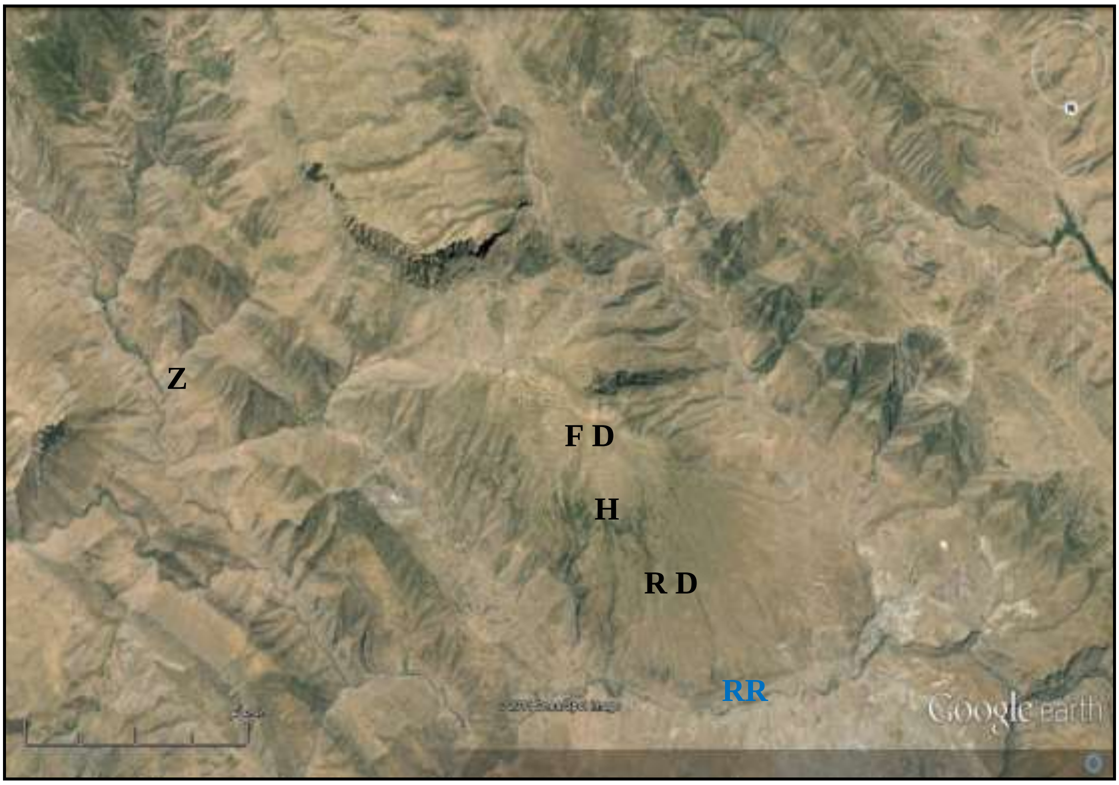


Fig.42: Google Earth image of the Rawandooz River (**RR**); crossing Zozik (**Z**) and Handreen (**H**) anticlines. Note the forked drainage (**FD**) and radial drainage (**RD**) on the northwestern plunge of Handreen anticline (Image facing south)

If two emerging folds join, it is possible that a river becomes pinched between the fold noses and forms a gorge in between. Because of the limited discharge through the narrow outlet, ponding of sediments behind the anticlines can form characteristic sediment depositions (Ramsey *et al*., 2008). Figure (43) shows this evolution in a setting of two emerging anticlines combined with the processes discussed before and shown in Fig. (41). Many examples occur in the HFZ of this type of fold propagation and development of gorges and water gaps, among them are Hareer (Fig.38) and Peris (Fig.39), Zozik, Handreen and Bradost anticlines.

A special form of wind gaps, called "curved wind gaps" occur locally in the HFZ. These forms of wind gaps are developed in areas with high tectonic uplift and propagation rates with simultaneous low incision rates, due to very fast propagation and high tectonic uplift ratios of a fold growing in length (Ramsey, 2008). A good example is the developed curved water and wind gaps in the northwestern plunge of Pera Magroon anticline (Fig.44). There are tens of such curved water and wind gaps in different anticlines in the HFZ (Sissakian and Abdul Jab'bar, 2010).

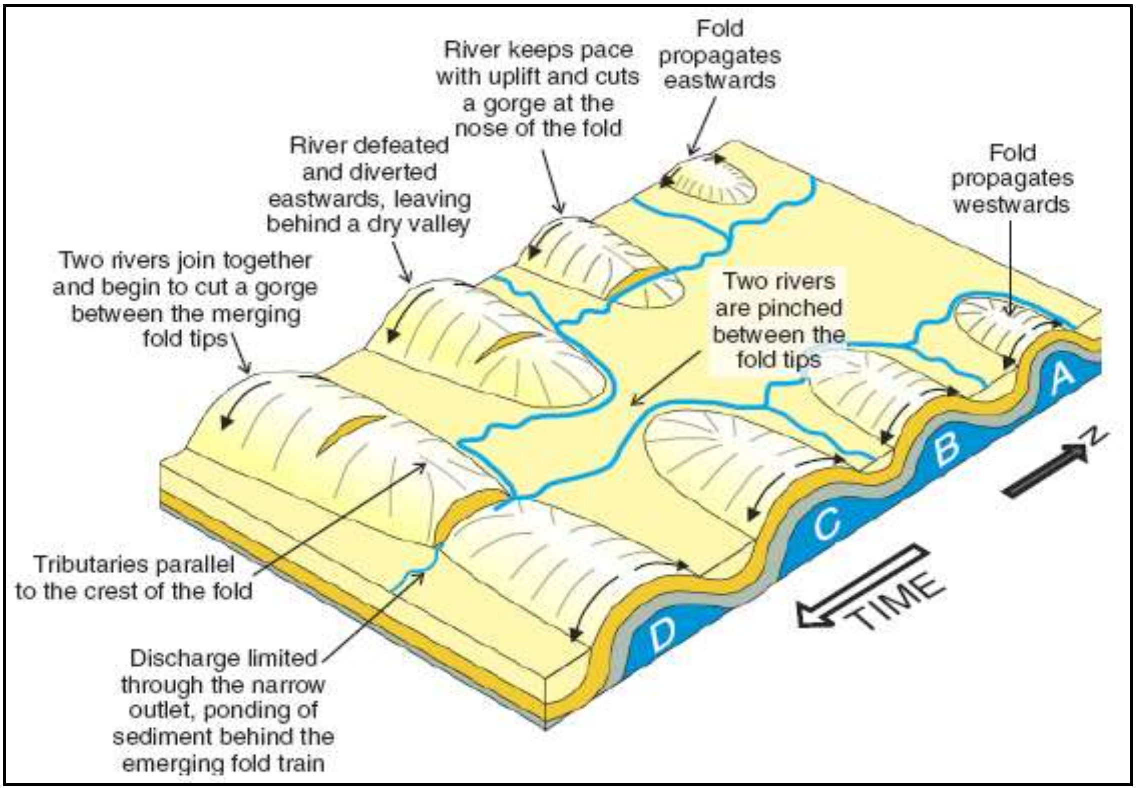


Fig.43: Diagrammatic show of the formation of a gorge between two propagating anticlines through time. **A)** Two small folds form in the east and west of the landscape. **B)** The folds propagate towards one another. Growth on aligned fold segments is enhanced by positive feedback in the stress changes around each growing fold. The incision rate of the western river keeps pace with uplift and the river incises a gorge through the nose of the fold. **C)** The western river is unable to keep pace with uplift and the gorge is abandoned and left as a dry valley. The river is diverted to the east and pinched between the tips of the two folds. **D)** The folds continue to propagate towards one another and the tips of the folds begin to form a continuous structure. The rivers have increased their stream power by joining together and incise a gorge through the almost continuous anticline (Ramsey *et al*., 2008)

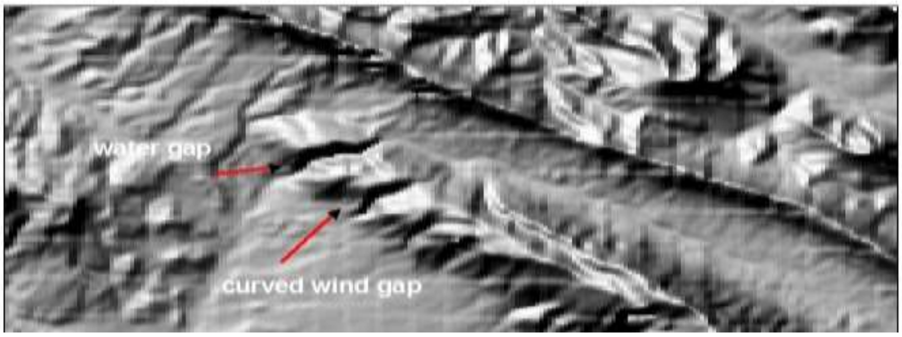


Fig.44: DEM of the northwestern plunge of Pera Magroon anticline. Note the left water gap, which was the original plunge area, where the stream was crossing. It was abandoned and changed to a wind gap due to lateral propagation, and then changed again to a water gap, due to the closure of the stream path in the plunge area, due to large scale land slides and alluvial fans (Sissakian and Abdul Jab'bar, 2011). To the right is an abandoned water gap, which represents now a curved wind gap

▪ **Derivation of the Drainage and Stream Pattern**

It has long been noted that rock structure and/ or ongoing tectonic activity in an area often influence the geometry of the fluvial system; this influence is reflected in the overall arrangement of individual stream channels. Where and when streams encounter actively uplifting structures, then there can be three possible consequences: **1)** Either the stream will continue to flow in spite of the deformation, but its path will be deflected by the deformation. **2)** Or the fluvial system will have enough power to maintain itself through downward incision, and **3)** Or an uplift will defeat the stream, forcing drainage to flow by some other route (Keller and Pinter, 2002). As a river incises through a growing structure, relief between the channel and the surrounding topography will increase, forming a water gap as a notch cut through an active structure or indeed any topographic barrier through which a river flows. Continuing uplift of a structure through which a river flows may exceed the ability of the river to down cut, forcing it to find an entirely different path around the structure. In such a case, the abandoned notch in the ridge that begins as a water gap is called a wind gap (Fig.45).

In the HFZ, distinct fold structures are crossed by multiple wind gaps, and many folds have water gaps at the tips, multiple wind gaps crossing along fold crest imply uniform and rapid uplift along this fold structures, causing abandonment and diversion of multiple stream channels. This in turn implies that these folds are fault-related-folds; therefore, these folds can be characterized by the presence of multiple cross cutting wind gaps along the hinge-line of the structure (Burberry, 2010).

Evaluation of drainage patterns for specific folds may suggest that some folds are propagating in two directions that adjacent folds are propagating toward each other or that younger folds are propagating parallel towards or against older fold in a fold belt. If two emerging folds join, then it is possible that a river become pinched between the fold noses and forms a gorge in between. Because of the limited discharge through the narrow outlet, ponding of sediments behind the anticlines can form characteristic sediment depositions (Ramsey *et al*. 2008). Folds can grow by the lateral propagation of a single segment, by the merger of several shorter fold segments into one continuous structure, or by combination of the two segments (Peacock and Sanderson, 1991; Cartwright *et al*., 1995; Dawers and Anders, 1995; Cowie, 1998; and Bennett *et al*., 2005). The individual fold segments that have merged are likely to be aligned along the strike, which adds degree of complexity; like in Qara Dagh, Permam, and Safeen anticlines. A series of wind gaps formed by the same stream is even stronger and easier visible feature to recognize the lateral fold growth. The development of wind gaps depends on the propagation and tectonic uplift rates of growing folds as well as on the incision rate of the river. However, Neotectonic activity cannot be ignored.

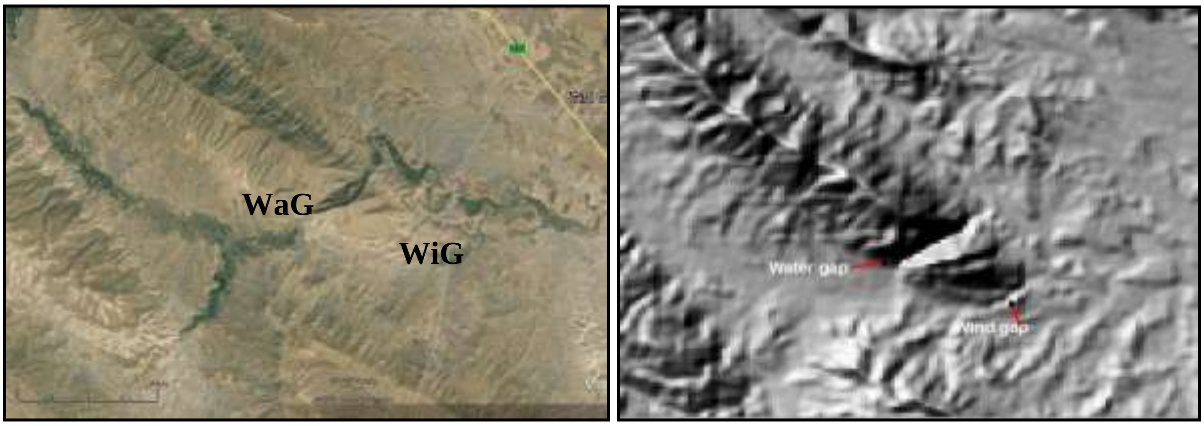


Fig.45: Southeastern plunge of Safeen anticline (**Left:** Google Earth image, **Right:** DEM image). Note the presence of a water gap (**WaG**) and a wing gap (**WiG**), which are developed with the same scenario mentioned in Fig. (44)

▪ **Rivers Basin Analyses**

The drainage system of the HFZ drains into the Tigris River through its three main tributaries, Greater Zab, Lesser Zab and Sirwan (Diyala) rivers, although off the HFZ. Each of these three main rivers have developed their own drainage basin, which consequently includes many sub-basins, and furthermore, smaller basins. The largest drainage basin is that of the Lesser Zab River, followed by the Greater Zab River and then the Sirwan rivers (Sissakian, 2013).

The shape of the drainage basins differs not only from river to another, but even within the course of the same river. A good example is the basin of the Grear Zab River, which includes five sub-basins (Sissakian, 2013). The five sub-basins have different shapes indicating different relative tectonic activity of High, Moderate, Very High, Very High and High, respectively. This was estimated by calculating the six morphometric parameters and their average values (***Iat***), which indicate their class values (2, 3, 1, 1 and 2, respectively for the five tributaries). Sissakian (2013) estimated these parameters using the technique used by El-Hamdouni *et al*. (2007) and Dhebozorgi *et al*. (2010). Unfortunately, adequate data are not available to calculate the relative tectonic activity of the remaining river basins. However, the authors believe that the sub-basins of the Lesser Zab River are almost the same as those of the Greater Zab River. This assumption is based on: **1)** The lithology of the exposed rocks in both basins are the same. **2)** The complexity and density of the anticlines, and structural and erosional cliffs are almost the same in both basins. **3)** The width, depth and gradient of the main river and streams are almost the same in both basins, and **4)** The coverage area of the both basins is almost the same. Moreover, the characteristics of the Tigris River's basin and that of the Sirwan River's basin are quite different from those of the Greater Zab and Lesser Zab rivers, for the same aforementioned four reasons. However, the details of individual basins and their relative tectonic activity are beyond the scope of this regional evaluation of the geomorphology of the HFZ.

▪ **Climatic Changes**

During the Quaternary Period, the climate became a leading factor in controlling the geomorphologic processes, such as weathering, erosion and fluvial processes, beside the lithologic, topographic and structural factors. The Quaternary long-term climatic changes in semiarid regions were represented by successive cycles of pluvial and inter-pluvial climatic phases. The deposition of fluvial sediments response to these climatic changes is rather complex. This response may vary from place to another and changes with historical times. During the pluvial phases, deposition of different fluvial and colluvial sediments took place, in the HFZ, specially the river terraces, alluvial fans, pediments and calcrete. On the other hand, during interpluvial phases erosion and down cutting processes were prevailing. The large-sized gravely nature of the aforementioned sediments indicates that they were deposited by very large rivers with high discharge and transport capacities, which reached their climax in Mid- Pleistocene, then started to decrease drastically.

▪ **River Terraces**

During the geological survey, the geologists of GEOSURV, emphasized the terrace sediments. Consequently, they recognized as maximum four main stages of terrace groups of Pleistocene age in the main rivers' valleys. Locally, sub-terrace stages also occur, indicating either minor climatic oscillations or local changes in the fluvial system itself. Generally, the average height of the oldest Pleistocene terraces ranges from (45 – 100) m above the present river level; this case is found only in Gulley Ali Beg gorge. Geomorphologically, this figure means that the local base level has dropped down around 100 m during the Quaternary Period; mainly due to down cutting erosion and partly owing to tectonic uplift of the mountainous areas.

At the end of the Pleistocene and the beginning of Holocene, the valley terraces were formed within deeply incised valleys, and then covered by thick blanket of flood plain sediments of Holocene age, forming the flood plain sediments. During the same time, the calcrete started to develop, too. During Holocene considerable worming of the climate occurred. Consequently, the river's discharge and load capacities dropped down and most of the rivers and streams incised in their older sediments. Weathering and erosion in different forms started to act on the already existing landforms. Therefore, new fluvial cycle was developed and is still in progress. All existing mass movements' phenomena, started to activate recently, however, few very old phenomena occur too in the HFZ.

CONCLUSIONS

From the data mentioned in this article, the following can be concluded.

- The HFZ is topographically divided into two main parts: the mountainous part; in the north and northeast and the flat and slightly undulated part; in the south and southwest.
- The slopes are classified into six classes depending on the gradient, expressed in degrees.
- Two main types of drainage patterns are recognized; these are dendritic and parallel.
- The most active mechanical weathering processes are: the unloading, alternate heating and cooling, repeated wetting and drying, whereas the main active chemical weathering process is solution, but with less intensity.
- The fluvial erosion was the most dominant processes during Pliocene and Quaternary Periods, and is still active, but with less intensity.
- The geomorphologic units are classified into six genetic classes; each class includes different lithomorphologic landforms. These units are developed as a result of weathering,

erosion and deposition processes, in conjunction with geologic structures, tectonics, neotectonics and climatic factors.

- Three Structural-Denudational units are recognized, these are: Central Anticlinal Ridges, Homoclinal Ridges and Flat Lying Highland Forms, in addition to five geomorphological features, these are: Fault Scarps, Wine glasses, Hoodoos, Water Gaps and Wind Gaps.
- Two major units of Denudational Origin are recognized: Glacis (Pediments) and Badlands.
- Many depositional landforms of fluvial origin are well developed in the HFZ, these are: Alluvial Fans, River Terraces, Calcrete, Flood Plains, Infilled Valleys and Dokan Conglomerate. The first three and the last landforms are of Pleistocene and Pleistocene – Holocene age, whereas the second two are of Holocene age.
- Caves are the most common solution landforms, beside very rare sinkholes, which are developed where limestone are widely exposed, with restricted exposures of gypsum.
- The main type of mass movements in the HFZ are: landslides, toppling, creep and rock fall.
- Tens of water gaps and wind gaps occur in the HFZ, some of them are curved. The main reason for development of the gaps is the lateral propagation of the folds, beside the neotectonic activity and other geomorphological features and processes.
- The HFZ is poor in anthropogenic landforms; some of them are represented by the ancient settlements, which are very rare, and the others related to different recent man activities.

EDITORIAL NOTE

The Editorial Board assigned writing of this article to Mr. Sabah Y. Yacoub (Expert) and his colleague Mr. Talal H. Kadhim. After his retirement, Mr. Ycoub moved off Baghdad and thus, was not able to complete writing the article. Consequently, and to keep issuing the series of the special issues, the Editorial Board assigned writing the article to Mr. Varoujan K. Sissakian (Expert, retired) with his colleagues Mr. Talal H. Kadhim and Mrs. Mawaheb F. Abdul Jab'bar.

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