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GEOMORPHOLOGY OF THE LOW FOLDED ZONE

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ABSTRACT

The geomorphology of the Iraqi Low Folded Zone (LFZ) is reviewed in the present article. Narrow, elongated and elevated mountainous chains with highly rugged terrain, and the wide gently sloping flat plains with local slight undulation represent the main topographic features of the LFZ. These features reflect the main geological structural relief's and the action of different geomorphologic processes. Moreover, the surface of the study area is dissected by complicated drainage patterns with variable density; they drain the study area towards the main streams and rivers, and then ultimately toward the Tigris River. The water flow erosion is dominant and active processes, beside less affectively wind erosion.

A simplified geomorphologic map of the LFZ is compiled. This elucidates the spatial distribution of the main geomorphologic units and related morphologic features. The geomorphologic units are classified genetically into seven classes, which include different landforms. The recognized genetic units are; **Structural-Denudational, Denudational, Fluvial, Solution, Evaporation, Aeolian, and of Man-made origins.** Each of these units include different lithomorphologic landforms, which were developed as a result of weathering, erosion and deposition processes, in conjunction with tectonic, structural, lithologic, and climatic factors.

The present study revealed that the geomorphologic evolution of the LFZ was greatly influenced by the last phase of intensive orogenic movement that took place during Late Miocene – Pliocene, and continued during Quaternary Period with less intensity. During the Quaternary Period, the climate became 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 Tigris River valley, in particular.

جيومورفولوجية نطاق الطيات الواطئة

صباح يوسف يعقوب، أرسلان أحمد عثمان و طلال حسن كاظم

المستخلص

شملت هذه الدراسة مراجعة جيومورفولوجية منطقة الطيات الواطئة في العراق. وأهم الظواهر السطحية الرئيسية في هذه المنطقة تتمثل بسلاسل جبلية عالية تتصف بنطاق ضيق وامتدادات طولية واسعة وبوعورة أراضيها، وكذلك السهول المنبسطة الواسعة ذات الانحدارات البسيطة مع قليل من التموجات المحلية. وتعكس هذه الظواهر السطحية التراكيب الجيولوجية وفعل العمليات الجيومورفولوجية، إضافة إلى ذلك فأن سطح منطقة الدراسة مشرح بواسطة شبكات التصريف السطحي المعقدة ذات الكثافات المتباينة. حيث تقوم شبكات التصريف بصرف مياه المنطقة باتجاه الأنهار والجداول الرئيسية وبالتالي تصب في حوض نهر دجلة.

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تم توليف خريطة جيومورفولوجية مبسطة لمنطقة الدراسة 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 ثمانية أصناف وهي الوحدات ذات الأصول، **التركيبية - التعروية، التعروية، النهرية، الإذابية، التبخرية، الريحية** ووحدات ناتجة عن فعل الإنسان. 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 الواطئة قد تأثر بشكل كبير بالمرحلة الأخيرة من الحركة الشديدة لتكون الجبال التي حدثت خلال عصر المايوسين المتأخر وعصر البلايوسين واستمرت خلال العصر الرباعي ولكن بأقل شدة.

خلال العصر الرباعي أصبح للمناخ دور متصدر في السيطرة على غالبية العمليات الجيومورفولوجية وبشكل خاص العمليات النهرية. وقد شهد العصر الرباعي عدة تغيرات مناخية طويلة الأمد تم استنتاجها من خلال تكون عدة مناسيب للمدرجات النهرية على امتداد الأنهار والجداول الرئيسية وبشكل خاص في الحوض الرئيسي لنهر دجلة.

INTRODUCTION

The present article is an attempt to review the geomorphology of the Iraqi Low Folded Zone (LFZ), 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 (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 Low Folded Zone. However, the geological maps and detailed description of lithology, stratigraphy and structural geology of the exposed formations are used to elucidate the geomorphologic evaluation of the LFZ area. Moreover, further useful geomorphologic information is acquired from the local detailed geological surveys of Mosul – Fatha area (Ma'ala *et al*., 1978 and Fouad, 2002 and 2004).

Tow specific regional geomorphologic maps of Iraq at scale of 1: 1000 000 were introduced by GEOSURV: The first is a reconnaissance Geomorphologic Map (Witold and Hassan, 1986) and the second is the published Geomorphologic Map of Iraq (Hamza, 1997). More detailed geomorphologic mapping, at scale of 1: 100 000 and 1: 250 000 were compiled in different parts of the Low Folded Zone by Azziz *et al*. (1983); Hamza (1993 and 2000); Al-Jaf *et al*. (2005) and Al-Jaf and Kadhim (2010). Al-Daghastani and Al-Daghastani (1996) have compiled a morphostructural map of the northern and northeastern parts of the LFZ; the map shows morphostructural landforms and some evidences for neotectonic activities.

In addition to the aforementioned data, the geomorphologic evaluation of the LFZ is partly updated by the authors using visual interpretations of the remotely sensed data, such as: Landsat (TM and ETM) and Quickbird images, supported with local field observations.

▪ Location

The Low Folded Zone from physiographical point of view is known as the Foothills Province, which is situated between the High Mountain and the Mesopotamian Plain Provinces of Iraq. Both the northeastern and southwestern boundaries are marked by distinct morphologic breaks in slope, as well as, they represent distinct tectonic lines. Consequently, the name of the zone has geological expression rather than physiographic. The LFZ covers about 56930 Km^2. It forms a wide hilly terrain oriented NW – SE and E – W, with average width of about 160 Km and length of 400 Km. In addition to its southeastern extent, which forms very narrow and discontinues strips, up to 15 Km width (discontinuous within the Iraqi territory), following the Iraqi – Iranian international borders (Fig.1).

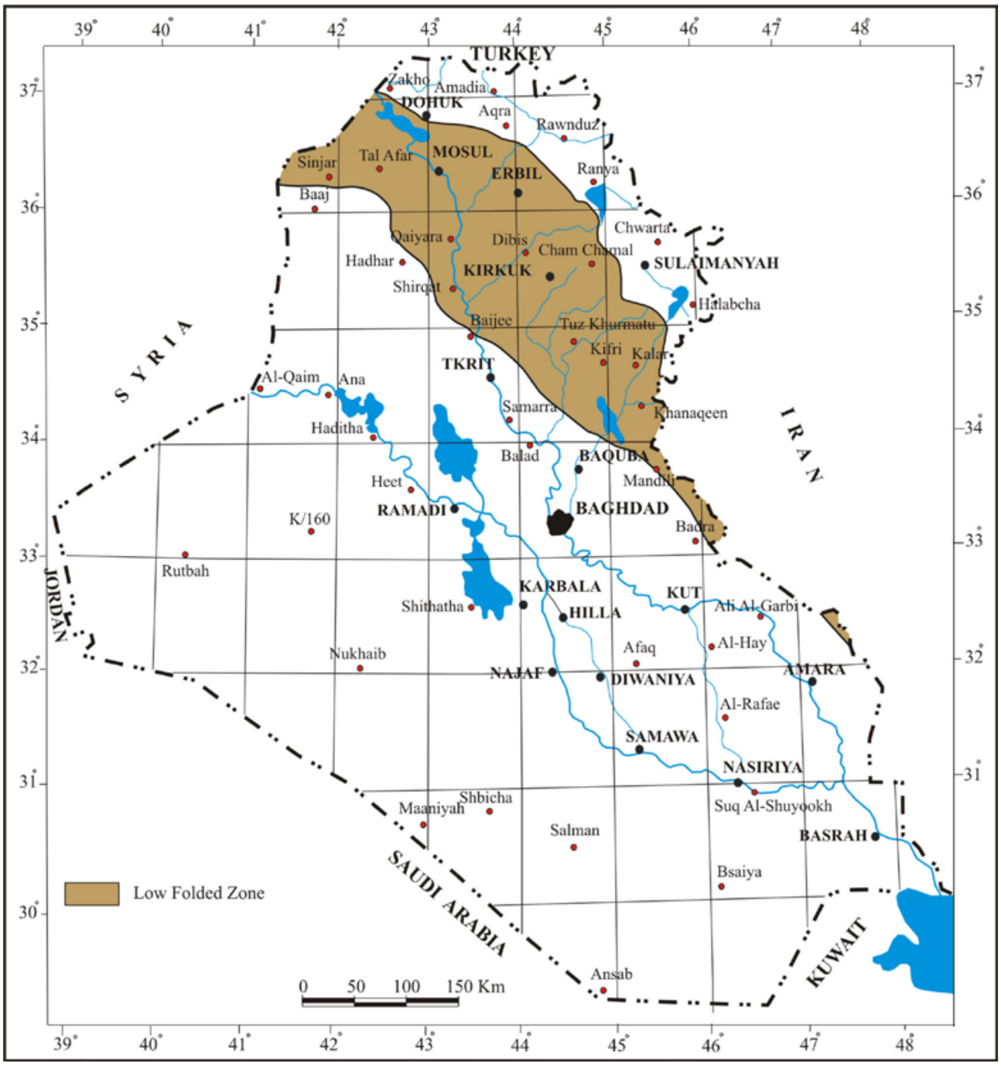

Fig.1: Location map of the Low Folded Zone

▪ Climate

According to updated World Map of the "Koppen – Geiger Climate Classification" (Kottek *et al*., 2006), the majority of the Low Folded Zone lies within the region of main arid climate, with steppe precipitation and hot arid temperature conditions. This global classification depended basically on the temperature and precipitation data for the period 1951 – 2000, on regular 0.5 degree latitude/ longitude grid. However, the LFZ lies within the arid to semiarid climate morphogenetic regions, according to the Peltier diagram (Peltier, 1950 in Fookes *et al*., 1971). The climatic data used to identify the climatic zone of the LFZ area, are acquired from the climatic records of four meteorological stations located within the area (Table 1 and Fig.2), although the first station is just on the borders of the LFZ. From reviewing these meteorological data, there are some variations in measured values of main climatic elements between the southeastern parts to the north and northeastern parts of the LFZ. It seems that there is gradual decrease in mean air temperature from 22.6 °C, in Khanaqeen Station to 19.9 °C, in Mosul Station; on contrary there is a considerable increase in mean annual rainfall from 198 mm, in Baiji Station to 390.6 mm, in Mosul Station. These variations are mainly attributed to the difference in elevation of ground level, which is generally increasing towards the north and northeast (Fig.3).

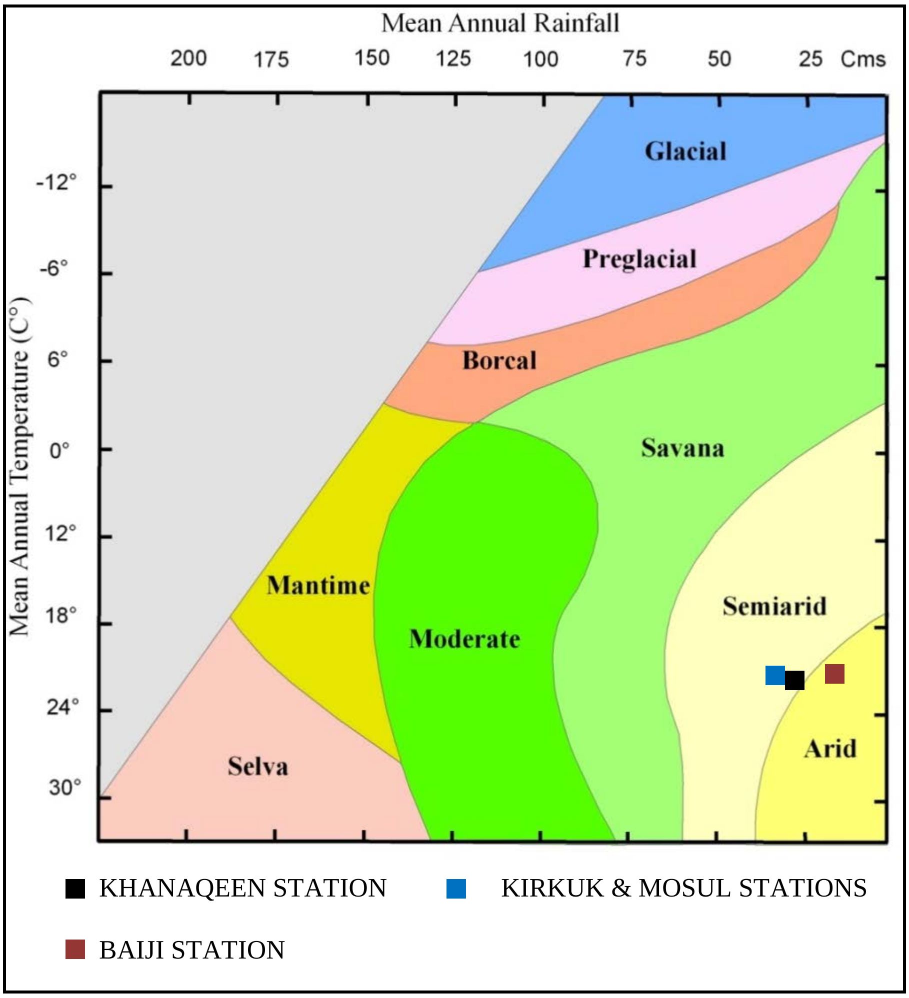

Fig.2: Climatic boundaries of the morphogenetic regions
(after Peltier, 1950 in Fookes *et al*., 1971)

GENERAL TOPOGRAPHY

The topographic surface of the LFZ generally rises in elevation from its southwestern boundary (about 125 – 300 m, a.s.l.) towards the north and northeastern boundaries (900 – 1000 m, a.s.l.) with some exceptionally high peaks of the mountains that reaches maximally 1462 m in Sinjar Mountain (Fig.3). The main structural pattern, lithology and geomorphologic processes generally affect it, which all played important roles in development of the surface features. The main topographic features are the narrow, elongated and elevated mountainous chains reflecting the narrow anticlinal structures, which are separated by wide synclinal troughs forming flat plains with local slight undulations.

▪ The Mountainous Parts

They are characterized by highly rugged and rocky terrain, dissected by dense v-shaped valleys and deeply cutting rivers and streams. The height of the mountains is greatly variable, ranging from (150 – 1000) m above the surrounding areas, which represent the local relief of the mountains. The heights of Himreen south and Qara Chouq north range between (200 – 300) m, whereas others like Qara Chouq south is around 600 m and the highest one among the others is Sinjar Mountain, which reaches a height of about 1000 m (1462 m, a.s.l.).

Table 1: Climatic data of the Low Folded Zone for the period (1980 – 2000)

Station	Climate Elements	JAN.	FEB.	MAR.	APR.	MAY	JUN.	JUL.	AUG.	SEP.	OCT.	NOV.	DEC.	Annual
BAIJI	Mean Air Temperature (°C)	8.8	10.9	15.2	21.5	27.7	32.8	35.8	34.5	30.6	23.9	15.5	10.2	22.3
	Mean Max. temp (°C)	14.7	17.3	22.0	28.4	35.4	40.3	43.7	43.2	39.6	32.4	23.2	16.4	29.7
	Mean Min. temp (°C)	4.1	5.4	8.9	14.5	19.9	24.1	27.0	25.9	21.9	16.6	9.5	5.4	15.3
	Mean Relative Humidity (%)	78.3	69.0	61.3	49.9	37.0	28.6	27.0	29.1	33.6	46.9	63.8	77.9	50.2
	Mean Relative Humidity (%)	1.4	1.9	2.2	2.5	2.8	3.5	3.7	3.2	2.0	1.6	1.5	1.3	2.3
	RAINFALL TOTALS (mm)	35.7	31.7	37.0	19.3	7.3	0.4	0.0	0.0	0.8	6.8	25.7	33.2	198.0
KHANAQEEN	Mean Air Temperature (°C)	9.5	10.8	14.8	20.9	28.5	33.1	35.8	34.9	30.7	24.7	16.9	10.9	22.6
	Mean Max. temp (°C)	15.3	17.2	21.2	28.6	36.1	41.6	44.7	44.3	40.0	33.1	24.0	17.5	30.3
	Mean Min. temp (°C)	4.7	5.6	8.9	14.4	21.2	24.1	26.8	25.8	21.8	17.0	10.7	6.5	15.6
	Mean Relative Humidity (%)	77.2	69.9	64.0	53.1	38.4	27.8	26.1	27.8	29.4	36.8	60.6	74.1	48.8
	Mean Relative Humidity (%)	1.8	2.4	2.5	2.6	2.6	2.5	2.3	2.1	1.8	2.1	1.8	1.6	2.2
	RAINFALL TOTALS (mm)	56.4	53.1	58.6	29.1	5.5	0.1	0.1	0.0	0.0	12.4	48.6	56.9	320.8
KIRKUK	Mean Air Temperature (°C)	9.0	10.3	14.0	20.4	27.4	33.0	36.2	35.3	31.2	24.4	16.4	10.8	22.4
	Mean Max. temp (°C)	13.9	15.3	19.4	26.5	33.9	39.9	43.5	42.8	38.6	31.4	22.3	15.8	28.6
	Mean Min. temp (°C)	4.6	5.4	8.7	14.2	20.2	25.2	28.4	27.6	23.8	18.4	11.5	6.6	16.2
	Mean Relative Humidity (%)	No data available												
	Mean Relative Humidity (%)	0.9	1.3	1.5	1.7	2.0	1.8	1.8	1.7	1.3	1.4	1.2	1.0	1.5
	RAINFALL TOTALS (mm)	68.6	67.9	54.4	41.1	13.8	0.3	0.4	0.1	0.9	15.9	54.8	59.5	377.8
MOSUL	Mean Air Temperature (°C)	6.8	8.2	12.2	17.8	24.4	30.9	34.3	33.3	28.5	21.1	13.4	8.2	19.9
	Mean Max. temp (°C)	12.3	14.4	18.4	25.2	32.8	39.3	42.8	42.4	38.0	30.1	20.8	14.0	27.5
	Mean Min. temp (°C)	2.4	3.0	6.1	10.8	15.8	21.1	24.9	23.7	18.6	13.1	7.5	3.7	12.6
	Mean Relative Humidity (%)	80.0	74.0	68.9	61.6	43.7	27.7	24.6	26.5	31.1	46.5	66.9	80.0	52.6
	Mean Relative Humidity (%)	1.0	1.3	1.4	1.5	1.8	1.8	1.8	1.5	1.1	0.9	0.8	0.9	1.3
	RAINFALL TOTALS (mm)	61.2	65.3	72.1	40.4	18.6	1.9	0.3	0.0	0.4	14.2	53.2	62.8	390.6

- **The Flat and Undulated Plains**

They represent plains with predominant gently sloping lands combined with low relief. These plains are commonly built up of different types of polygenetic sediments; fine clastics dominate on their surface sediments. They often cover wide areas reach several thousand square kilometers, mostly cultivated. The surface of the plains is dissected by widely spaced shallow drainage system, forming low relief. The main rivers (Tigris, Greater Zab, Lesser Zab, Adhaim and Diyala) cut across these main plains, forming wide meandering belts bounded by vertical cliffs.

- **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 LFZ area that is characterized by variable relief ranging from flat to steep. The slopes are expressed in degrees and classified into six classes. The zonation of these classes are suggested by the authors depending on the topographic nature of the LFZ, taking into consideration the resolution of the available DEM (30 m) data and the scale of the final layout (Fig.4). The **first class** (0 – 1)° represents the widely extended flat plains and the flood plains of the main rivers. The **second class** (1.01 – 3)° represents the foothills slopes and the upper parts of the pediment plains. The **third class** (3.01 – 5)° is common in the margins of the main mountains, which are characterized by undulated terrain, and low tilted and moderately dissected strata. The **fourth class** (5.01 – 15)° 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** (15.01 – 30)° and **sixth class** (> 30.01)° are restricted in the cores of the high anticlines, such as Sinjar, Maqloub, and Qara Chouq, where steep structural slopes, erosional cliffs, and structural scarps are well developed; moreover they occur along the deeply cut valleys. The statistical analysis shows that the first and second classes are prevailing as compared with the others.

- **Drainage**

The LFZ is well drained by the Tigris River and its tributaries, like Duhok, Al-Khosar, Al-Khazir, Al-Gomal, Greater Zab, Lesser Zab, Al-Adhaim, and Diyala Rivers, and related drainage patterns. These rivers and streams drain large sector of the LFZ, east of Tigris River. Numerous ephemeral steams and valleys drain the western sector of the zone, most of them flow towards the Tigris River and the others flow towards Al-Tharthar valley and partly inside Syrian territory. The ephemeral streams and dry valleys of the LFZ are often flooded quickly after heavy rain showers, because they run down from wide catchment's areas in the adjacent mountains.

The shape of the valleys is widely variable, in the LFZ, depending mainly on the type of rock and morphology. Usually, they are “U” and “V” shaped, in addition to few 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 Bai Hassan Formation and terrace sediments. Gorge and canyon types are locally developed in the mountainous parts, especially when the main streams and rivers dissected across the main geological structures.

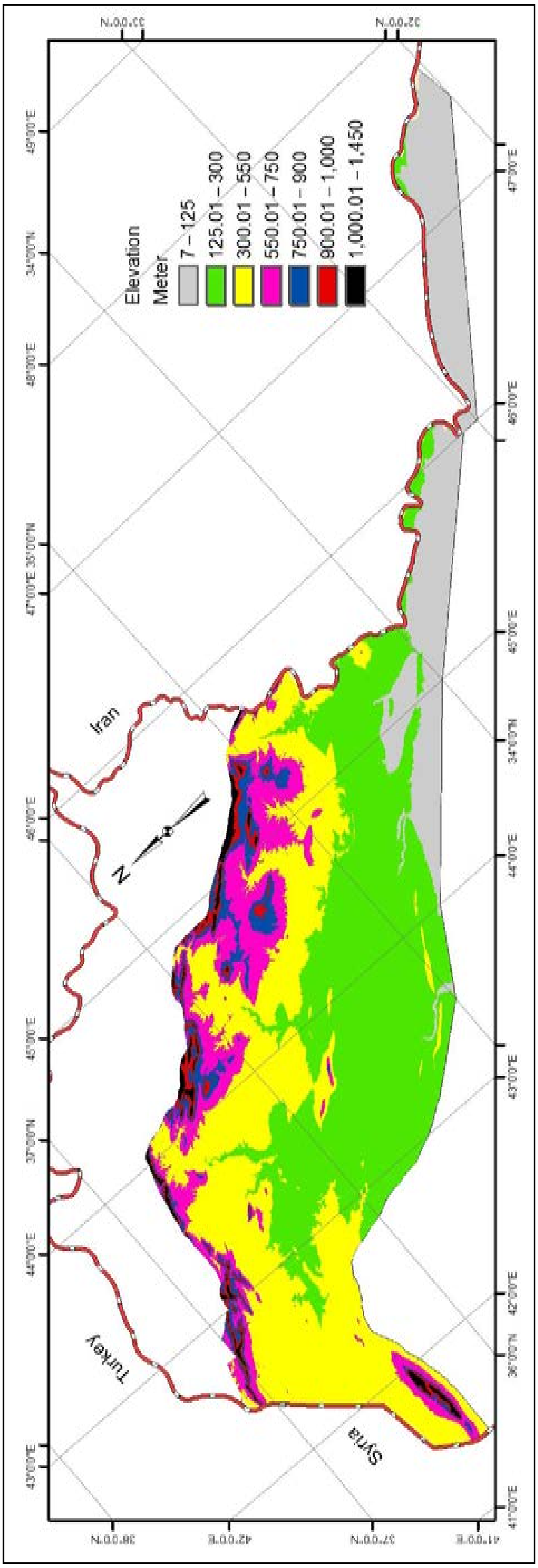

Fig.3: Map of topographic zonation of the Low Folded Zone

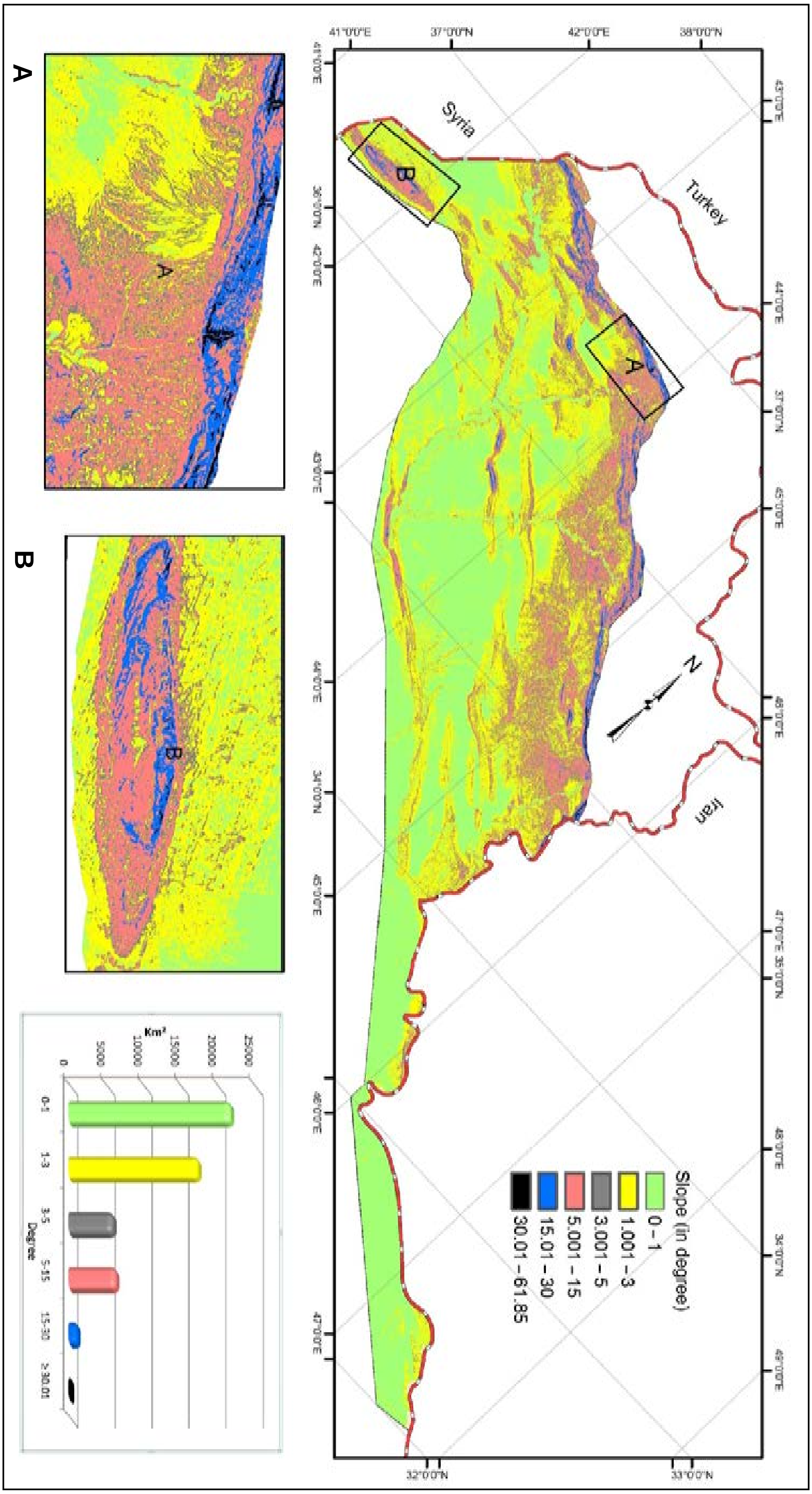

Fig.4: Slopes classification of the Low Folded Zone

The types of drainage patterns are also variable, reflecting the tectonic, lithological and climatic conditions that prevailed in the involved area. The major types of drainage patterns are shown in Fig. (5).

– **Dendritic:** This type is often developed in homogenous and uniformly resistant strata and unconsolidated sediments, where there are no structural controls, such as in Shiranish Formation (Sinjar Mountain) and in many exposure areas of Bai Hassan, and Mukdadiya formations. Dense branching of tributaries occur on steep slopes and in impervious rock types, whereas, in clastic sediments and gentle slopes the wide spaced drainage network is developed (Fig.5A).

– **Parallel:** The main valleys and those developed along dip slopes of hard rocks have parallel drainage patterns, locally regularly spaced. This type is structurally controlled and commonly developed on the limbs of the main structures, like Sinjar, Makhoul, and Makhmour anticlines …etc (Fig.5B).

– **Rectangular:** This type of drainage is found in valleys developed in alternating rock strata of different hardness, like the clastics of Injana and Mukdadiya formations (Sissakian and Youkhanna, 1979 and Sissakian, 1995). The drainage pattern is controlled by structural joints and faults (Fig.5C).

– **Radial:** This type of drainage is found on topographic domes, such as the domal structures, which are locally developed in the study area, such as the domal structure south of Taq Taq town (Fig.5D).

GEOLOGICAL SETTING

The LFZ is an integral part of the Western Zagros Fold – Thrust Belt of the Iraqi territory (Fouad, 2012a and b), which is characterized by narrow and longitudinal anticlines separated by broad synclines. Many of the anticlines are affected by longitudinal thrust and strike-slip faults. Therefore, the tectonic and structural effects, beside the type of the exposed rocks and climatic conditions have controlled the main geomorphologic units and geodynamic processes in the involved area.

The LFZ is built of sedimentary rocks ranging in age from Cretaceous to Pliocene, beside various types of Quaternary sediments (Sissakian and Al-Jibouri, 2012). The oldest exposed rocks belong to Shiranish Formation, which is exposed along Sinjar anticline and as very small exposure in Qara Chouq anticline. It comprises of marl marly limestone. The Paleogene and Neogene (Oligocene) rocks are mainly of marine carbonate with rare clastics; they usually form the cores of the high anticlines, forming structural ridges, such as in Sinjar, Maqloub, Ba'shiqa and Qara Chouq. The Early and Middle Miocene rocks are of lagoonal carbonates and evaporate, respectively. The former are exposed only in restricted areas, whereas the later (Fatha Formation) covers considerable parts of the LFZ, especially the area west of Tigris River from Ain Zala anticline to Al-Fatha vicinity. The Late Miocene – Pliocene (Injana Formation) rocks are mainly fluvial and lacustrine sediments, which marked the beginning of continental environment, together with the rocks of Pliocene – Pleistocene consist of molasse sediments (Mukdadiya and Bai Hassan formations), deposited in strongly sinking foredeep. The Quaternary sediments are well developed, especially the Pleistocene river terraces and alluvial fans of different stages, polygenetic sediments that fill the synclinal troughs, with other different types (Sissakian and Al-Jibouri, 2012).

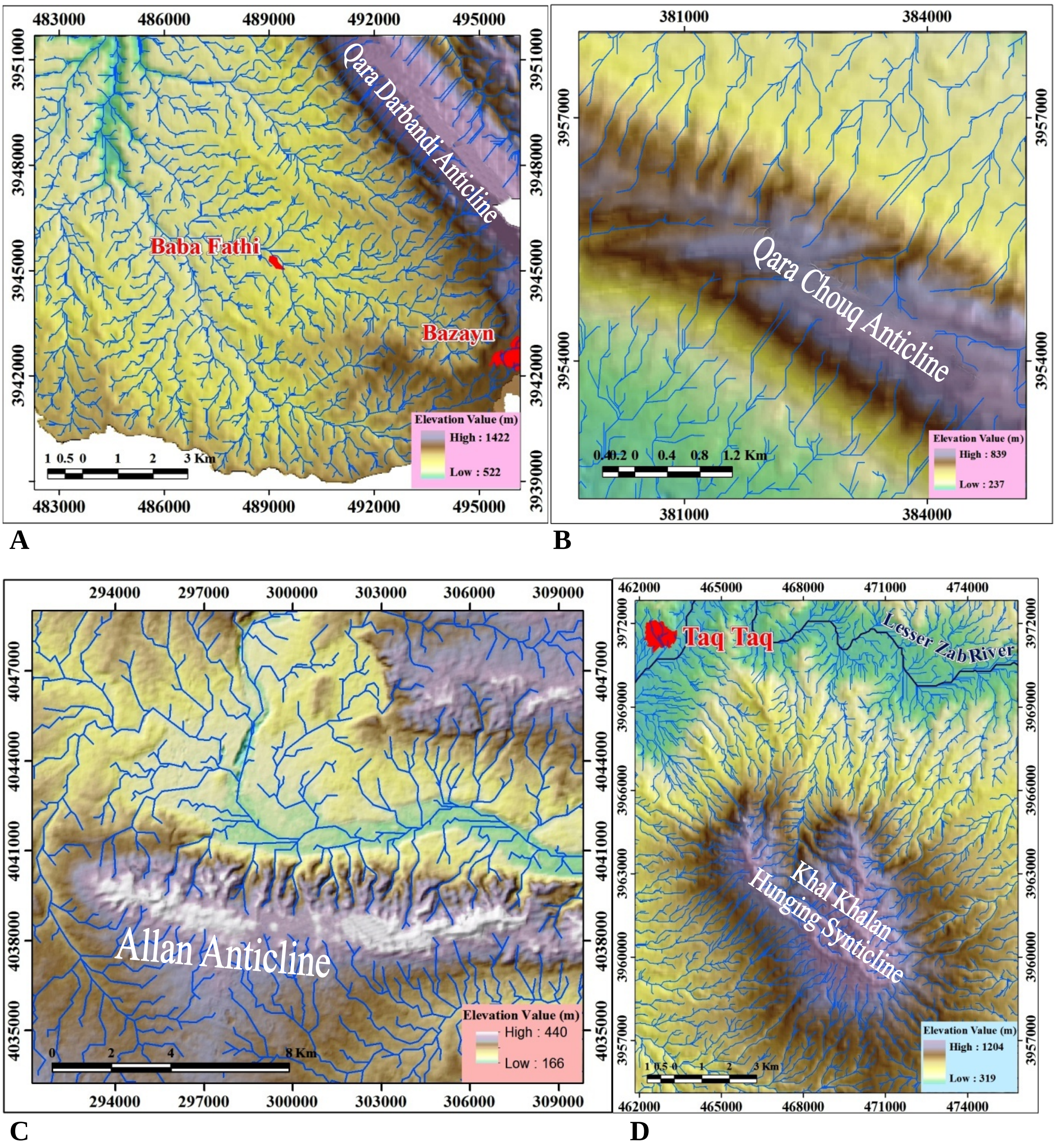

Fig.5: Major types of drainage patterns in Low Folded Zone,
A) dendritic, **B)** parallel**, C)** rectangular and **D)** radial

It is worth to mention that during Early Pleistocene, the Alpine Orogeny reaches its climax; and the last geological formation involved in this intensive orogenic movement was Bai Hassan Formation, as being evidenced by the highly tilted strata of the formation in most exposures along many structures in the area. During the Pleistocene, the intensity of the orogenic movement has continuously decreased and new cycles of denudation and aggradation have started, accompanied with considerable climatic changes. These processes have controlled the development of different geomorphologic units and landforms in different parts of the LFZ.

GEOMORPHOLOGIC PROCESSES

Weathering, mass movement, erosion, transportation and deposition are the essential geomorphic processes in the LFZ. In conjunction with geological structures, tectonic processes, climate and living thinks, they fashion landform and landscapes (Huggett, 2007). However, in the LFZ the activity of these processes and their impact on the exposed rocks and soil vary in different topographic units and they are greatly influenced by the climatic changes with time, particularly during Quaternary Period. Human activities have also significant impact on the modification of landforms, mainly through different land uses, dams and roads construction, mining and quarrying.

▪ Weathering

The LFZ 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 in the LFZ. The main reasons for that are the intensive erosion, which continuously removes the weathering material, and the scarce vegetation, especially in the barren mountainous part of LFZ. 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.

The main active mechanical processes in the LFZ area are the unloading, alternate heating and cooling (day and night, and seasonal cycles), repeated wetting and drying, whereas, the main chemical weathering processes are the solution and hydration (Fig.6). These processes are more active in gypsum and limestone bearing formations, such as Fatha, Euphrates, and Pila Spi formations, which often exposed in the mountainous and undulated areas.

▪ Erosion and Transport

The fluvial (water flow) erosion is the most prevailing and active processes in the LFZ, beside the wind processes, which have less affect on the rocks and sediments. Rill, gully, and stream (both vertical and lateral) are the main fluvial erosion types (Fig.7), 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 LFZ area. They are carrying and transporting the weathered and eroded materials from the high attitudes, and then depositing them inform of different fluvial sediments, downstream.

Fig.6: Solution hole in gypsum beds of Fatha Formation, Himreen Mountain

Fig.7: Lateral erosion on a stream bank in the badland area NE of Cham Chamal town. Note also the rill erosion on the cliff, which is built up of fine clastic sediments, within Mukdadiya Formation

The wind erosion includes two main processes; the deflation and abrasion. These processes are more effective during dry seasons, especially on the fine grained soil and sediments. The activity of wind is obviously found on the southwestern part of the LFZ, where bare and clastic sediments of Bai Hassan, Mukdadiya, and Injana formations are widely exposed. The wind activity decreases northwards in the LFZ, in accordance with increase of vegetation cover.

- **Aggradation**

The alluviation is the most dominant aggradational process, which leads to level up the topographically low surface in the LFZ. This large-scale depositional process took place in the broad synclines and flood plains of the main rivers and streams, since the beginning of Quaternary Period and still active. The recent fluvial deposition processes are restricted to narrow belts along the floors of the valleys and within the meandering belts of the rivers and streams. The colluvial deposition process has also contributed in leveling up the surface of the slopes along the margins of the intermountain depressions.

- **Mass Movements**

The main types of mass movements are landslides, rock falls, mudflow, soil creep and surface subsidence. They are developed in the mountainous and undulated areas of the LFZ, especially along the river valleys. Most types of these mass movements are related to gravity action or combined actions of gravity and water. The water saturation accelerates and increases the possibility and rate of mass movements down slopes by weight, such as landslides, mudflows and earth flows.

Several landslides have been recorded by the geological survey in different parts, of the LFZ, among them, the landslide of Sinjar Mountain (Sissakian *et al*., 1993). It was recognized within the Sinjar Formation (thick limestone beds), which overlies the Shiranish Formation (marl, marly limestone). Another good example of landslide is the three landslides developed along the northern limb of Makhoul Range (Msa'hak Dome) that extends parallel to Tigris River (Sissakian *et al*., 2004). In addition to the landslides, rock fall and mudflows have also recorded in different parts of the LFZ (Sissakian, 1993 and 1997, and Sissakian *et al*., 2006).

The rock falls, toppling and rock debris are more common, especially in the landscapes with high cliffs and steep slopes along the anticlinal ridges and the riverbanks of Tigris, Greater Zab, Lesser Zab and their main tributaries (Fig.8).

The surface subsidence phenomenon is chiefly developed in the karst areas, west and south of Mosul city, due to presence of gypsum beds of Fatha Formation. The subsidence formed as gravity collapse, when rock or soil plumped into underground cavities.

The authors believe that there may be other mass movement cases developed in different parts of LFZ, but they have not well documented during the regional geological mapping.

Fig.8: Toppled blocks of sandstone on a cliff, southern bank of Lesser Zab River, about 25 Km east of Taq Taq town

GEOMORPHOLOGIC UNITS

The geomorphic map of the LFZ at scale of 1: 1000 000 (Figs.9, 10, 11 and 12) 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 involved area. These units are classified, hereinafter into seven genetic classes; each class includes different lithomorphologic units.

▪ 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 exposed bed rocks. The following units and landforms are recognized in the LFZ area.

– **Structural Ridges (Anticlinal Ridges):** These ridges represent the narrow and convex crests of the tight anticlines in the LFZ (Figs.9, 10, 11 and 12). They are well developed on top of the most anticlines of the LFZ, especially when hard limestone and dolomitic limestone rocks are exposed, such as on Sinjar, Ain Al-Safra, Ba'shiqa, Maqloub, Makhoul, Makhmour, (Fig.13) Butma, Ain Zala, Allan, Himreen etc… anticlines. The ridges generally have asymmetrical slopes, trending NW – SE, in central and southeastern parts of the LFZ, then gradually changes east, west and northwest of Mosul to almost E – W; their surface is semi-barren, uneven and dissected by net of rills, galleys and streams.

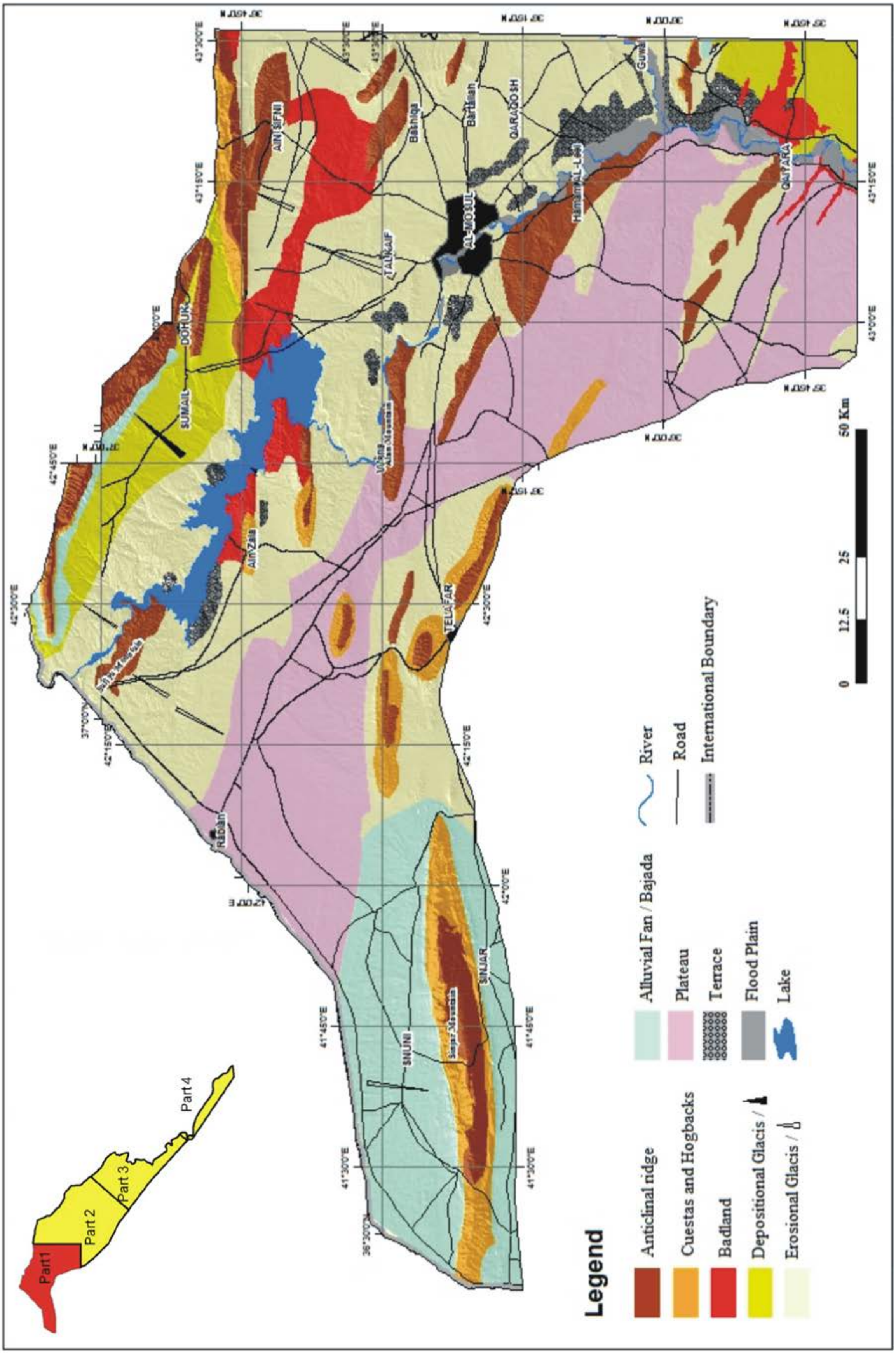

Fig.9: Geomorphological map of the Low Folded Zone (Part 1)

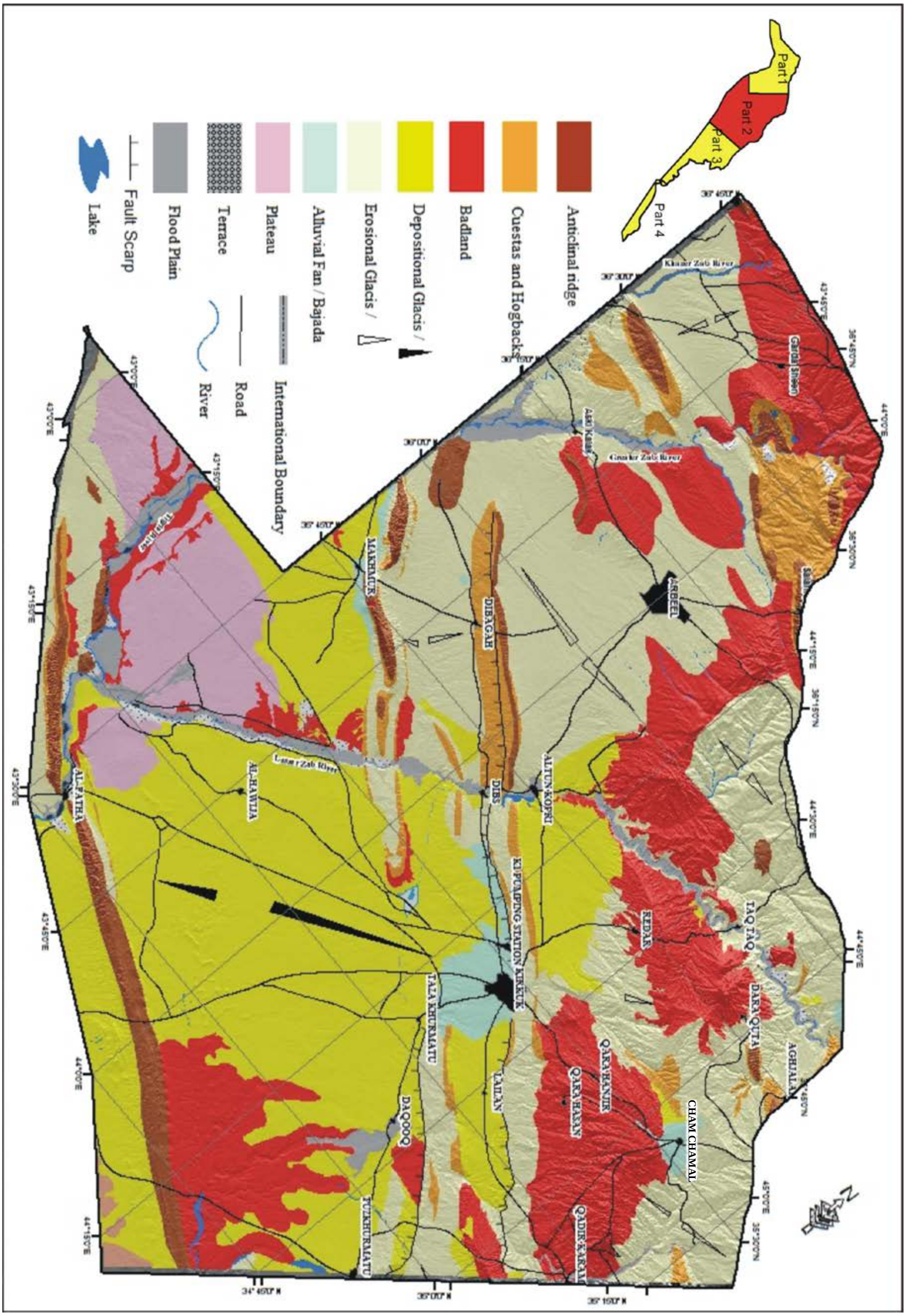

Fig.10: Geomorphological map of the Low Folded Zone (Part 2)

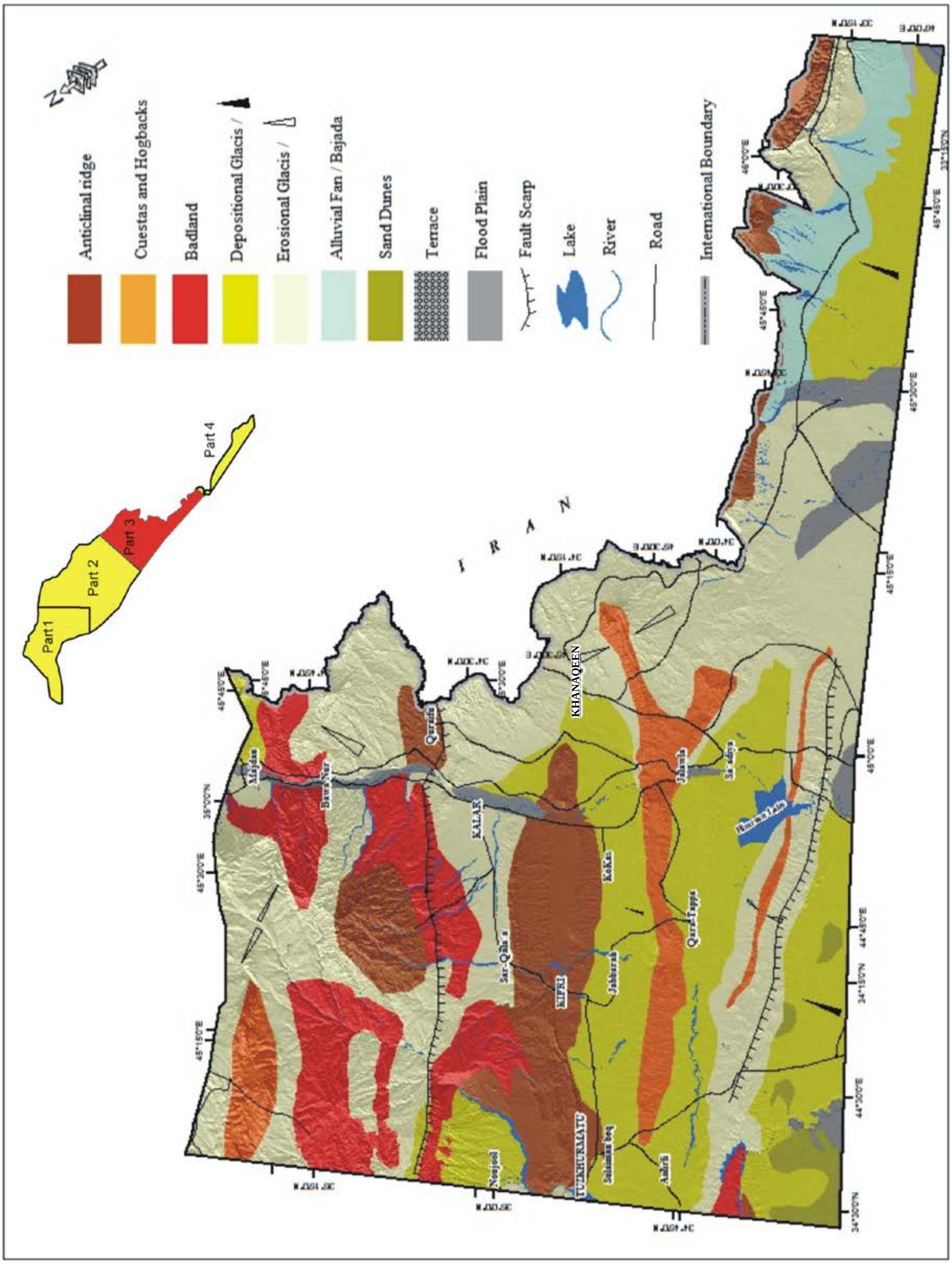

Fig.11: Geomorphological map of the Low Folded Zone (Part 3)

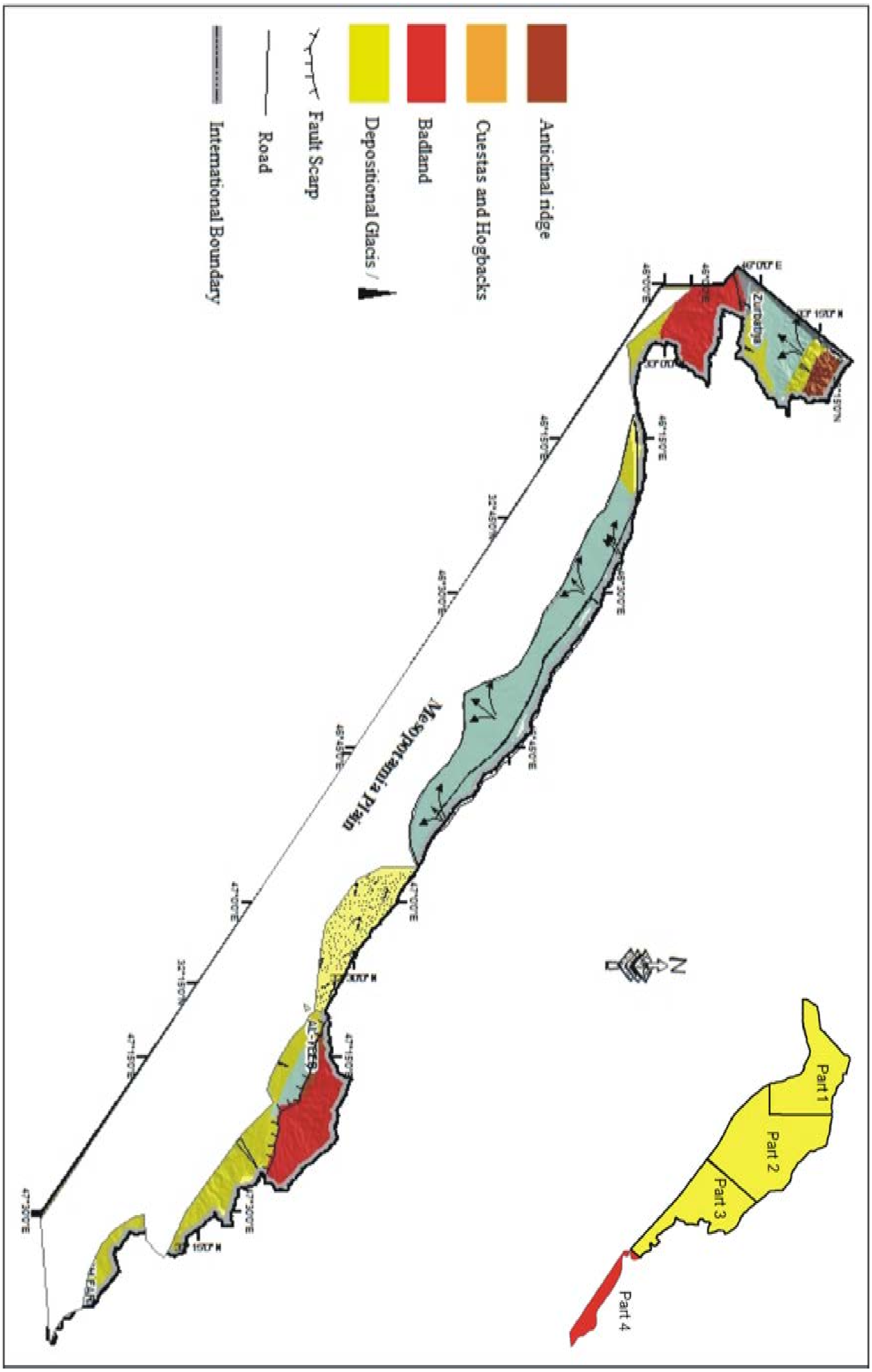

Fig.12: Geomorphological map of the Low Folded Zone (Part 4)

– Homoclinal Ridges (Cuestas and Hogbacks): These ridges are well developed over broad areas along the strike of almost all anticlines in the LFZ (Figs.9, 10, 11 and 12). They are formed, when strata of different resistance to erosion are inclined and subjected to erosion. These types of ridges are differentiated according to the dip of the beds. **Cuestas** form in beds dipping gently perhaps up to 5 degrees. **Homoclinal ridges** are just asymmetrical and develop in more steeply tilted beds with a dip of (10 – 30)°. **Hogbacks** are symmetrical forms that develop where the strata dip very steeply at 40° plus (Huggett, 2007). Cuestas are well developed in broad low anticlines and the outer limbs around the anticlines, such as in Himreen, Qara Chouq, Cham Chamal Taq Taq and many other anticlines, especially in Injana, Mukdadiya and Bai Hassan formations, which comprise of alternation of soft and hard rocks. Homocline and hogback ridges are well developed on the inner limbs and near cores of almost all anticlines, where the strata are more steeply tilted, such as in aforementioned anticlines. The ridges are often developed on hard rocks, especially in limestone, dolomite and dolomitic limestone, and sometimes in sandstones and conglomerates of different exposed formations. These tilted rocks either form continuous ridges or dissected by streams that cross the strike of the strata. When the steeply tilted strata are deeply cut by streams, then **flatirons** are formed with apices pointing up the dip of the strata. Flatirons are well developed in Sinjar, Maqloub and Ba'shiqa anticlines, especially in Pila Spi Formation. Their heights depend mainly on the thickness of the beds. The thicker the beds the higher the flatirons are.

– Plateaus: These landforms are developed on top of more or less horizontal strata, when they are dissected, then mesas are developed. In the LFZ area, both landforms are found in synclinal troughs, and some times on the top of anticlines, which have broad hinge zones. Hamza (1993) recognized many plateaus: on the top of gypsum beds of Fatha Formation, on Injana Formation in the area between Qaiyara and Makhoul anticlines and in Bai Hassan Formation, which extends between Ain Al-Safra anticline and Greater Zab River. The authors also noticed such land forms in the broad syncline northeast of Kirkuk structure.

– Fault Scarp: Most of NW – SE trending structures, in the area between Himreen and Kirkuk structures, are affected by low-angle thrust faults (Sissakian, 1993, and Barwari and Slewa, 1995). The front of the up thrown blocks of these thrust faults form scarp landforms, following the fault lines. The height of these scarps varies from few tens to more than one hundred meters; anti-dip valleys and streams usually dissect their slopes. Such scarps are well visible along Pulkhana and Kirkuk structures.

- **Units of Denudational Origin**

Two major units of denudational origin are developed in the LFZ; glacis (pediments) and badlands. They cover vast areas; reach many hundred square kilometers, distributed on different places throughout the LFZ area (Figs.9, 10, 11 and 12).

– Glacis (Pediments): In the LFZ pediments are well developed on both sides of majority of the anticlines, with greatly variable extensions, e.g. the width of the pediment south of Sinjar mountain reach 22 Km (Al-Daghastani, 1989), and the width of the pediment plain southwest of Kirkuk city reaches more than 50 Km. The later is entrenched by many wide braided streams. However, two types of glacis are differentiated in the LFZ area; these are: **1) Depositional Glacis** and **2) Erosional Glacis** (Figs.9, 10, 11 and 12). However, mixed glacis also exist in the LFZ, but they have not differentiated on the attached map, because it requires further detail mapping. These landforms are represented on the GEOSURV's geological maps as slope sediments, polygenetic and sheet run-off sediments.

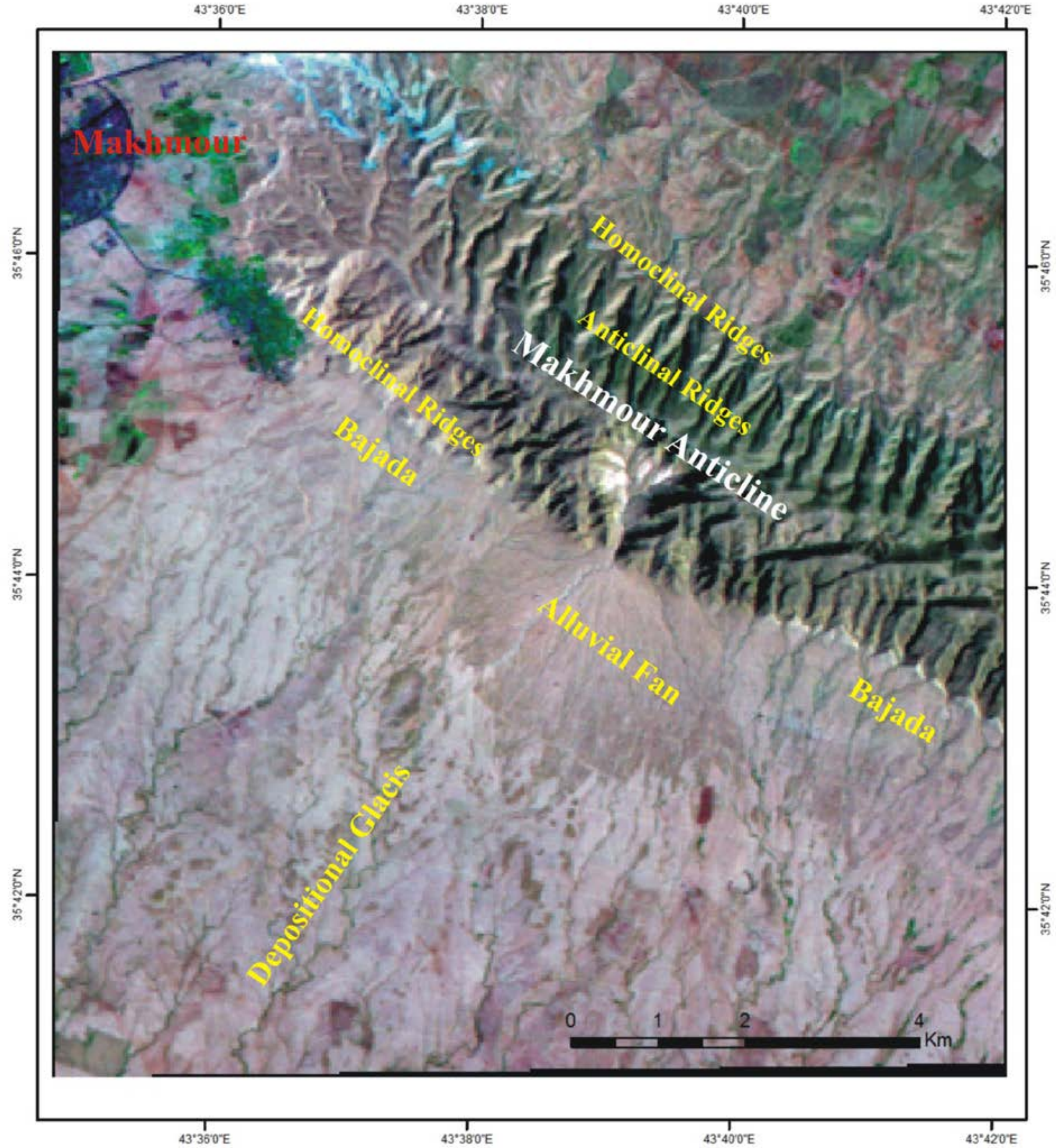

Fig.13: Different geomorphologic units in Makhmour area
(Landsat TM image, 2010)

1) **Depositional Glacis** form broad gentle slopes with smooth or low relief surface (Fig.13); they are formed by running water, mainly sheet wash and sheet flow. They are built of heterogeneous alluvial sediments derived from the upland masses, generally loamy soil with admixture of rock fragments and/ or pebbles. Their thickness may exceed 10 m, but mainly ranges from (2 – 5) m, usually; areas of these glacis are occupied as agricultural fields.

2) **Erosional Glacis** form gently sloping rock-floored erosion commonly of low relief or slightly undulated surface; they are developed by running water, mainly sheet and rill erosion. They are commonly mantled by thin discontinuous veneer of alluvial sediments, underlain by bedrocks (occasionally tilted beds).

– **Badlands:** Badlands are developed in both flat and mountainous areas: they are distributed in deferent parts of the LFZ. They are well developed in the areas built up of soft rocks, like Bai Hassan (Fig.14), Mukdadiya, Injana, and Fatha formations, and also Quaternary alluvial sediments, but with less extend. The badland areas are characterized by very dense drainage network separated by narrow water divides, with either flat or rounded crests. The valleys of 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 showers.

It is worth mentioning that badlands in the present study are genetically, considered as one of denudational units, depending on the major factor, which is denudational processes. But, in some badland areas, tilted strata are also involved, which reflect existence of structural influence. Therefore, in such cases denudational – structural origin is more applicable, such as the badlands within Cham Chamal North and Taq Taq anticlines.

Fig.14: Badland morphology, east of Kirkuk vicinity

- **Units of Fluvial Origin**

Many depositional landforms of fluvial origin are developed in different places in the LFZ. 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 terraces, alluvial fans and flood plains. The following fluvial landforms have well developed in the LFZ 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 down-cutting and lateral migration of the river channel. They generally are built up of rounded to sub-rounded gravels and sands with greatly variable gravel sizes. All main rivers; in the LFZ deposited their own suites of alluvial terraces; the suites of terraces in particular river valley have developed in different levels above the present river level. Generally, (2 – 4) terrace levels are recorded along the main rivers, after the geological mapping, which has been conducted by GEOSURV in different parts of the LFZ. However, **Tigris River** terraces are well recorded by many authors among them; Taufiq and Domas (1977), Hamza (1993) and Fouad (2002). Hamza (1993) recognized four stages of terraces along the left bank of Tigris River between Mosul and Greater Zab River. The surfaces of the four stages lie on different levels above the present level of the river; these are, from older to younger: (90 – 100) m, (55 – 60) m, (35 – 40) m and (5 – 10) m, respectively. The lower two levels can be further divided into more than two sub-levels. On the right bank of the river, the fourth level is not well preserved, either it has not been deposited due to structurally high position or it has been eroded. These terrace also confirmed by Fouad (2002), Hagopian and Veljupek (1977) and Al-Mubarak and Youkhanna (1976). However, Taufiq and Domas (1977) and Domas and Taufiq (1987) recognized ten stages of terraces in Dohuk – Ain Zala area. The relics of the upper (older) four stages lie very far from the present day river course and at relative elevations range from (240 – 142) m. The same authors concluded that these terraces are the result of deposition on a vast Pliocene plain, while all younger terraces were deposited in a narrow valley. In this case, the authors believe that these terraces could be equivalent to Bai Hassan Formation, and/ or to the recently suggested "Dokan Conglomerate" by Karim and Taha (2012). The remaining six stages (Pleistocene) were merged into four groups, which are more or less correlated with those terraces developed in Mosul vicinity and continue downstream to north of Al-Fatha. However, the lower two levels of terraces have been inundated by the Mosul Dam Lake after construction of the dam.

It is worth mentioning that the geomorphic positions and spatial distribution of remnants of different terrace stages in Tigris valley have often had complicated histories, with several phases of accumulation and down cutting that interrupted by phases of lateral erosion. These different phases have mainly controlled by climatic changes, and tectonic and structural factors. The other main rivers flowing within the LFZ area have the same histories, like in Tigris, but with less complication. From the authors' field observations four river terrace stages have been recognized along the Lesser Zab River, east of Taq Taq town (Fig.15).

– **Alluvial Fans:** The alluvial fans are developed on both limbs of Sinjar Mountain, along southwestern flanks of Makhmour (Fig.13), and Kirkuk structures, in the vicinities of Makhmour town and Kirkuk city, respectively. In addition to many small alluvial fans deposited by ephemeral streams, when they emerge from the mountains in different places of the LFZ; the majority of them are not recorded during the geological mapping. The alluvial fans are either found as individual fans with clearly visible fanlike shape on plan view, or laterally coalescent forming Bajadas (Fig.13). The Bajadas often form narrow belts, with (2 – 3) Km width, along the foothill slopes of the aforementioned localities. The extensions of large alluvial fans reach up to 17 Km; such as in Kirkuk fan, which was recognized by the satellite images (Al-Jaf and Kadhim, 2010).

Fig.15: Four terrace stages of Lesser Zab River, east of Taq Taq town
A) First (oldest) and second stages, **B)** Third and fourth stages

The alluvial fan system of Sinjar Mountain area represents good example for the fans of semiarid region and tectonically active areas. Many authors have studied this fan system; some of them covered different geomorphologic aspects of it. Ma'ala (1978) designated only two stages of alluvial fans that were developed during Pleistocene – Holocene. The first stage comprises boulders of size range (20 – 70) cm, but blocks up to 1 m occur too, whereas in the second stage it is smaller and range from few centimeters to 20 cm. Al-Daghastani (1989) introduced a geomorphic map of Sinjar anticline, in which the alluvial fans and Bajada are well delineated, using aerial photo interpretation. He recognized one stage of alluvial fans surrounded by accumulation glacis. Al-Daghastani and Al-Dewachi (2009) have mapped the alluvial fan system of the northern plain of Sinjar mountain that forms "Bajada", but they did not mention about the stages. They concluded that this alluvial fans system crosses many structural lineaments indicating that these fans respond to neotectonic activity. However, Sissakian (2011) concluded that generally four stages of alluvial fans have developed along the northern slopes of Sinjar Mountain. They extend northwards to (20 – 22) Km whereas, in the southern slopes they are relatively not well developed, and their extent is (8 – 9) Km. He also concluded that the first stage of alluvial fans are still active, whereas the fans of the remaining three stages are partly dormant. The age of the first stage fans is Early Pleistocene, whereas, the fans of the other three stages are of Pleistocene – Holocene age. The authors believe that the deposition (alluviation) processes of Early Pleistocene alluvial fans of the first stage are not still active, but the active processes are represented by sheet, rills, gully and stream erosion, which incised the bodies and old surface of the alluvial fans. Recent and sub-recent (Holocene) valley fills of the streams, which are emerging from the mountains, represent the still active depositional unit. These valley fills separated from the Pleistocene fan bodies by small cliffs or break in slopes, which could be considered as the fifth stage of alluvial fan system.

– **Flood Plains:** The flood plain sediments form irregular strips along the main rivers and large streams in the LFZ; their stretches are limited within the extent of meandering belts of the river channels. The fluvial channels are often bounded by high cliffs built up of river terraces or by bed rock walls in some places, when the rivers or streams cross the mountain areas. The morphology of the flood plains is also influenced with different types of river channel; such as straight, meandering and braided channels. The width of the flood plains is greatly variable within the same river or steam, as well as from one river to another; it is ranging from few tens of meters in small branches, (1 – 2) Km in Greater Zab and Lesser Zab rivers and reach up to 5 Km in some places along the Tigris River. 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. Extensive areas of flood plains are occupied as agricultural lands (Fig.16).

The flood plains are developed in stages of different levels above the river. Generally, (2 – 3) levels; separated by low cliffs of (1 – 3) m height are often visible in many places along the main rivers; such as Tigris, Greater Zab, Lesser Zab and Diyala. However, Hamza (1993) recognized four stages of flood plain in the area between Mosul and Al-Fatha; exceptionally the surface of the oldest level attains 24 m above the river. Taufiq and Domas (1977) also mentioned a height of flood plain reach up to 22 m on Tigris River in Dohuk – Ainzala area. Nevertheless, they attributed this exceptional case due to a disproportion between the water discharge during high water conditions and a small width of the river valley, which raises water high above the normal level. The authors are in accordance with this explanation.

Fig.16: Flood plain of the Lesser Zab River, about 25 Km east of Taq Taq town.
It is bounded by river banks of (10 – 12) m height

– Infilled Valleys: These are developed everywhere in the LFZ area. The valleys are created mainly by fluvial processes, but often in conjunction with tectonic processes. Their composition, width and thickness are greatly variable, depending on source rocks, geomorphic position and size of the valley. The valleys in mountainous areas are filled by mixture of fine and large rock fragments with sands and gravels, whereas in the flat areas the valleys are filled by relatively finer clastics and better sorted. The width of the valleys ranges from few meters in the young streams' orders to more than one kilometer in the mature orders. Khassa Soo, Tawouq Soo and Tuz Chai are good examples of very wide infilled valleys. Hamza (1993) mentioned that the old infilled valleys are either buried below thick pediment sediments or left as two-cycle valley, after re-incision of their courses, in Mosul – Fatha area. The formation of two-cycle valleys indicates climatic changes. Another example of two cycles of infilled valley is given in Fig. (17).

Fig.17: Two levels of valley fill sediments developed along the course
of one of main streams that drains into the Lesser Zab River,
NE of Cham Chamal town

▪ **Units of Solution Origin**

The solution landforms are mainly developed in the mountainous areas of the LFZ, where gypsum and limestone rocks are widely exposed. Caves are the most common solution landform found in limestones, which are well exposed in Ba'shiqa, Maqloub, Ain Al-Safra, and Sinjar mountains. The entrance of the caves varies from less than one meter to several tens of meters. In some of these large caves stalagmites and stalactites are developed; such as Al-Naqout cave, (near) in Maqloub mountain, NE Mosul city.

Sinkholes are another type of solution landforms, which are commonly developed, in gypsum beds of Fatha Formation, especially in the undulate and mountainous areas, west of Tigris River, from south of Mosul city up to Mosul Dam. They are formed due to solution of gypsum beds. The shape of the sinkholes is usually concave, irregular shapes are also common. The diameter varies from one meter up to (15 – 25) m, whereas the depth does not exceed 10 m (Sissakian, 1995). Karstified gypsum landforms are also well developed in the aforementioned areas, leading irregular channels and cavities. The karts system is of two types: the old karsts (fossil karsts), and the active karsts. The former are less active now and are often filled by heterogeneous materials (rich in marl), whereas the later are still active; usually empty (Jibrail, 1990).

▪ **Units of Evaporation Origin**

There are two landforms of evaporation origin in the LFZ area, they are mentioned hereinafter.

– **Gypcrete:** The gypcrete commonly caps different Pleistocene clastic sediments in the LFZ area, such as terrace, slope and locally polygenetic sediments; especially in the areas built up of Fatha Formation. It is well developed on the slope sediments along the limbs of the anticlines in Fatha – Mosul area, Himreen anticline and southwestern slopes of Pulkhana anticline. Sissakian (1978) mapped considerable gypcrete bed on the top of slope sediments in vicinity of Jallawla town (Khanaqeen area). Good exposures of gypcrete could be found along the banks of Tuz Chai and Tawooq Soo Rivers, when they cross Pulkhana anticline. Moreover, gypcrete is developed on the residual soil of the Fatha, Injana Mukdadiya and Bai Hassan formations. The thickness of gypcrete commonly ranges from (< 1 – 2) m and occasionally reaches 5 m. Gypcrete formed by fine gypsum crystals growing at the top of clastic sediments, either by enclosing or displacing the clastic sediments (Huggett, 2007). It is formed by evaporation of the solutions enriched in calcium – sulphate, raised to the surface by capillary action.

– **Sabkha:** This is well developed in one locality, which lies at about 20 Km northeast of Fatha on both sides of Fatha – Kirkuk road. It forms very flat surface with salt crust. Salt is deposited in wide shallow depression after evaporation of saline surface water and also contribution by near surface ground water. Aeolian sediments influence the depression.

▪ **Units of Aeolian Origin**

Although the whole LFZ is affected by wind activity, but the Aeolian landforms are restricted in small areas. Sand dune fields and discontinuous scattered sand sheets, especially in the flat area northeast of Al-Fatha, represent them. Sand dunes are well developed along the left bank of the Lesser Zab River; west, northwest of Al-Hawija town, forming narrow strip with about 1 Km width. Other small sand dunes field is developed in the shallow depressions south of Al-Hawija. The sand dunes are mainly of Barchan type, partly fixed, and

(1 – 2) m in height. Moreover, many small patches of Aeolian accumulations are scattered every where in Himreen Mountain, due to the presence of thick sequence of soft clastic sediments.

The southwestern parts of the LFZ are considerably affected by the Aeolian sediments, which are transported from the Mesopotamian Plain and Al-Jazira Province. These Aeolian contaminations are progressively increasing, nowadays due to drought climatic conditions and scant vegetations.

- **Units of Man-Made Origin**

The study area is rich in anthropogenic landforms; some of them are related to historical sites and others are related to the recent human activities. The ancient sites are represented by old settlements, like Nineva, Namrood, and Khorsabad; high fences, which may reach 10 m in height, usually surround them. Others are the isolated hills (or hillocks locally called tells), which are frequently scattered in the flat and slightly undulated areas; their height may exceed 25 m. Erbil and Kirkuk castles are good examples of outstanding ancient artificial mounts within the flat areas of the LFZ. Over the last two centuries or so, human activities have had an increasingly significant impact on the transfer of Earth materials and the modification on the landforms, chiefly through agricultural practices, mining and quarrying, and the building of road and cities (Huggett, 2007), in addition to construction of dams. In the LFZ, these man activities have produced different landforms; such as the four dams located in the study area namely, Mosul, Dibis, Adhaim and Himreen dams with related wide lakes. Many hundreds of gravels and sand (Fig.13), limestone and gypsum 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.

Fig.18: Gravels and sand quarry in Lesser Zab River valley, east of Taq Taq town

DISCUSSION

The geomorphologic evolution of the LFZ 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 tilted beds of old Tigris River terraces, which has been mentioned by Fouad (2002) in Khanouga area. However, the effect of tectonic activity continued during Quaternary Period, but with low intensity, as being evidenced by the horizontal lying beds. This tectonic activity and 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 Pliocene and beginning of Pleistocene. The denudational processes were dominating in the structurally elevated areas, where the downward erosion was activated, whereas the aggradational processes were prevailing in the structurally low troughs; and they have tended to level the surface up. The flowing water was a dominant geomorphologic agent, which led to formation of many erosional and depositional landforms in the involved area.

During the Quaternary Period, the climate became 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 are 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 LFZ, specially the river terraces, alluvial fans and pediments. Whereas, 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.

During the geological survey in the LFZ, emphases have been paid to evaluate the terrace sediments. Consequently, maximum four main stages of terrace groups of Pleistocene age were recognized in the main rivers' valleys. In places sub-terrace stages also occur, indicating either minor climatic oscillations or local changes in fluvial system itself. However, Domas and Taufiq and Domas (1977), in Dohuk vicinity, also suggested Pliocene terrace group. The authors believe that this suggestion requires further chronological evidences. Generally, the average height of oldest Pleistocene terraces is around 100 m above the present river level. Geomorphologically, this figure means that the local base level has dropped down around 100 m during Quaternary Period; mainly due to down cutting erosion and partly owing to tectonic uplift of mountain areas. However, the average height ranges from (80 – 140) m.

At the end of Pleistocene and beginning of Holocene, the valley terraces were deposited within deeply incised valleys, then covered by thick blanket of flood plain sediments of Holocene age. During the same time, the gypcrete and very locally calcrete duricrust 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. Therefore, new fluvial cycle was developed and is still continued; it is accompanied by progressive increasing in aeolian activities on different parts of the LFZ area.

CONCLUSIONS

From reviewing the aforementioned data, the following can be concluded in the LFZ.

- The LFZ is topographically divided into two main parts: the mountainous part and the flat and slightly undulated part.
- The slopes are classified into six classes depending on the gradient, expressed in degrees.
- Four main types of drainage patterns are recognized; these are dendritic, parallel, rectangular and radial.
- The most active mechanical weathering processes are: the unloading, alternate heating and cooling, repeated wetting and drying, whereas the main active chemical weathering processes are: solution and hydration, but with less degree.
- The fluvial (water flow) erosion was most dominant processes during Pliocene and Quaternary periods, and is still active, but with less degree.
- The geomorphologic units are classified into seven 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 and climatic factors.
- Three Structural-Denudational units are recognized, these are: Anticlinal Ridges, Homoclinal Ridges and Plateaus, in addition to Fault Scarp landforms.
- Two major units of Denudational Origin are recognized Glacis (Pediments) and Badlands.
- Many depositional landforms of fluvial origin are well developed in the LFZ, these are: River Terraces, Alluvial Fans, Flood Plains and Infilled Valleys. The first two landforms are of Pleistocene age, whereas the second two are of Holocene age.
- Sinkholes and caves are most common solution landforms, which are well developed where gypsum and limestone are widely exposed. Their diameter reaches up to (15 – 25) m, and the depth ranges from (1 – 25) m.
- Gypcrete and sabkha represent the units of Evaporation Origins; their formation refers to arid and semiarid climatic conditions.
- The LFZ is rich in anthropogenic landforms; some of them are represented by the ancient settlements and artificial hills, and the others related to recent man activities, such as agricultural lands, cities, roads, dams, water reservoirs and quarries.

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