Factors Controlling the Development of Straight Valleys and Streams in the Kurdistan Region, North and Northeast of Iraq

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***Abstract*–The Iraqi Kurdistan Region is a mountainous area with relief difference ranging from few hundred meters up to 3000 m, and locally more. Almost all of the mountains form anticlines that have NW–SE trend changing westwards of longitude to E–W. The carapace of the majority of the mountains is built up of Cretaceous rocks; however, some of them are of older rocks. Many of those anticlines are crossed by straight valleys and/or are crossed by streams and rivers which form again straight lines and almost coincide with regional lineaments, usually in N–S or NE–SW trend. The studied straight valleys are controlled, most probably by tectonic factors, therefore, exhibit special topographic forms, like straight lineaments crossing many successive anticlines, and also clear bending in some of the ridges in their crossing points to the valleys and/or streams. This paper aims to determine and discuss the factors that control the development of the straight valleys and/or lineaments. To achieve this aim, remote sensing and GIS techniques were followed, using Landsat, QuickBird images as well as geological maps of different scales, and different published articles.**

***Index Terms*–Iraq, Lineament, Straight valley, Zagros.**

I. Introduction

The northern and north-eastern parts of Iraq (Iraqi Kurdistan Region) form physiographically mountainous areas with very rugged topography, including many shallow plains; all of them are almost tectonically controlled (Sissakian and Fouad, 2012). The relief differences of the mountains are highly variable in different parts, increasing north- and northeastwards and attaining up to 3000 m, and exceptionally more. This rugged topography with the presence of long and narrow anticlines (Sissakian and Fouad, 2012; Fouad, 2012; Othman and Gloaguen, 2014; 2013a; 2013b) and climatic effect has contributed in increasing the intensity of the erosion, the water being the main agent. Consequently, the anticlines are deeply dissected by tens of erosional forms, which are continuously developing and enlarged in size due to the continuous growth of the anticlines (Keller and Pinter, 2002; Huggett, 2007; Ramsey, *et al*., 2008).

The main aim of this study is to delineate and discuss the factors controlling the development of straight valleys that drain many developed wine glass forms in many anticlines within the study area.

The location of this study extends in the northern and northeastern parts of Iraq; it almost coincides with the southern limits of the Low Folded Zone in Iraq, which runs along the southern limits of Himreen–Makhoul–Sinjar Mountains (Fig. 1). The coverage area of the study area is about 83240 km^2. The studied area is located, physiographically in the extremely rugged, high amplitude mountainous and low mountainous provinces (Sissakian and Fouad, 2012), whereas tectonically, it is located in the Outer Platform of the Arabian Plate with small part of the Iranian Plate "Sanandaj–Sirjan Zone" (Fouad, 2012). The exposed rocks in the study area range from Ordovician up to Pliocene, but the Cretaceous rocks being the most widely exposed (Sissakian and Fouad, 2012).

A. Materials Used and Methodology

To achieve the main goal of this study, many materials were used represented by geological maps, at the scale of 1:100,000 and 1:250,000, topographical maps, at the scale of 1:100,000, Google Earth, DEM, and satellite images such as QuickBird data, with 0.6 m spatial resolution.

The geological and topographical maps with the satellite images of Landsat 8 Operational Land Imager (OLI) and QuickBird images were used to recognize those anticlines, which exhibit straight valleys and/or streams, in the studied

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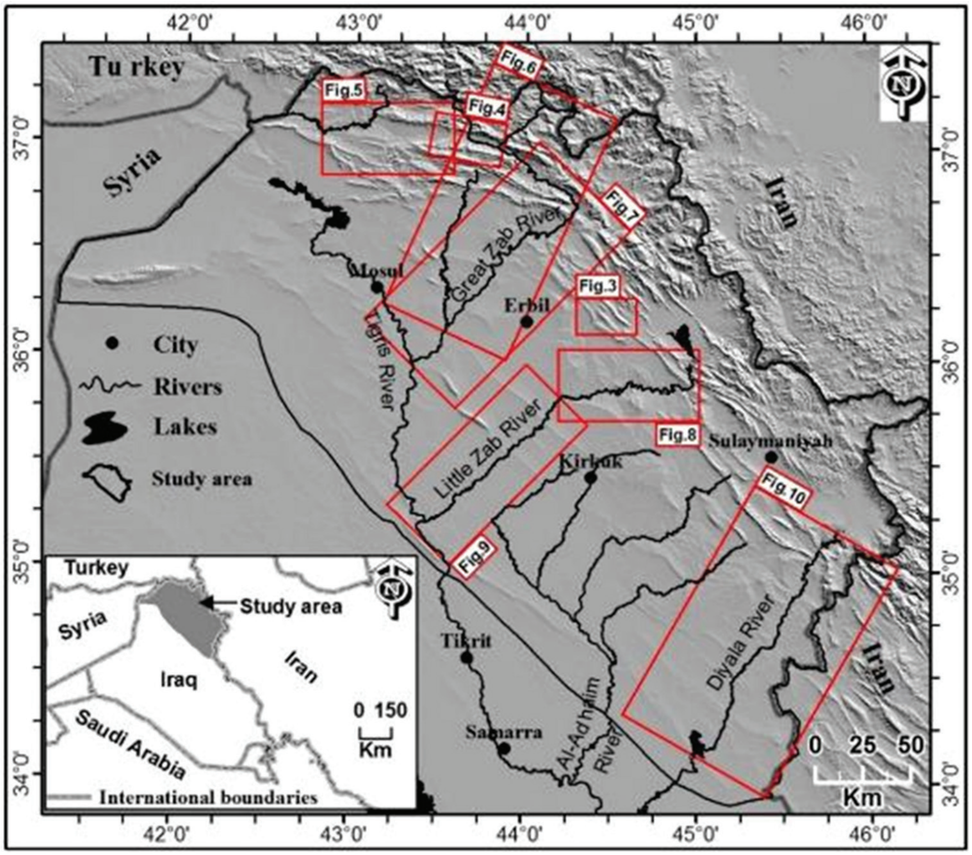

Fig. 1. Hillshade image generated from digital elevation model GMTED2010 (resolution 7.5 Arc) showing the location of the study area.

area. Geological maps and reports of the studied area are compiled by Sissakian (1995; 1993); Fouad (2007); Al-Mousawi, *et al*. (2008); and Sissakian and Fouad (2014a; 2014b; 2014c).

Fieldwork was carried out during 2006–2012 (Sissakian and Fouad, 2012) to acquire interesting data, such as type of the exposed rocks in and around the straight valleys and/or streams. Some structural data were also reviewed to elucidate the relationship between the straight valleys and the present structural features.

B. Previous Studies

The geomorphological and tectonic aspects of the studied area are dealt by many authors. However, none of them emphasized on the factors that control the development of the straight valleys and/or streams developed in some of the anticlines. Nevertheless, some dealt with the subject and they are mentioned bellow. Parts of the studied area were investigated by Al-Jaf and Kadhim (2010) and Al-Ma'amar, *et al*. (2011). They compiled the geomorphological map with a scale of 1:250,000 for Kirkuk, and Erbil and Mahabad Quadrangles, respectively (Sissakian 1993; Sissakian and Fouad, 2014a; 2014b). Both maps mentioned the presence of some wine glass forms but did not comment on the form of the draining straight valleys and/or streams. Yacoub, *et al*. (2012) and Sissakian, *et al*. (2014c) created the geomorphological map of the Low Folded Zone and the High Folded Zone in Iraq, respectively, and reported about the presence of many wine glass forms, and they also did not comment on the form of the draining straight valleys. In addition, Sissakian and Abdul-Jabbar (2010) studied the origin of many transversal gorges in the studied area, but they dealt only with those gorges that cross the whole anticline. Sissakian *et al*. (2014a) studied some transversal linear features in the study area but did not comment on the concerned straight valleys of the current study. Moreover, Sissakian *et al*. (2015) studied the Galley Ali Beg Gorge, which is within the current studied area, and dealt with many wine glass forms but again did not comment on the developed straight valleys and/or streams which are dealt with in the current study.

Tectonically, Jassim and Goff (2006) identified five major transversal blocks in Iraq, based on various sources, including satellite images, gravity and magnetic gradients, and to a lesser extent seismic data. These blocks are bounded by major transverse faults, which have a NE–SW or a N–S trend and are called "Transversal System." However, some of these transversal faults coincide with straight valleys in the current study area, such as the Greater Zab, Little Zab, Diyala Rivers, and Galley Ali Beg Gorge.

Shihab (2015) studied structural analysis in the High Folded Zone northeast of Iraq, and the results of his study manifested that the transversal faults could be grouped with another one, which is a type of strike-slip fault, and had played an important role to be developed with en echelon set or transpression zone. However, the structural model suggested by his study explains that the structural factors might have controlled and formed extensions to the valleys, being either straight or curved.

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II. Geological Setting and Study Area

The majority of the studied area is located in the extreme northeastern part of the Arabian Plate, except a very small part that is located in the Iranian (Eurasian) Plate, called Shalair Terrane (Sanandaj–Serjan Zone) (Fig. 2). The studied area is located within the Zagros Suture, Imbricate, and High Folded Zones, and most parts of the Low Folded Zone, from northeast toward southwest, respectively (Fig. 2).

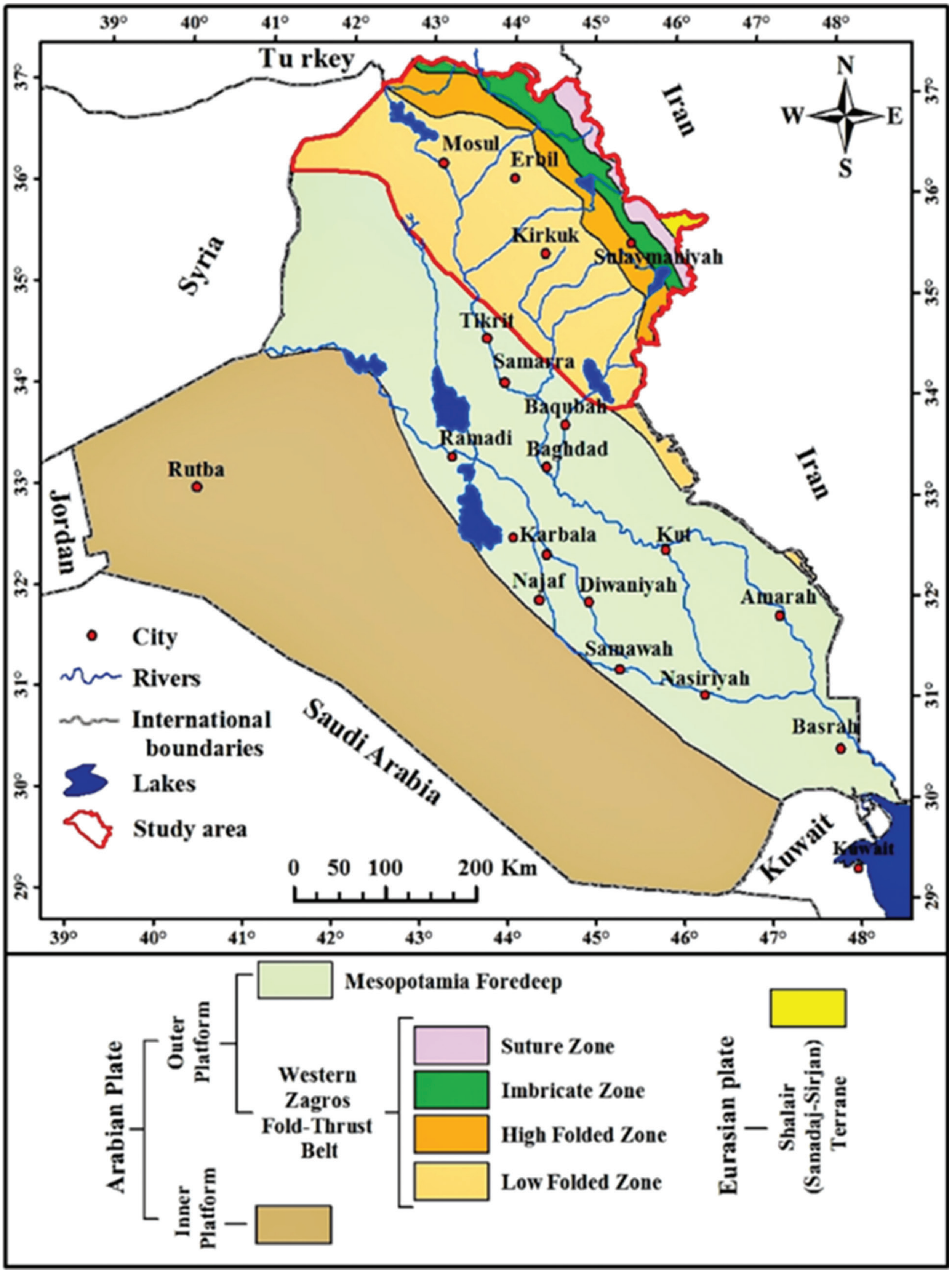

Fig. 2. Tectonic zones of Iraq (modified after Fouad, 2012) showing the limits of the study area.

The studied area is characterized by existing of N–SE anticlines, which change approximately west of the longitude 43°30′ E to E–W direction and the presence of transversal longitudinal structural elements with NE–SW trend (Fouad, 2012; Sissakian, *et al*., 2014a). Among those, longitudinal transversal forms are rivers, streams, valleys, playas, anticlines, and offsets, in parallel trend to the main compressional forces (Sissakian and Abdul-Jabbar, 2010; Sissakian, *et al*., 2014a) created by the collision of the Arabian and Iranian Plates (Fouad, 2012; Sissakian, 2013).

The carapaces of the majority of the anticlines are built up of Cretaceous rocks, characterized by massive and thick carbonate rocks of Qamchuqa and Bekhme formations; however, in the extreme northern parts of the studied area, older rocks form the carapaces of the anticlines. In contrary, in the extreme southern parts of the studied area, Eocene rocks of the Pila Spi formations form the carapace of all existing anticlines. The cores of the anticlines are usually built up of softer rocks of different ages, forming low lands as compared to the surrounding limbs, built up of hard rocks (Sissakian and Fouad, 2012; 2014a; 2014b; 2014c). Within those low lands, hundreds of wine glass forms are developed (Sissakian, *et al*., 2017). Some of those wine glass forms are drained by straight valleys with NE–SW and N–S trends, which extend occasionally to cross successive anticlines or both limbs of an anticline.

The most significant morphological units and forms in the studied area are the structural–Denudational units represented by anticlinal ridges and erosional cliffs (Sissakian, *et al*., 2014c) formed along banks of the outlets of the developed wine glass forms, and more especially, those forming straight valleys (Fig. 3), which are the main scope of this study. Moreover, flat iron forms are also well developed on thickly bedded carbonate rocks, some of them exhibit large bending off their main trend, indicating a deep-seated weakness zone that had contributed in the development of the outlet (Fig. 3).

III. Straight River Courses and Valleys

The studied area is characterized by a large number of straight valleys that are controlled structurally. The authors have presented many of them. Other structurally controlled valleys are many river courses, such as the Greater Zab, Little Zab, Diyala (Sirwan), and Adhaim rivers. All of these rivers have straight courses, and each one of them crosses many anticlines and/or ridges without shifting their courses. However, small meanderings and curvatures may occur mainly due to the effect of mass movement phenomena and/or growth of alluvial fans. Each of the mentioned rivers is described hereinafter with available presentation images.

Majority of the anticlines in the studied area exhibit wine glass forms of different sizes and shapes. Each of those wine glass forms has an outlet; however, occasionally, they may have many outlets (Sissakian, *et al*., 2017). Among those outlets, few are in the form of straight valleys and extend for few kilometers with many features and forms that are directly related to the straight valleys, indicating deep-seated weakness zones, which may represent faults.

Many examples of those straight valleys are selected from the studied area and presented in the current study, showing their details and explaining the related features and forms. This does not mean, however, that there are no more such valleys in the studied area. The following examples are selected to represent different valleys with different indications clarifying their development.

A. Degala Gorge Lineament

Degala Gorge is located NE of Erbil city; it is represented by a straight valley before and after the gorge (Fig. 3). The length of the valley is 3.89 km, whereas the length of the gorge is about 0.75 km. The gorge is developed within the carbonate rocks of the Pila Spi Formation, whereas the valley starts from Kolosh Formation (point P2, Fig. 3) and crosses Gercus, Pila Spi, Fatha, Injana, and Mukdadiya formations (point P1, Fig. 3) (Sissakian and Fouad, 2012; 2014b). The indications for the presence of a deep-seated weakness zone along which the Degala Gorge and the straight valley (Fig. 3) are developed and are presented by the following aspects:

1. Bending of the flat irons within the Pila Spi formation (point P3) and Shiranish formation (point P4).
2. Presence of three springs on both sides of Safeen anticline; opposite to each other (points S1, S2, and S3, Fig. 3A and B, respectively).
3. Bending of the axis of Safeen anticline between the points S1 and S3 (Fig. 3).
4. Plunging of the hanging syncline; north of Safeen anticline (point HS).
5. Disturbance of the beds, possibly due to a fault within the beds of the Pila Spi formation and development of large V-shaped feature (point P6, Fig. 3C).
6. Presence of a straight valley that dissects the southeastern plunge of Safeen anticline; parallel to Degala valley and gorge (point SG).

B. Greater Zab River Lineament (Upper Reach)

Greater Zab River is one of the main tributaries of the Tigris River. It enters the Iraqi territory from Turkey north of Erbil city. The concerned part of the river in this study forms a straight course in N–S direction, with a length of 11.54 km (Fig. 4, points P3–P2), and its extension southwards as a valley in S–N direction for 11.34 km (Fig. 4, points P1 – P2) that means the total length of the straight lineament is 22.88 km (P1–P3 in Fig. 4).

The southwards extension of the Greater Zab River is represented by a straight valley that crosses Gara anticline, northwards between points P2 and P3 (Fig. 4A), whereas the Greater Zab River has straight course crossing Mateen anticline between the points P1 and P2 (Fig. 4A) (Sissakian and Fouad, 2012; 2014b).

The Greater Zab River and the straight valley (will be called Dera L'lok valley) have opposite flowing direction to each other (Fig. 4A). They both have carved very hard and massively bedded carbonate rock of the Qamchuqa and Bekhme formations (Fig. 4B), although the beds of the

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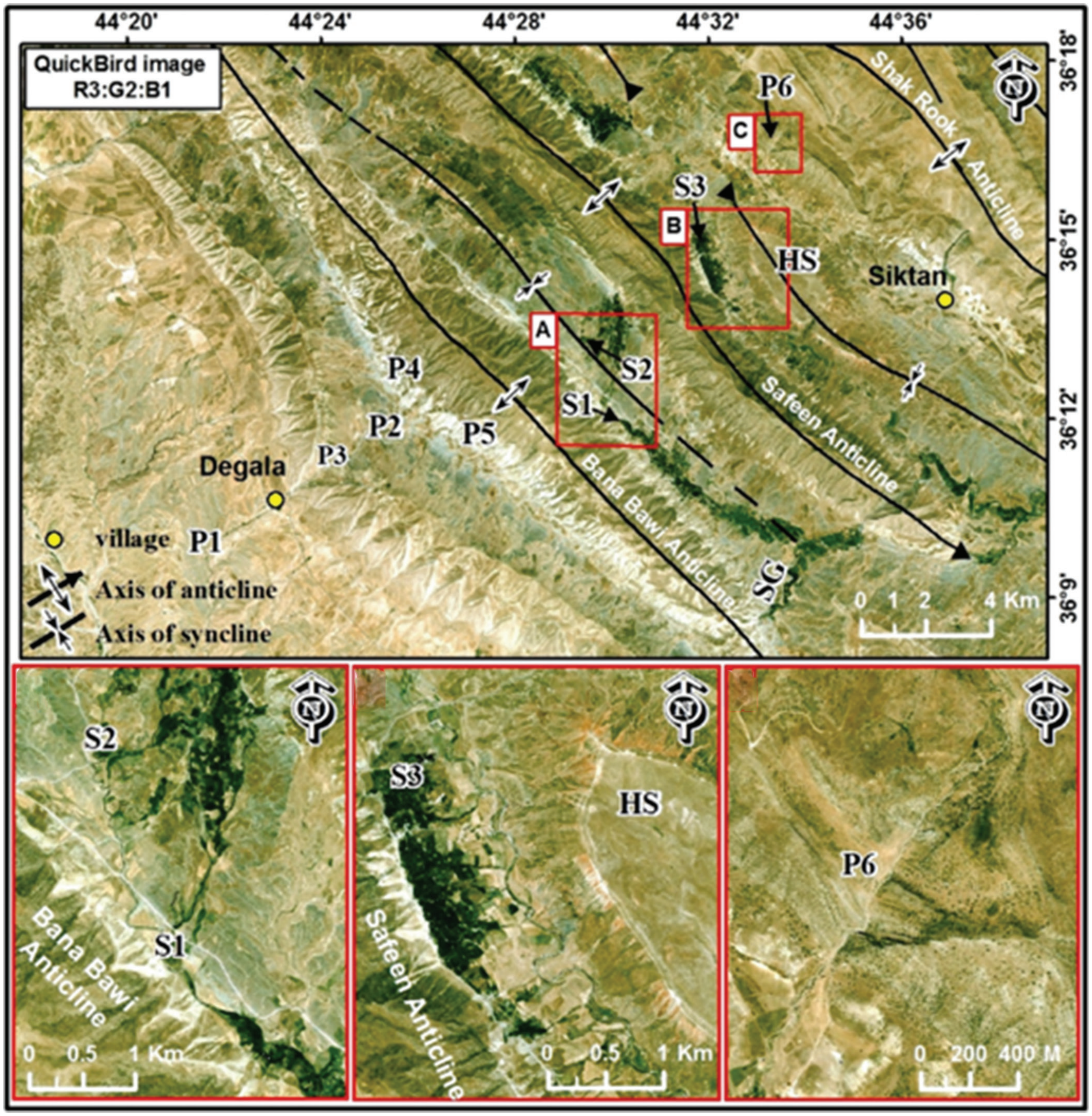

Fig. 3. QuickBird images (R3: G2: B1) of Degala Gorge and the indication of the straight valley. P1–P2 = straight valley, P4 = Bending of the flat irons of the Shiranish Formation (the white colored), S1, S2, and S3 = Springs, HS = Plunging of a hanging syncline, P6 = A fault trace, and SG = Sami Quly Gorge.

carbonates in the latter formation are not massive like those of the former.

The gradient of the Greater Zab River in its straight course (P3 – P2 in Fig. 4A) is 1.8%, whereas that of Dera L'lok valley (P1–P2 in Fig. 4A) is 2.26%. The former forms typical water gap when crossing Mateen anticline. Such water gaps are a good indication for the eastwards growth of the anticline (Keller and Pinter, 2002; Huggett, 2007; Ramsey, *et al*., 2008; Sissakian, *et al*., 2015).

Although many gentle curvatures occur within the straight courses of the Greater Zab River and Dera L'lok valley (Fig. 4C-E), still they both are considered to form a straight line lineament. The curvatures are related either to mass movements or growth of alluvial fans. Such curvatures in the courses of the streams and valleys are very common in the studied area (Sissakian, *et al*., 2015). The Greater Zab River exhibits many such curvatures. Two of them are related to mass movement features (Fig. 4C), whereas another one is related to alluvial fan development that has shifted the river course westwards, near Dera L'lok town (Fig. 4D). Dera L'lok valley also exhibits such curvatures; all are related to mass movement features (Fig. 4E).

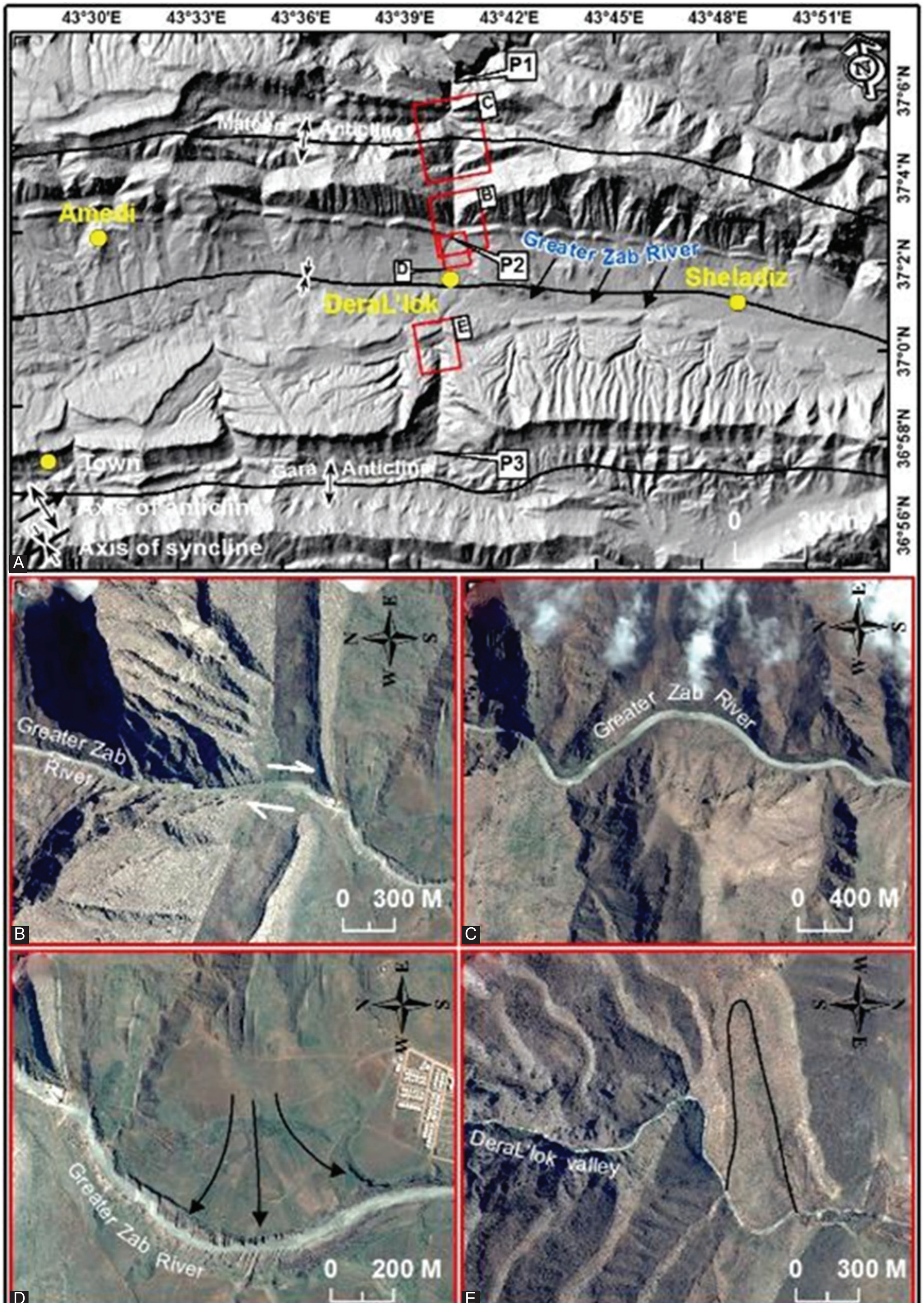

Fig. 4. (A) Hillshade image generated from digital elevation model SRTM (resolution 1 Arc) showing the straight courses of the Greater Zab River and Dera L'lok valley, (B) a dextral strike-slip fault across the southern limb of Mateen anticline, (C) two curvatures within the course of the Greater Zab River, (D) Alluvial fan near Dera L'lok town, (E) two curvatures within the course of Dera L'lok valley.

In this particular area of the Greater Zab–Dera L'lok Lineament, many other lineaments represented by straight valleys can be seen. A very obvious one is located just west of the described straight valley, east of Amadia town.

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It is represented by a straight valley flowing downslope of the northern limb of Gara anticline, and its continuation northwards is represented by another straight valley flowing southwards on the southern limb of Mateen anticline. Moreover, there is a faint expression of the latter valley on the northern limb of Mateen anticline (Fig. 4A). Further northwards, the continuation of this faint expression coincides with the straight course of the Greater Zab River when entering the Iraqi territory (Fig. 1).

C. Khabour River–Mangesh Lineament

This lineament is represented by many sectors; all are forming straight valleys. It starts in the northern part from the area where the Khabour River leaves the Thrust Zone running southwards to near Mangesh town in the south (Fig. 5). The total length of the lineament is about 30 km divided into sectors; the most prominent one is the southern part with a length of about 3 km (Fig. 5). The straight valleys are indicated by the following aspects:

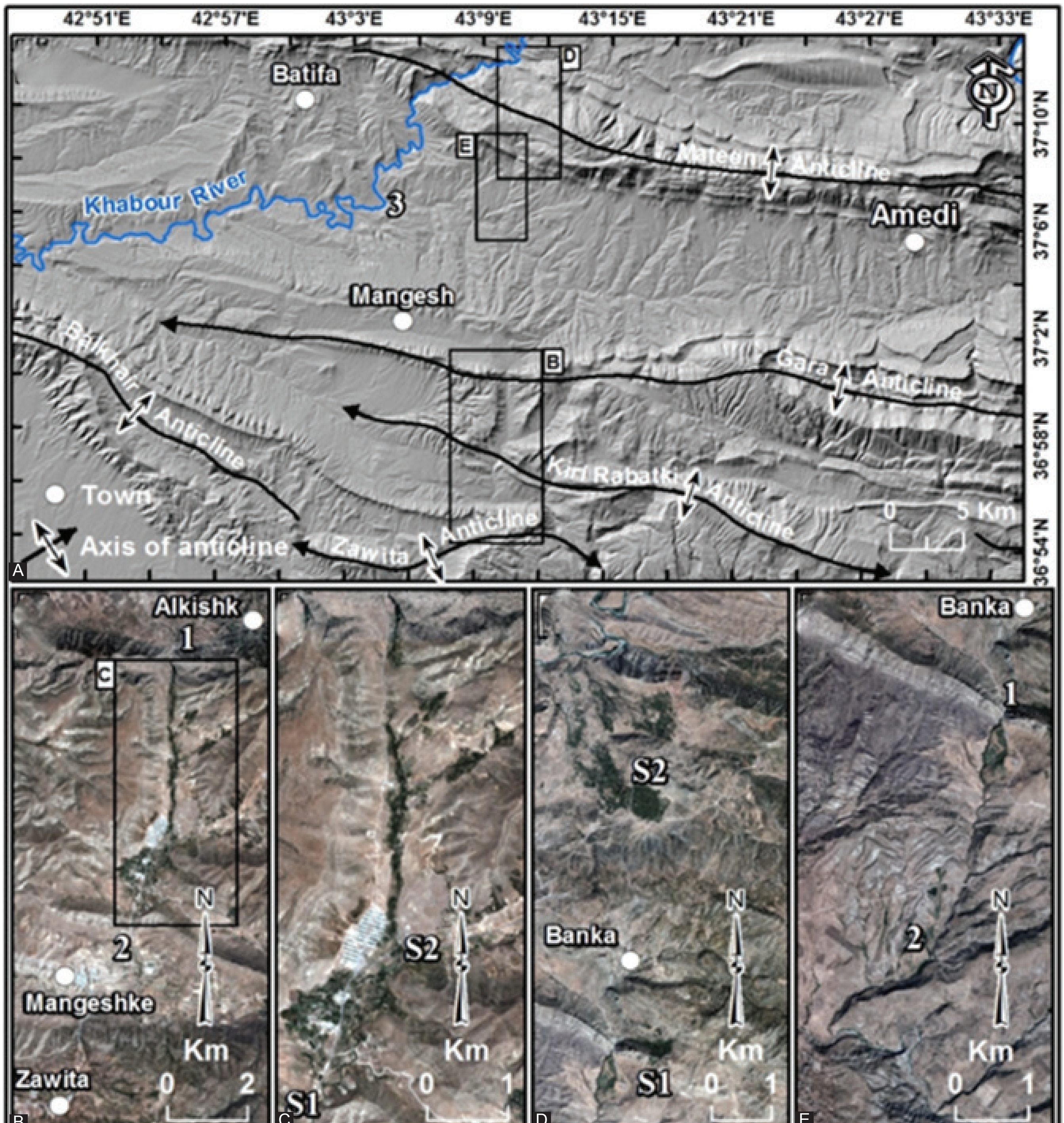

Fig. 5. Hillshade image generated from digital elevation model SRTM (resolution 1 Arc). (A) Khabour River–Mangesh Lineament, (B and C) crossing of Gara and Kiri Rabitki anticlines, note the straight valley and springs S1 and S2, (D) crossing of Mateen anticline, note the springs S1 and S2, and (E) note the straight valley between points 1 and 2, and merging in the Khabour River (point 3 in A).

1. The straight carved valley in Gara and Kiri Rabitki anticlines (Fig. 5B and E, points 1 and 2).
2. The developed springs across the western plunge of Gara and Kiri Rabitki anticlines (Fig. 5C; S1 and S2).
3. The developed gorges on both limbs of Mateen anticline and the presence of springs (Fig. 5D; S1 and S2).
4. The straight valley that starts from Mateen anticline at point 1 to point 2 (Fig. 5E), then turns westwards to merge in the Khabour River at point 3 (Fig. 5A).

D. Shamdinan–Sheladiz–Bakerman Lineament

This is one of the most prominent and unique lineaments in the studied area, and it extends for 134 km in NE–SW trend but changes its trend to N–S to be in coincidence with the regional strike of the beds (Fig. 6A, points 1, 2, and 3). This is attributed to the change of the trend of the anticlines in the studied area from NW–SE to E–W, as it is clearly visible in Fig. 6A west of Sheladiz town.

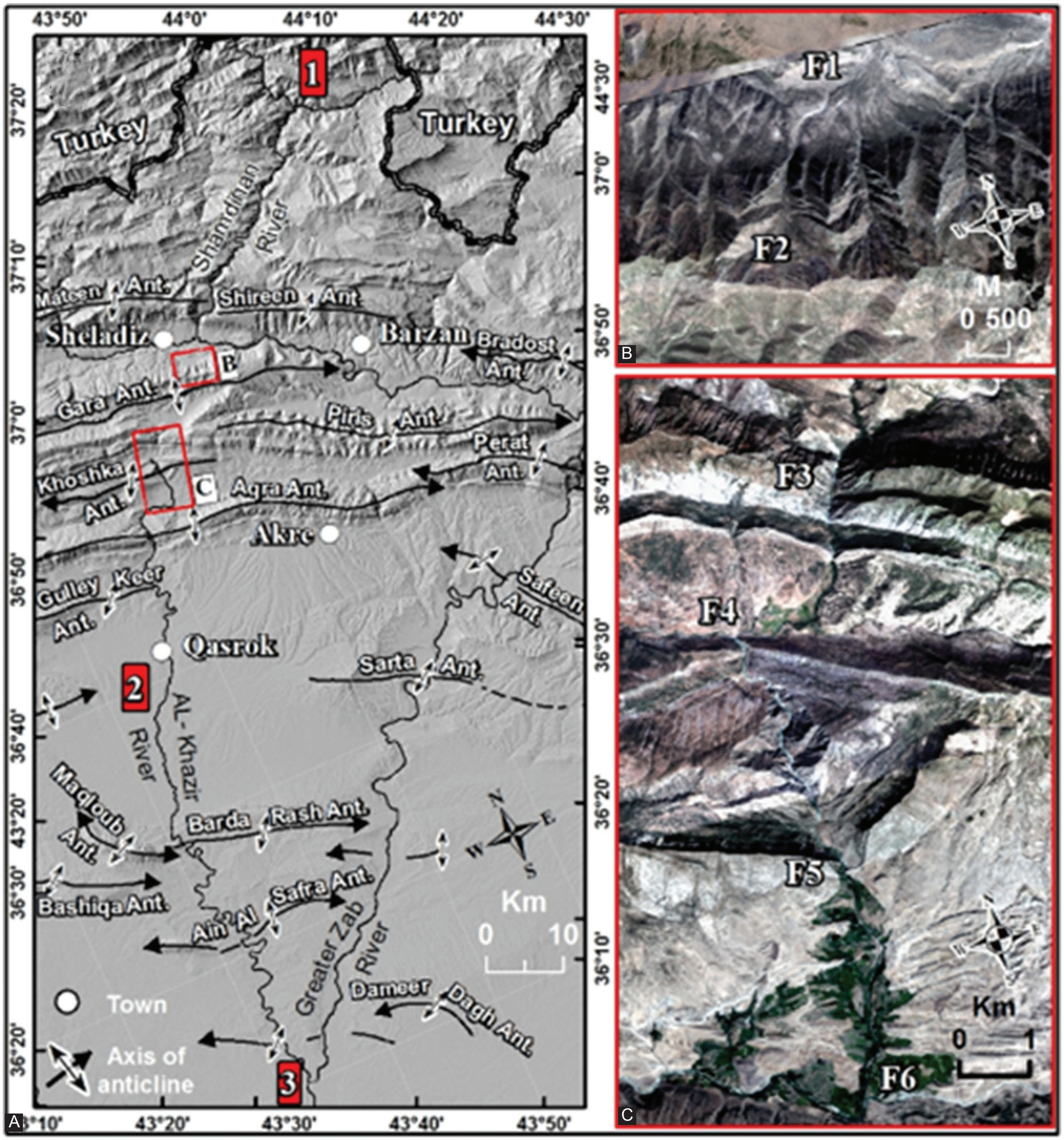

Fig. 6. (A) Is hillshade image generated from digital elevation model SRTM (resolution 1 Arc) showing Shamdinan–Sheladiz–Bakerman Lineament (1 – 2 – 3). Note the change in the direction of the lineament at point 2. (B and C) are enlarged parts of the main area.

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The Shamdinan–Sheladiz–Bakerman Lineament consists of two parts. The northern part starts near the Iraqi–Turkish international borders, represented by Shamdinan stream, and continues southwestwards to Sheladiz town where it merges with the Greater Zab River. The extension of the lineament more southwestwards is represented by a dry valley along the north-easterner limb of Mateen anticline. The valley's trend is clearly different from the neighboring valleys along the limb of Mateen anticline (F1–F2 in caption B of Fig. 6). Moreover, the flat irons have also changed their trends and size, west of the concerned valley.

The southwards extension of Shamdinan–Sheladiz–Bakerman Lineament, after crossing the northeastern limb of Mateen anticline by a dry valley (point F2 caption B in Fig. 6), becomes very faint, although another stream runs parallel to it until it crosses the southwestern limb of Mateen anticline in the form of a small gorge (point F3, caption C in Fig. 6). After that crossing, the stream continues in N–S direction and crosses the eastern side of Khoshka anticline (F3 – F4, caption C in Fig. 6). The local change in the main trend of the stream is attributed to local change in the main trend of Khoshka anticline (Fig. 6A). After crossing Khoshka anticline, the stream continues in N–S trend for 6.3 Km, and then returns to its original trend of NE–SW (point F5, caption C in Fig. 6).

E. Greater Zab River Lineament (Lower Reach)

The Greater Zab River after crossing the mountainous area in Bekhme Gorge runs in flat to undulatory plains, crossing many anticlines (Fig. 7A). The length of the straight course is 110.2 km, whereas the thalweg length is 153 km with NE–SW flow direction. After crossing Bekhme Gorge, the Greater Zab River can be divided into three parts. The straight length of the first one is 12.7 km, whereas the thalweg length is 13.6 km, flowing in a straight line in NE–SW direction. The straight length of the second part is about 11 km, whereas the thalweg length is 23.25 km with ENE–WSW flow direction and includes three main meanders; the first one is caused by plunging of Safeen anticline. The others are due to mass movements' phenomena and/or alluvial fans (Sissakian, *et al*., 2015). The straight length of the third part is 116.9 km, whereas the thalweg length is 91 km with NE–SW flow direction and includes 4 main meanders; all are tectonically controlled (Fig. 7A-C).

F. Little Zab River Lineament

The Little Zab River after crossing the mountainous area in Haibat Sultan Range (Fig. 8) runs in flat and undulatory plains, crossing many anticlines. The total length of the straight course is about 164 km. After crossing Haibat Sultan Range, the Little Zab River can be divided into two parts. The length of the first one is about 67 km, flows in a straight line in E–W direction, and includes 9 main meanders (Fig. 8 A and B). Three of the meanders are formed due to plunging of Agh Jalar, Taq Taq, and Cham Chamal North anticlines (Fig. 8).

The length of the second part of the Lesser Zab River is about 97 km with NE–SW flow direction and includes many meanders; almost all of them are due to over maturation of the river and running in a flat plain with wide floodplain (Fig. 9). The river crosses two main ranges: Kirkuk structure, which includes three domes, and Qara Chough Range, which also includes three domes. In between the two ranges, a small anticline exists, called Bai Hassan anticline. The river crosses the three ranges in the sharp straight course, although small meanders do exist in the wide floodplain (Fig. 9b and c). However, in the southwestern part of the river course, before merging into the Tigris River, two meanders exist. They are caused due to the plunging of growing Dhahir and Shari'a subsurface anticlines, indicating neotectonic activity in that particular area.

G. Diyala (Sirwan) River

The Diyala River is another straight lineament trending NE–SW between Derbendi Khan and Himreen lakes (Fig. 10A), and its length is about 135 km; although, after Himreen lake, the river continues in a straight course, it is not included in this study due to numerous bifurcation of the river into distributaries causing hindering of the main course of the river. The straight course of the river can be divided into two main parts, the upper and lower (Fig. 10B and C, points D1–D2 and Fig. 10D and E, points D3–D4). The length of the upper part is 59 km, while the thalweg length is 81.9 km, whereas the length of the lower part is 67 km, while the thalweg length is 75.7 km.

At the lower end of the upper part, there is a clear change in the trend of the straight course of the Diyala River (Fig. 10 points D2 – D2′). The change in the main trend of the river is attributed to Chia Surkh anticline, and it can be seen clearly that the river has changed its course to cross the anticline almost perpendicularly. The same case can be seen within the middle of the lower part (Fig. 10 points D3–D3′), where the river crosses Pulkhana and Qumar anticlines perpendicularly.

The main difference between the two parts is that in the upper part of the Diyala River runs in area built up mainly of conglomerates of the Bai Hassan Formation (Sissakian and Fouad, 2012; Barwary and Slewa, 2014) and within two wide synclines (Fouad, 2012; Barwary and Slewa, 2014). The second part, however, runs in area built up of the Bai Hassan, Mukdadiya, and Injana formations (Sissakian and Fouad, 2012; Barwary and Slewa, 2014) and within five main anticlines with NW–SE trend. Some of the anticlines exhibit thrust faulting, where the northeastern limb is thrusted over the southwestern limb (Fouad, 2012; Barwary and Slewa, 2014). Significantly, these factors have influenced on the course of the river.

Within the two parts of the Diyala River, tens of major meanders are developed within the course of the river. In the upper part, a majority of the meanders are developed due to alluvial fans and mass movements, and such meanders are very common in the rivers and main streams in the northern part of Iraq (Sissakian, *et al*., 2014b). In the lower part, however, the main meanders are developed due to the

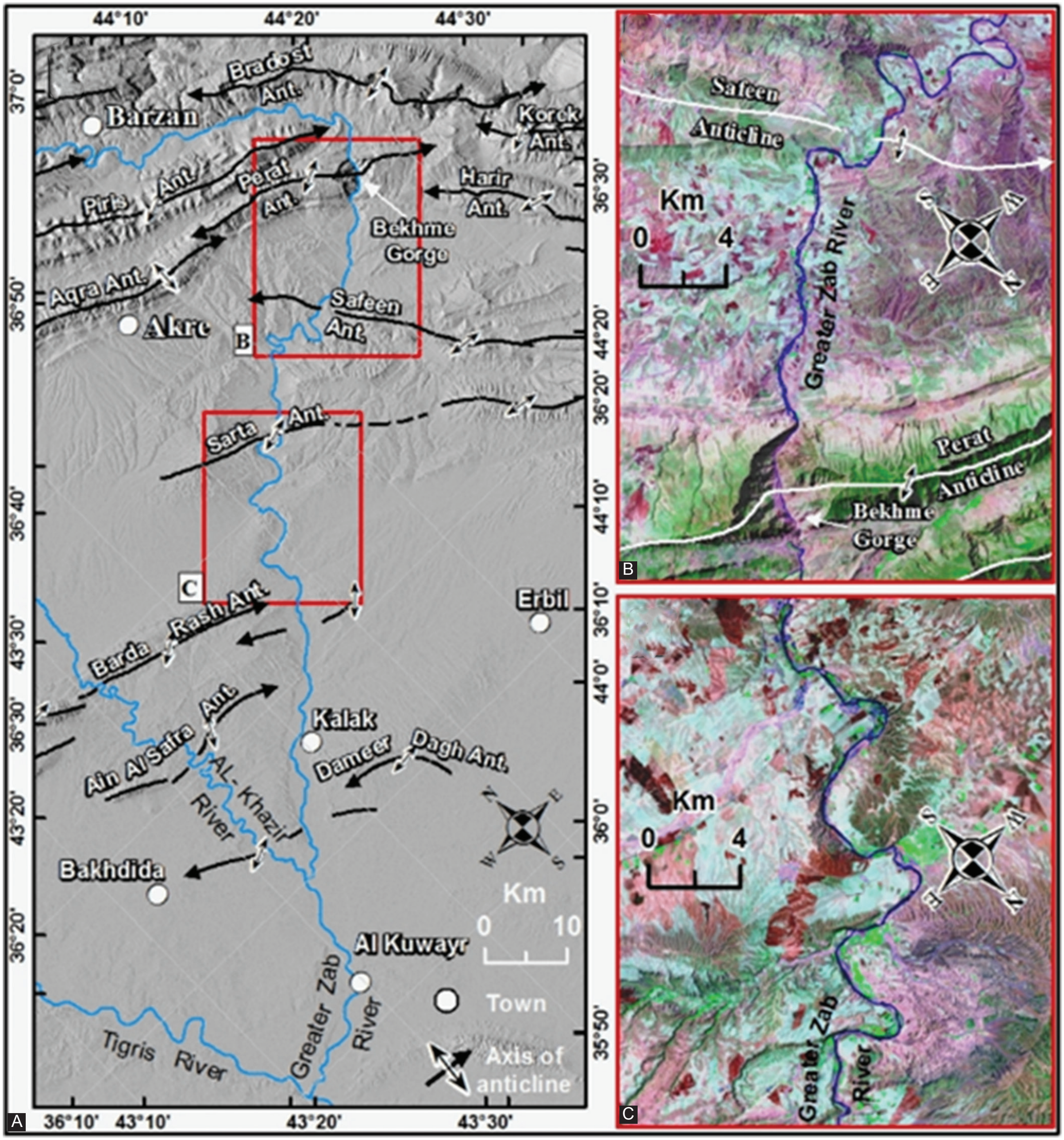

Fig. 7. (A) Digital elevation model SRTM (resolution 1 Arc) in hillshaded mode image showing the course of the Greater Zab River. B and C Landsat 8 (Operational Land Imager) (R7: G5: B3). (B) The first and second parts, (C) upper half of the third part. Note the existing meanders, which are either controlled structurally or developed due to the growth of alluvial fans.

presence of anticlines and alternation of hard and soft rocks in the exposed formations.

It is worth mentioning that in both parts, hundreds of small meanders are developed within the course of the Diyala River (Fig. 11 B-E). These meanders are developed when the floodplain is wide and the river starts exhibiting braided style and partly starts behaving as mature river.

IV. Discussion

The Iraqi territory is located in the extreme northeastern part of Arabian Plate, which is in collision with the Eurasian (Iranian) Plate since Cretaceous (Buday and Jassim, 1987; Jassim and Goff, 2006; Aqrawi, *et al*., 2010; Fouad, 2012). The continuous collision has formed the nowadays structural regime and morphology, consequently, forming the present

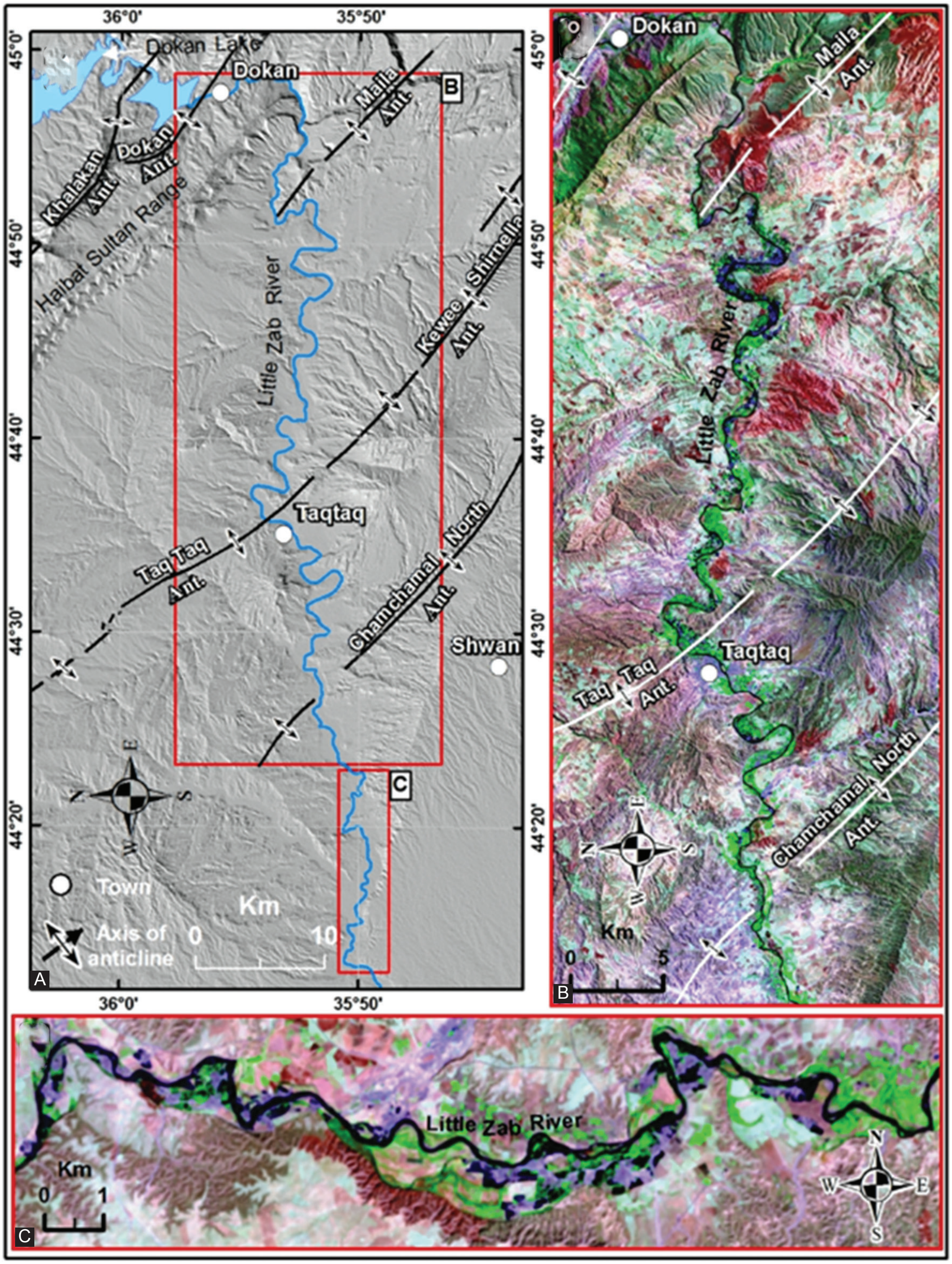

Fig. 8. (A) Digital elevation model SRTM (resolution 1 Arc) in hillshaded mode image showing the first part of the Little Zab River. Note the acute meanders in B and C. B and C are Landsat 8 (Operational Land Imager) (R7: G5: B3).

folds and faults. Among the main faults are the longitudinal and transversal faults that are recognized by Buday and Jassim (1987); Jassim and Goff (2006); and Aqrawi, *et al*. (2010); however, Fouad (2010) did not confirm them. Moreover, some of them have names (Fig. 12) and partly coincide with those lineaments mentioned in the current study.

The majority of the mentioned lineaments, in the current study, have NE–SW trend; others have N–S trend. The formers follow the Zagros regime, whereas the latter's follow the Torus regime. However, some of them have combined both regimes, depending on their locations where the folding system in Iraq changes from Zagros regime to Torus regime; consequently, the trends change from NE–SW to N–S,

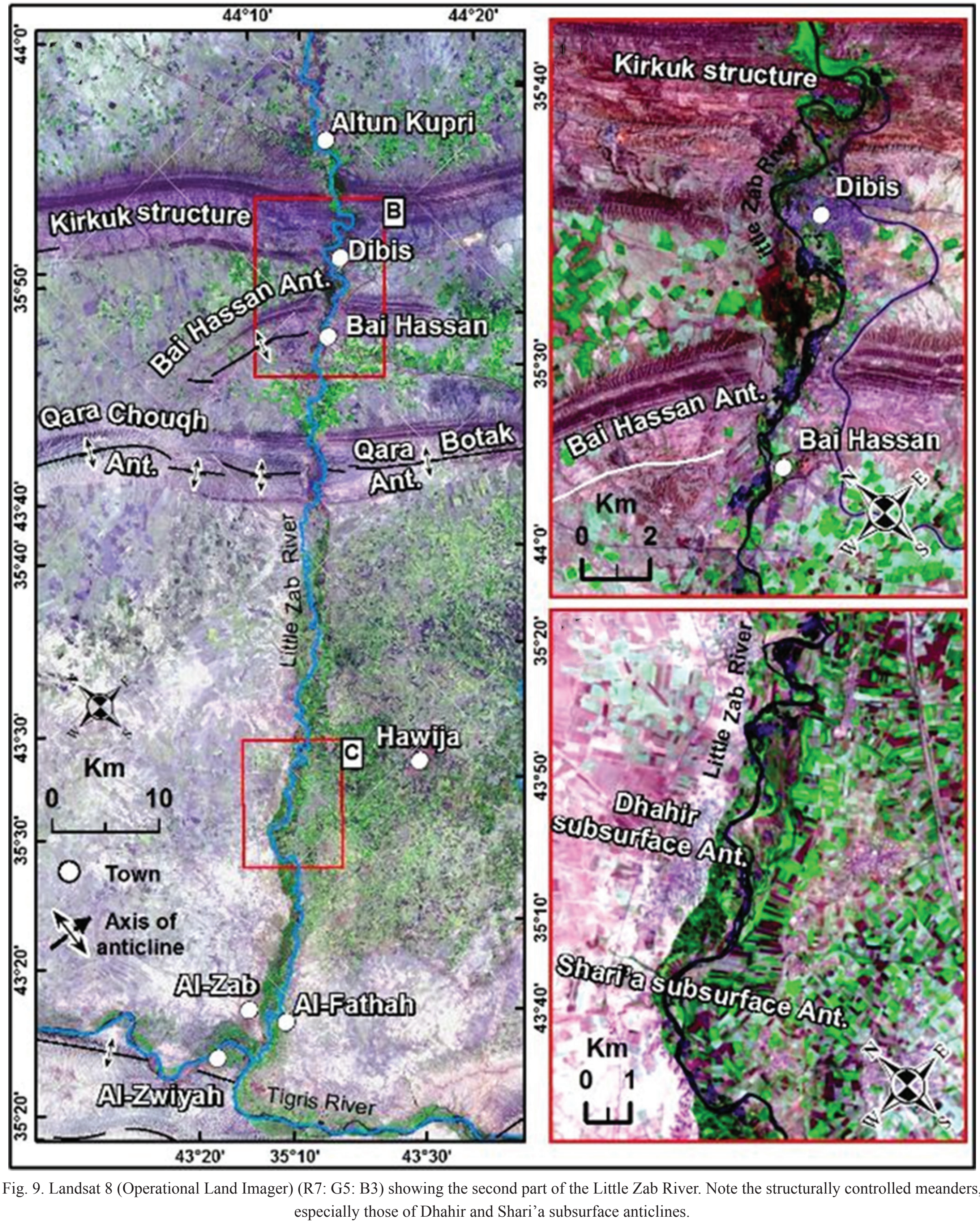

Fig. 9. Landsat 8 (Operational Land Imager) (R7: G5: B3) showing the second part of the Little Zab River. Note the structurally controlled meanders, especially those of Dhahir and Shari'a subsurface anticlines.

which are normal to the fold axes, from NW–SE and E–W, respectively.

Majority of the lineaments are believed to be expressions of deep-seated faults (Ditmar, *et al*., 1971; Buday, 1980; Buday and Jassim, 1987; Al-Kadhimi, *et al*., 1997; Jassim and Goff, 2006; Aqrawi, *et al*., 2010). Some of them have very clear indication, even on surface, such as Sirwan Fault (Figs. 10 and 11D). Others are represented on the surface

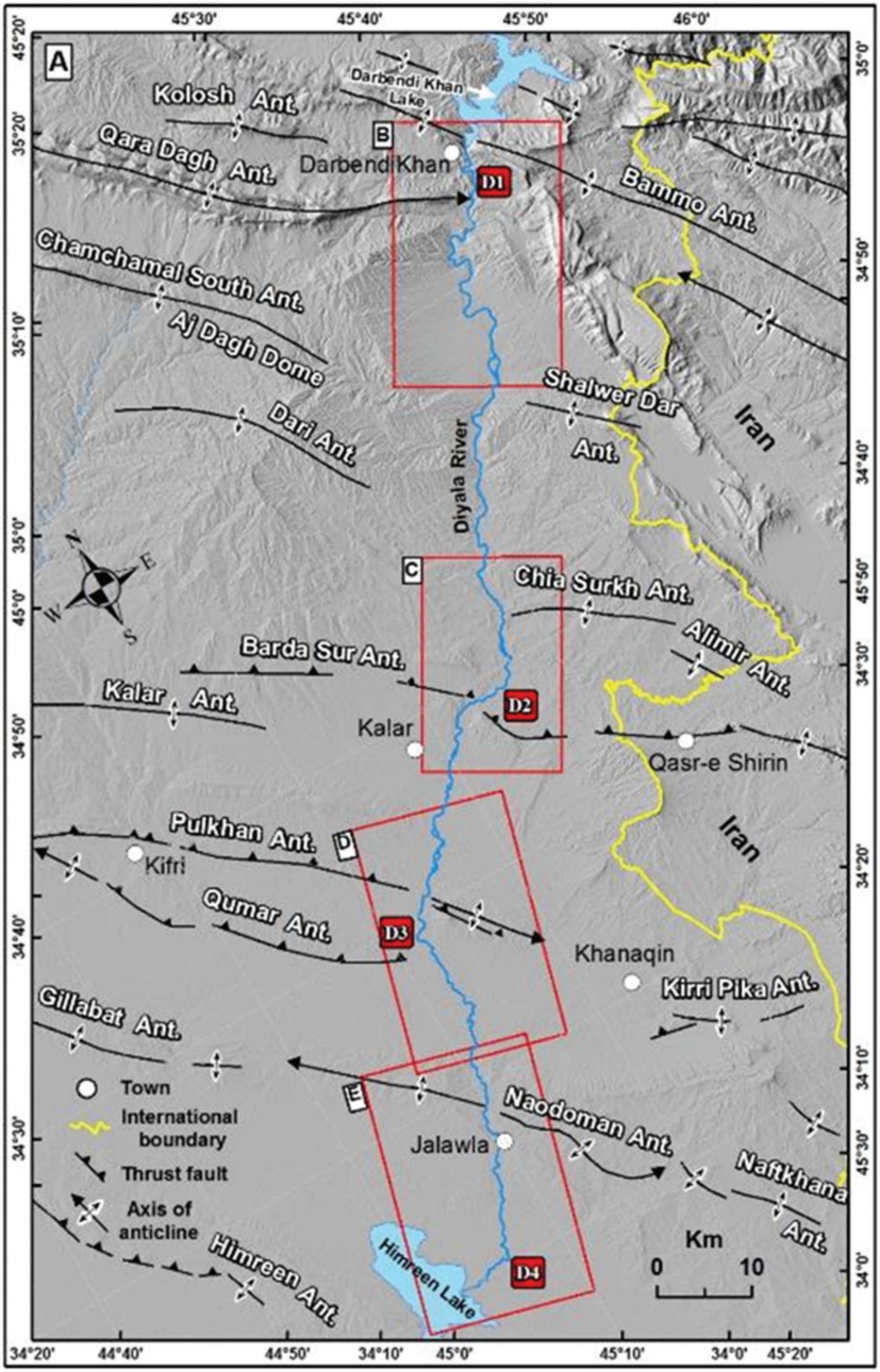

Fig. 10. Digital elevation model (DEM) provided by SRTM, the DEM is 1 Arc resolution in hill-shade model image showing the Diyala River with locations of four enlarged images in Fig. 11.

as lineaments of different lengths that are presented in the current study. Others have been proved by geophysical methods where clear anomalies confirm their presence (Jassim and Goff, 2006).

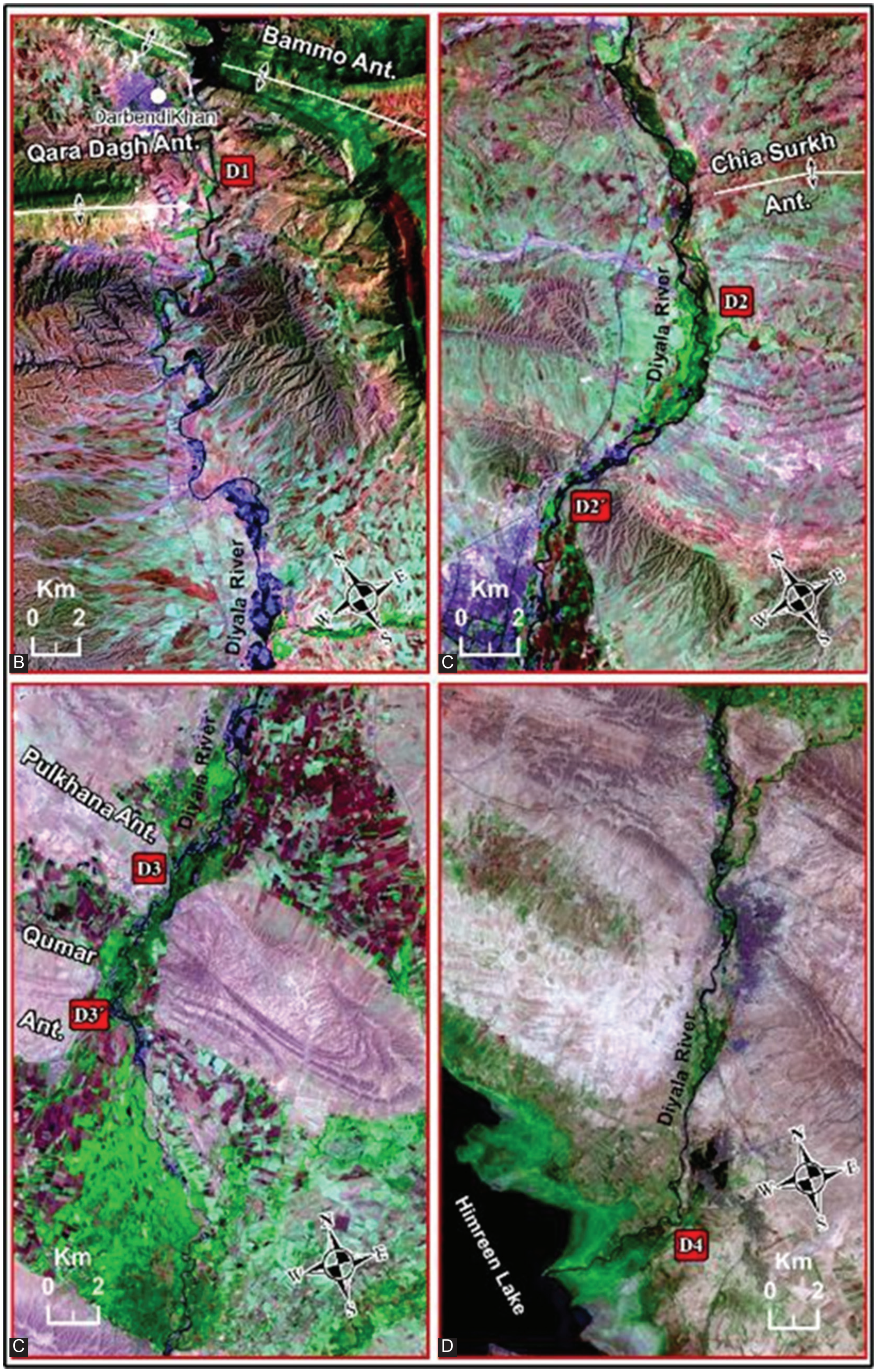

Fig. 11. (B-E) Landsat 8 (Operational Land Imager) (R7: G5: B3) Four enlarged parts of the Diyala River. Note the developed meanders, either due to structural effect or mass movements, and alluvial fans.

The straight courses of rivers and streams and even dry valleys are excellent expressions for those lineaments. However, those rivers, streams, and dry valleys after suffering different tectonic and morphological effects have developed

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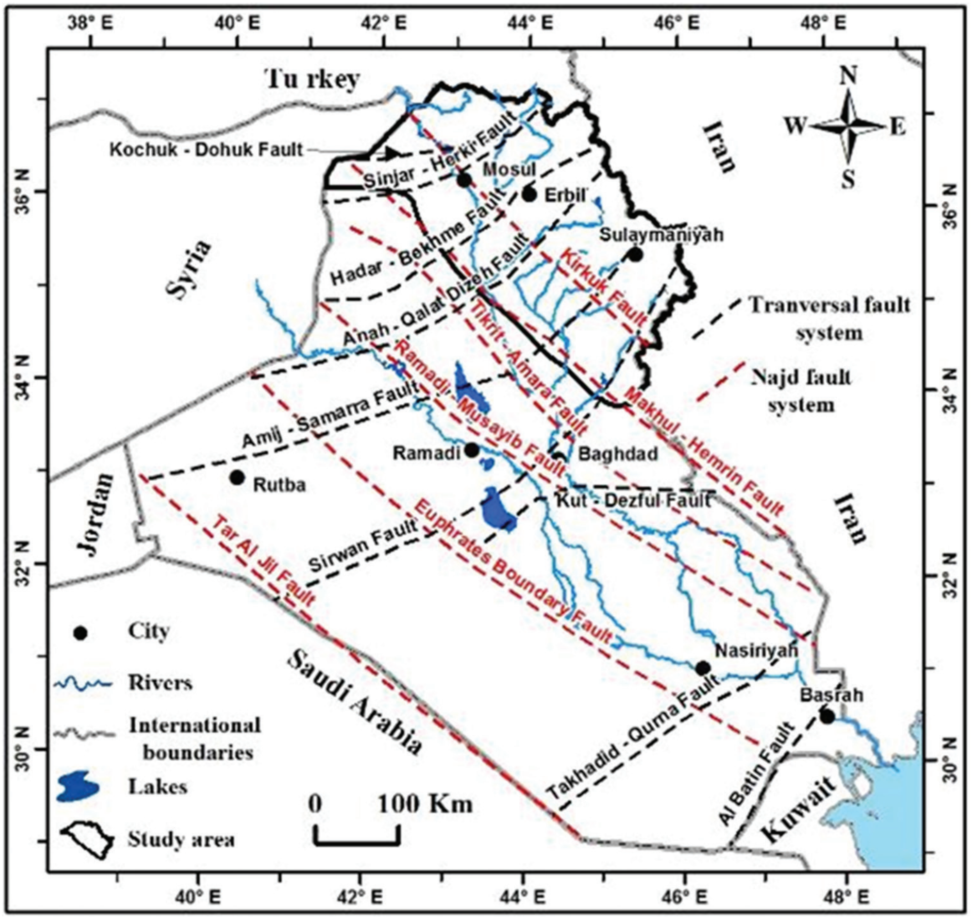

Fig. 12. Distribution of fault system in Iraq (modified after Jassim and Goff, 2006).

tens of meanderings along their courses; nevertheless, they still preserve their straight courses as a main trend. The different aspects that have developed meanders along the courses of the rivers, streams, and valleys are explained hereinafter.

- Subsurface growing anticlines: Subsurface growing anticlines are present crossing the lower part of the Little Zab River (Fig. 9C), as in Shari'a and Dhahir subsurface anticlines.
- Curved water gaps: Curved water gaps are developed following the plunges of existing anticlines (Fig. 9B) as in Kirkuk structure and Barda Sur anticline (Fig. 10). This phenomenon indicates that the rate of the incision of the river was more than the rate of the growth of the anticline; otherwise, the river would not have the ability to cross the anticline. Such cases are proved by Keller and Pinter (2002) and Ramsey, *et al*. (2008) and were observed by Sissakian and Abdul-Jabbar (2010) and Sissakian, *et al*. (2014b).
- Plunging anticlines: In many cases, rivers have developed acute meanders following the plunge of anticlines such as in Maila anticline (Fig. 8A) and Qara Dagh anticline (Fig. 10). A good example is Maila anticline near Dokan town, where the Little Zab River follows the plunge of the anticline forming acute meandering. This phenomenon indicates that the rate of the incision of the river was less than the rate of the growth of the anticline; otherwise, the river would cross the growing anticline. Such cases are proved by Keller and Pinter (2002) and Ramsey, *et al*. (2008) and recognized by Sissakian and Abdul-Jabbar (2010).
- Growing alluvial fans: This phenomenon is more abundant in dry valleys and small streams rather than rivers. This is attributed to the fact that the amount of the flowing water in the rivers has the ability to wash out the sediments of alluvial fans, and hence, less chance for developing meanders. Some rivers, however, have developed meanders due to growing alluvial fans in the studied area. A good example is the Greater Zab River (Fig. 4D), the Little Zab River (Fig. 8A-C), and the Diyala River (Figs. 10 and 11), where wide or acute meanders are developed depending on the size of the growing alluvial fan. Such forms were observed and studied by Sissakian *et al*. (2014a; 2014b) in the studied area too.
- Mass movements: Mudflows and landslides are common types in the studied area. Such movements have caused the development of meanders along rivers, streams, and dry valleys. A good example is along the Greater Zab River (Fig. 4E), where a large landslide has developed an acute meandering to the river. Such forms were observed and studied by Sissakian *et al*. (2014a; 2014b) in the studied area too.

Locally and very rarely, the rivers change their straight courses by certain angles and return to gain the same trend. This phenomenon is recognized and attributed due to different aspects; these are as follows:

- Change in tectonic style: As it was aforementioned, the Iraqi territory is under the effect of two tectonic regimes: Zagros and Taurus. Therefore, when a certain lineament, especially when is a long one and extends within the two tectonic regimes' zones, then it changes its trend following the two main trends. A good example is Shamdinan–Sheladiz–Bakerman Lineament (Fig. 6), where the lineament changes its trend from NE–SW to N–S due to the change of the tectonic regime.
- Crossing anticlines: Some of the river courses change their trend for very short distance to be normal to anticlinal trend during their crossing to the anticline. A good example is the Little Zab River in crossing Cahm Chamal North anticline (Fig. 8B) and Diyala River in crossing Barda Sur anticline (Fig. 11C, at point D2), crossing Qumar anticline, after crossing Pulkhana anticline (Fig. 11D, at point D3) and crossing Naodoman anticline (Fig. 11E). This phenomenon is recognized when the river crosses an anticline in its middle part or far from plunge area. It indicates that the rate of the anticlinal growth is lower than the rate of the river's incision; otherwise, it was not possible for the river to cross the anticline in its middle part. Therefore, the perpendicular trend to cross the anticline is easier with shorter distance; consequently, the river has changed its trend slightly to be in perpendicular trend on the anticlinal trend, and then returns to its original course with the regional trend.
- Structurally controlled factors: In the studied area, the large-scale lineaments express different orientations, which are nearly restricted between N–S and E–W trends; however, the majority of these lineaments have NE–SW orientation and they have an acute angle between them. However, these oriented lineaments may represent shear lineaments and/or system of two sets of large-scale fractures. Structurally, the direction of the maximum stress axes (σ1) should bisect this acute angle. However, the orientation of the main stress axes or the stress inversion results have been proved nearly with N–S to NE–SW direction in many studies in the north and northeastern parts of Iraq; among those studies are Abdulnaby, *et al*. (2014) and Shihab (2015). As well, the movement direction toward north and northeast and anticlockwise rotation of the Arabian Plate and collision with Eurasian Plate play a key role to generate this system of lineaments. In the studied area, a good example coincides with the concept of generated system of two set fractures. As can be seen the orientation of the two parts of the Shamdinan–Sheladiz–Bakerman Lineament (Fig. 6A), the convergence extension lineaments represented by two river courses of Al-Khazir River and Greater Zab River (Fig. 6A) and the Tigris River and the Greater Zab River (Fig. 7A), the two parts of the Little Zab River (Fig. 1) and Al-Adhaim River's main course with the concerned valleys (Fig. 1).

Other indications for the coincidence of the lineaments to deep-seated faults are geomorphological, structural, and hydrogeological indications. These are explained hereinafter.

- Geomorphological indications*:* In many anticlines, flat irons are well developed due to the type of the exposed rocks. A good example is Bana Bawi anticline with Degala Gorge lineament (Fig. 3). There, the flat irons change their trend and size near the lineament (Fig. 3A, points P3, P4, and P5) to be in a perpendicular direction to the lineament. This is a good indication that the deep-seated faults are initiated during the beginning of the folding and with the continuation of the folds growth; the folds have manifested their present-day forms including the shape, size, and trend of the developed flat irons. Otherwise, the flat irons would not change their trends on both sides of the lineaments. Another geomorphological aspect is the braided river style for some of the rivers on crossing the anticlines, not near to their plunge areas, such as the Little Zab River (Fig. 9) and the Diyala River (Fig. 11). Such aspects are considered as geomorphological evidence for location and orientation of neotectonic activity (Whitney and Hengesh, 2015).
- Structural indications: In many anticlines and synclines, it was recognized that the folds exhibit plunging along the lineaments. A good example is the Degala Gorge Lineament (Fig. 3). Many anticlines and synclines exhibit plunging along both sides of the lineaments, between Safeen and Shakrook anticlines (Fig. 3). Moreover, some fault traces are recognized near and along the lineaments (Fig. 3C, point P6). Bending of the axes near the lineaments is another indication for the presence of a weakness zone, represented by the lineament.
- Hydrogeological indications: Along the lineaments, many springs are developed indicating weakness zones that are represented by the lineaments indicating most probably deep-seated faults. A good example is along Degala Gorge Lineament, where many springs are developed along the lineament (Fig. 3), and Khabour River–Mangesh Lineament, where many springs are developed too along the lineament (Fig. 5C and D).

V. Conclusions

The studied area is a part of Zagros mountainous areas. Almost all of these mountains form anticlines. Most of the cores of the anticlines are built up of soft rocks, forming low lands as compared to the surrounding limbs, which are built up of hard rocks. The studied area is drained by straight valleys that cross successive anticlines or both limbs of an anticline. We used several examples of these valleys to delineate and discuss the factors controlling the development of the straight valleys that drain many anticlines within the studied area. This was achieved using different types of DEM, Landsat 8 OLI Landsat, and QuickBird satellite data. Some of these valleys are in the form of straight valleys and extend for few tens of kilometers with many features and forms that are directly related to the straight valley with N–S to NE–SW trends, which represent shear systems of strike-slip faults. The NE–SW straight valleys follow the Zagros regime, whereas the N–S follows the Torus regime. These straight valleys may indicate deep-seated faults zones. Some of these straight valleys have very clear indication(s), even on the surface, such as Sirwan Fault. Others are represented on the surface as straight valleys of different lengths. Some others have been proved by geophysical methods, where clear anomalies confirm their presence. Along the straight valley courses, several meanders are present witnessing different tectonic and morphological effects. Nevertheless, they still preserve their straight courses as a main trend. These meanders are developed as results of subsurface growing anticlines, curved water gaps, plunging anticlines, growing alluvial fans, and mass movements. Locally, the valleys change their straight courses by particular angles and return to gain the same trend. The main reasons of that are either due to the change in tectonic style or during crossing anticlines, to be in right angle as much as possible, or structurally controlled factors.

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