Deducing the Lateral Growth of Anticlines using Drainage Analysis and Geomorphological Features¹

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Abstract—The Low Folded Zone in Iraq is an active tectonic area witnessing different evidences for Neotectonic activities, among them are the lateral growth of Jambour, Pulkhana, and Qumar anticlines which are part of anticlinal series in the Low Folded Zone and Zagros Fold–Thrust Belt. The exposed rocks are of Middle Miocene – Pleistocene age overlain unconformably by different types of Quaternary sediments which show different indications for lateral growth. Three anticlines are dissected by tens of different size valleys crossing the anticlines forming water gaps and wind gaps which are good indication for the anticlines lateral growth. We studied the lateral growth of three anticlines using different means of qualitative analysis of satellite imagery and digital topography and ArcGIS technique. The anticlines lateral growth was mainly manifested by the drainage system and patterns which exhibited strange courses during dissecting the three studied anticlines. Moreover, the main streams deposited alluvial fans during Early Pleistocene and even Early Holocene which were also influenced by both lateral and vertical anticlines growth. Their abnormal shapes, abandoned fans and streams were among indications. We measured different geomorphological indices which indicated tectonic activity of the study area.

Keywords: neotectonic activity, geomorphological features, Quaternary sediments, lateral growth, anticlines, alluvial fans, Zagros Fold–Thrust Belt, Iraq

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INTRODUCTION

The studied Jambour, Pulkhana, and Qumar anticlines are three long anticlines in the central part of Iraq with NW–SE trend; located in the Low Folded Zone [21] of Zagros Fold – Thrust Belt. The lengths of the three anticlines are 105, 127, and 69 km, respectively, whereas their widths are 11.8, 11.4, and 5.7 km, respectively. The anticlines exhibit thrusting which caused, over riding of the northeastern limb over the southwestern one, hindering the latter limb [33, 39].

The studied area is located to the west of the central part of Iraq (Fig. 1), the Diyala River crosses the eastern part. The coverage of the studied area is about 15 km².

Studies dealing with the lateral growth are not common in the study area; however, some studies are indirectly related to the Neotectonic activity, which confirm the lateral growth of the anticlines; among those studies are:

Regional geological mapping for the concerned area and near surroundings performed in [33, 39]

where excellent geological base maps at the scale of 1 : 20 000 were presented and the stratigraphy of the exposed rocks within the formations was described. They also gave excellent description to the existing anticlines with different types of faults and the tectonics of the area, and estimated thrust amounts in all three anticlines and, moreover, geomorphological features and units were described in [33, 39].

Geological maps of Kirkuk, Khanaqeen, and Samarra Quadrangles at scale of 1 : 250 000 were compiled in [7, 8, 33], the studied area is located within the three quadrangles but the lateral growth of the anticlines wasn't discussed [7, 8, 33].

Geomorphological study of three tributaries of Al-Adhaim River was performed [32] with using six geomorphological parameters to deduce tectonic activity of the concerned area in which the current studied area is located. Different tectonic activities in different hydrogeological basins of the studied area were indicated [32].

Tectonic-geomorphological study was conducted [34] for developed alluvial fans in the current studied area and near surroundings. The developed alluvial

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Fig. 1. Satellite image showing the location of the study area.

Fig. 2. Calculating of the fold indices: (a) aspect ratio (AR) = length of hinge line (L) divided by width of the fold (W); (b) fold symmetry index (FSI) = width of forelimb (S) divided by half of fold width (W) with forelimb and back limb labelled; (c) fold front sinuosity (FFS) = length of the fold front (FS) divided by fold length (L) (after [17], modified).

fans and their relation with the lateral growth of the existing anticlines, which include Pulkhana, Qamar, and Jambour anticlines were discussed [34].

Many recent studies dealt with the influence of tectonic movements upon stream development in such areas as the Zagros Mountains, among them are [6, 11, 17, 19, 22, 23, 27, 40]. We have used the presented data from these studies for different geomorphological features to deduce activity of the studied three anticlines.

The main aim of this study is to deduce the tectonic activity of Jambour, Pulkhana, and Qamar anticlines using tectonic and geomorphological history, drainage analysis and ArcGIS technique. The study area is located in oil province and large towns with hundreds thousand population are situated in the area, therefore, the risk of the lateral growth and the main streams respond to the lateral growth may cause serious risks to the existing towns, oil industry infrastructure and the existing infrastructure.

MATERIALS AND METHODS

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

topographic and geological maps of different scales of the studied area;

DEM images;

ArcGIS program.

Geomorphic criteria evaluated fold growth [24]:

(1) deformation of progressively younger deposits or landforms;

(2) development of characteristic asymmetric drainage patterns;

(3) occurrence of a series of wind gaps (Dry gap) with decreasing elevation in the propagation direction.

The study of [24] is considered as the main guide line for our study and what we have concluded; as the study area is concerned.

Fig. 3. Morphotectonic map of the study area.

The geomorphological features and aspects of the Zagros were used to uncover aspects of the growth, evolution and interaction of anticlinal folds within the study area. The channelized drainage networks of mountain belts are perhaps the most sensitive indicators of horizontal and vertical surface deformation, at least during Holocene time scales [15].

We used remote sensing data, which includes:

(1) satellite image (Geological Survey, Baghdad, Iraq) and (2) Digital Elevation Models (SRTM 90 meters) are used to indicate the dendritic drainage pattern (DD) (Geological Survey, Baghdad, Iraq).

By means of remote sensing we have recognized the following abnormal aspects:

Fig. 4. Satellite image of Pulkhana anticline near Tuz Khurmatu town. Dissected thrust fault (black line) shown. Note: developed bajada (B) and anticlinal ridges (AR).

- (2) flood plain sediments (FP);
- (3) valley fill sediments (VF);
- (4) width of the developed flood plain (FP);
- (5) terraces (Tr);
- (6) fork-shaped valleys (FV).

Digital Elevation Model (SRTM 90 meters) is used to calculate geomorphic indices of folds that may help categorizing them and detecting geomorphic criteria that indicate fold growth. The ArcGIS program is used for completing the aims of this study calculating the geomorphic parameters of folds;

Satellite image was used for the space ratio and SRTM was used for calculating the front fold sinuosity. Drawing the drainage basin and calculating geomorphic parameters were obtained by ArcGIS.

Geomorphic parameters were used in this study to characterize the tectonic activity of certain regions were aspect ratio (AR), fold symmetry index (FSI), and fold front sinuosity (FFS).

These geomorphic parameters were calculated (Fig. 2). FSI equals the width of the forelimb of the fold, divided by half-width of the fold [16]. If the forelimb is the shortest, then the FSI will be less than 1.0. For a hinterland-verging structure the FSI will be greater than 1.0. The value of 1.0 indicates perfectly symmetrical fold. These indices are typically used together to estimate whether the symmetrical fold is likely to be thrust-cored or not [15]. A low aspect ratio (<10) and near-perfect symmetry (FSI close to 1.0) indicate that the fold formed by buckling, rather than by some forcing member, whereas high aspect ratio (>10) and pronounced asymmetry typically indicate the thrust-cored or forced fold [2, 10, 16].

Abandoned courses of streams and/ or valleys, elevated terraces, abandoned alluvial fans, abnormal shaped alluvial fans, elevated conglomerate beds of Pleistocene age, fault escarpments, thrust faults, transversal faults and inferred faults—all are recognized by careful inspection of different satellite images of different scales and were presented in the morpho-tectonic map of the study area (Fig. 3).

The presented data in the Neotectonic map of Iraq [30] is utilized to indicate the up-warping and down-warping areas in the study area. All the existing main thrust faults in the study area are considered as active areas, since the age of the thrust rocks is up to Pleistocene, accordingly, are considered as neotectonic activity. The estimated rate of the up-warping and down-warping in the study area is 6 mm/100 yrs and -8 mm/100 yrs, respectively [30].

The amount of the downward warp and upward movements are estimated by dividing the amount of movements as measured by meters elevation of existing contact between Middle Miocene and Upper Miocene above sea level, by the time span of Upper Miocene which is about 12 Ma.

The elevation of the contact between Middle Miocene and Upper Miocene; when is exposed on the surface is indicated from the geological maps whereas on subsurface down-warped areas are measured from drilled boreholes, oil wells, water wells and constructed geological cross sections.

GEOMORPHOLOGICAL UNITS AND FORMS

The studied area is located within the Low Mountainous Province [7, 8, 21, 33, 32, 39]. Below are the main geomorphological units and forms in the studied area.

Fig. 5. Satellite image of Tuz Chai. Note: dendritic drainage pattern (DD), flood plain sediments (FP) and valley fill sediments (VF).

(1) Alluvial fans. Tens of large alluvial fans and hundreds of small alluvial fans are developed in the studied area. The small alluvial fans usually form Bajada (Fig. 4), whereas the large alluvial fans cover vast areas more than tens of square kilometers that is attributed to the size of the feeder stream and its basin. They are covered usually either by gypcrete or thin veneer of flood plain silty clayey soil.

(2) Anticlinal ridges. Anticlinal ridges form continuous ridges (Fig. 4) for few tens of kilometers and are the main outlets of the rivers and streams that have developed alluvial fans in the studied area.

(3) Flood plain and valley fill sediments. These forms are well developed almost in all valleys, especially in the large perennial streams (Fig. 4). The flood plain sediments consist of silt and clay with very rare sand and few pebbles, whereas the valley fill sediments consist of loose pebbles up to 50 cm in size but as average they range from (<1 – 35) cm, with thickness of up to 5 m.

(4) Drainage patterns. The main drainage pattern in the studied area is the dendritic pattern which is developed along the flanks of the ridges (Figs. 4, 5). Trellis drainage pattern (Fig. 5) is developed within the anticlinal ridges which consist of alternation of hard and soft rocks. Parallel drainage pattern (Fig. 5) is developed in the main valleys and/or streams following the regional slopes.

TECTONIC FRAMEWORK

The studied area is located within the Low Folded Zone of the Outer Platform, which belongs to the Arabian Plate [21]. The zone is characterized by long anticlines and shallow and wide synclines. The anticlines form typical anticlinal ridges (Fig. 4) that are dissected usually by rivers, streams and valleys.

Three anticlines occur in the studied area: they are Jambour, Pulkhana, and Qumar, they trend

NW–SE (Fig. 1). These anticlines exhibit thrusting: the northeastern limbs are thrust over the southwestern limbs covering mainly the axis and the southwestern limb of the anticlines (Fig. 6).

Ramsey et al. [27] mentioned that the age of initial collision between Arabian Plate and Eurasian Plate is poorly constrained and is possibly diachronous from NW to SE [37]. The minimum age of continental collision is estimated at 16–23 Ma from structural and sedimentation records [28] to no later than ~10 Ma from the reconstruction of plate motions [26]. Before the onset of subduction in the Late Cretaceous [20, 9, 1], the Zagros Range formed passive continental margin on the northeastern margin of the present-day Arabia Plate with seafloor spreading in the Neo-Tethys ocean to the north–east. Earlier still, the Zagros Range shows evidence of Permian–Triassic rifting [35, 36], and some of the present-day north-dipping thrust faults may be reactivated normal faults from this time [25]. However, plate-circuit models suggest steady convergence rate between Arabian Plate and Eurasian Plate of (~2–3) cm/year since 56 Ma [26]. The mechanism by which shortening occurs may have undergone a reorganisation about 5 Ma ago [3–5], which is thought to coincide approximately with the onset of deformation in the Simple Folded Belt (Low Folded Zone in Iraq), although some shortening within the Simple Folded Belt may have started as early as 8 Ma [23]. Therefore, even though deformation probably began synchronous from NW to SE [24], the shortening rate across the Simple Folded Belt of the Fars region (the SE Zagros) may be greater than that in the Lorestan and Dezful regions (the NW Zagros) and Kirkuk Embayment (the study area).

The style of the deformation appears to vary along the strike of the Zagros. In the NW (Dezful), north–south shortening between Arabian Plate and Eurasian Plate is accommodated on a spatially separated system

Fig. 6. Geological map of the studied area and near surroundings (after [6, 7, 33, 37], modified).

of NW trending right-lateral strike—slip and thrust faults [27]. It is worth mentioning that Dezful is equivalent to Kirkuk Embayment in Iraq [21].

GEOLOGICAL FORMATIONS

The exposed geological formations in the studied area are described very briefly, hereinafter depending on [7, 33, 39]. The geological map is presented (Fig. 6).

The Fatha Formation (Middle Miocene) includes lower and upper members. Both members consist of cyclic sediments, each typical cycle consists of green marl, limestone and gypsum. However, in the upper member red claystone occurs above green marl and reddish brown sandstone occur in the uppermost cycles.

The Injana Formation (Upper Miocene) consists of fining upwards cycles. Each cycle consists of reddish brown sandstone, siltstone and claystone with various sedimentary structures.

The Mukdadiya Formation (Upper Miocene) consists of fining upwards cycles. Each cycle consists of grey sandstone with some sandstone pebbly beds, siltstone and claystone, with various sedimentary structures.

The Bai Hassan Formation (Pliocene—Pleistocene) consists of fining upwards cycles. Each cycle consists of conglomerate and reddish brown claystone, with rare sandstone. Many sedimentary structures occur in the beds.

DRAINAGE ANALYSIS

Drainage system and its respond is a good indication for tectonic activity [13–15, 27]. Usually, rivers, streams and valleys tend to follow the easiest path for their courses, however, locally they cross anticlines and ridges, especially when the rate of the incision of the valley course is higher than the rate of tectonic activity.

Fig. 7. Crossing of the Diyala River to Pulkhana, and Qumar anticlines. Thrust faults (black lines) between two anticlines: the former is thrust over the latter.

Fig. 8. Satellite image of Tuz Chai. Note: eastern branch (EB), width of the developed flood plain (FP), terraces (Tr), crossing of the conglomerate ridge (C) of the Bai Hassan Formation.

In the studied area Jambour, Pulkhana, and Qumar anticlines are dissected by many perennial streams and valleys, besides the Diyala (Sirwan) River that dissect the south-eastern plunge area of Pulkhana and Qumar anticlines (Fig. 7).

The eastern branch of Tuz Chai is a good example for the respond of the drainage system to the fold propagation (Fig. 8). The main course of the perennial stream is the nowadays eastern branch, this is evidenced by:

(1) existing flood plain along the eastern branch is very wide as compared to the size of the eastern stream

as soon as the eastern stream can't develop a flood plain with width of 2–6 km;

(2) deposited terraces west of the eastern branch located ≈ 12 m above the existing valley course, this size of a valley can't deposit this kind of terraces;

(3) weathering of the conglomerate of the Bai Hassan Formation in the crossing area with width of ≈ 2.18 km, whereas, the width of the crossing of the main stream is only 463 m.

From the obtained evidence it is clear that the Tuz Chai had changed its course as respond to the lateral

Fig. 9. Drainage system in Pulkhana and Qumar anticlines. Note: water and wind gaps, bifurcation and merging of the valleys.

propagation of the Pulkhana anticline. The original course forms a wind gap, whereas, the recent course forms a water gap. Both gaps are good indication for the lateral propagation of the anticline; the evidence considered to be good indication for the lateral growth (propagation) of anticline that proved tectonic activity along Tuz Chai basin and its lateral growth [13, 18, 27].

Another good example for the respond of the drainage system to the fold growth in the studied area is the drainage system in Kifri vicinity and both crossed Pulkhana and Qumar anticlines. Three large perennial streams form the drainage system, it will be called Kifri Chai, Kifri West and Kifri East streams; in this study (Fig. 9).

Kifri Chai is the main perennial stream across Pulkhana anticline forming a water gap (Fig. 9, point 1), then crosses Qumar anticline forming another water gap (Fig. 9, point 2). A large alluvial fan is formed after crossing Pulkhana anticline [34] and another one after crossing Qumar anticline. The growth of the former one is ceased by the presence of Qumar anticline. A feeder channel of the fan is deflected eastwards and merges in Kifri East stream (Fig. 9, point 3).

Kifri East stream crosses Pulkhana anticline forming a water gap (Fig. 9, point 4) and a large alluvial fan. Two feeder channels cross Qumar anticline forming two water gaps (Fig. 9, point 5, point 6) and merge together after the crossing (Fig. 9, point 7). Another alluvial fan is developed after crossing Qumar anticline with the help of another stream that crosses

Qumar anticline forming the third wind gap (Fig. 9, point 8). The growth of this alluvial fan ceased by the presence of Qumar anticline.

Kifri West stream crosses Pulkhana anticline forming a wind gap (Fig. 9, point 9, Fig. 10, point 1) and crosses Qumar anticline forming another wind gap (Fig. 9, point 2) as well. The original crossing of Kifri West stream to Qumar anticline occurred by another course which is as abandoned as the main stream (Fig. 10, point 3) indicated by the following features.

(1) Wide developed flood plain along the original stream (Fig. 10). If the stream wasn't the original Kifri West stream then it wouldn't be able to develop the wide flood plain and erode conglomerates of the Bai Hassan Formation in the large area as compared to the nowadays crossing of Kifri West stream.

(2) The downstream continuation of original Kifri West stream and nowadays Kifri West stream (Fig. 10, point 2, point 3) makes clear that the abandoned stream was the original stream that was crossing Pulkhana anticline. Another abandoned feeder channel from Kifri Chai (Fig. 10, point 4) deflects west wards and merges to the original Kifri West stream. All these streams and the other small ones merge together (Fig. 10, point 5) to form nowadays Kifri West stream and flows out of Qumar anticline forming large alluvial fan (Figs. 9, 10). All those developed wind gaps abandoned course of original Kifri West stream and developed wide flood plain with colluvial sediments are good indications for Pulkhana and Qumar anti-

Fig. 10. Satellite image showing the details of Kifri West stream and crossing of Qumar anticline. Thrust fault (black line). Note: bended and dissected parts.

clines activity. The evidence is considered indications for lateral growth of anticlines by different authors and among them are [6, 18, 27].

Tawouq Chai crosses Jambour anticline in the form of two branches forming two water gaps (Fig. 10, top, point 1, point 2), they merge together before crossing (Fig. 10, top, point 3). Both branches change their trend almost in the right angle to their trend following the strike of the beds. After merging together the stream changes its trend to be again perpendicular to the regional strike of the beds because weakness zones, like joint trends, will be perpendicular to the strike of the bedding; therefore, the streams will follow those weakness zones.

Three other perennial streams dissect both Jambour and Pulkhana anticlines forming six wind (dry) gaps at points 1, 2, 3, 4, 7 and 8 (Fig. 11, bottom). Branches 1 and 2 merge at point 5 and branches 3 and 4 merges at point 6 and two branches cross Pulkhana anticline in two wind gaps at point 7 and point 8; almost all of them flow perpendicular to the strike of the beds (Fig. 11, bottom).

Another abnormal behaviour for the Tawouq East streams is their strange trends during crossing Jambour anticline and the tributaries of Tawouq Chai (Fig. 12). These abnormal trends are developed only in the soft rocks (claystone and conglomerate) of Bai Hassan Formation, whereas in older exposed formations, the trend of Tawouq East streams and their trib-

utaries changes to normal trend following the regional gradient of the topography because the claystone beds are weak; therefore, they are easily eroded and the drainage net is developed in irregular forms and directions.

RESULTS

Geomorphologic indicator of aspect ratio and fold asymmetry are shown (Figs. 13a, 13b). The aspect ratio has been recorded as 5, 6 and 10 for Qumar, Jambour, and Pulkhana anticlines, respectively. Thus the formed folds in the study area are the thrust-core folds in Qumar anticline and buckling in Jambour and Pulkhana anticlines. The fold symmetry index indicates the presence of perfectly symmetrical fold in Jambour and near-perfect symmetry in Pulkhana and Qumar anticlines.

Geomorphic index of the fold front sinuosity in the study area is shown (Fig. 14). Higher values of the front sinuosity can be found in firstly uplifted fold and exposed to erosion for a long time. The values of the fold sinuosity (Table 1) vary from 0.5 in Jambour, to 0.8 in Pulkhana and 0.6 in Qumar anticlines. The fold front sinuosity may change from one anticline to another. Higher sinuosity is in the middle and the south-eastern end of Jambour anticline. The north-western and south-eastern parts of Pulkhana anticline and the middle part of Qumar anticline have higher fold front sinuosity.

Fig. 11. Satellite images. (**Top**) Tawouq Chai, (**Bottom**) Tawouq East Streams. Thrust faults (black line).

The three studied anticlines show clear lateral growth as indicated from the fold front sinuosity (Figs. 13, 14, Table 1), beside other indications among them are:

(1) Water gaps and wind (dry) gaps. Tens of water gaps and wind gaps are developed along the studied

three anticlines (Figs. 7–12). Both types of gaps are good indication for lateral growth of anticlines [11, 18, 27];

(2) Fork-shaped valleys. The other indication for lateral growth of folds is the fork-shaped valleys presence [11, 18, 27]. Tens of fork-shaped valleys are

Table 1. Fold front sinuosity in the study site

Geomorphic parameter of fold front	Anticlines		
	Jambour	Pulkhana	Qumar
Length of fold (L)	80.37	90.48	32.75
Length of fold front (FF)	147.71	117.35	51.02
Fold front sinuosity (FFS)	0.5	0.8	0.6
Activity	High	High	High

Fig. 12. Satellite image of Jambour anticline with abnormal drainage trends of streams and their tributaries during their crossing.

Fig. 13. Geomorphic parameters of aspect ratio (AR) and fold sinuosity index (FSI).

developed on hard rocks of exposed formations within the three studied anticlines (Fig. 15);

(3) Alluvial fans. Tens of alluvial fans of different shapes and sizes are developed along the three studied anticlines. Some of those alluvial fans exhibit strange behaviour in their feeder streams (Figs. 9–11). The abandoned streams with their bifurcation and re-emerging are other indications for the anticlines lateral growth. Moreover, some of the alluvial fans are not grown normally due to the presence of a facing anticline that was growing too, consequently, it ceased the normal fan growth. Alluvial fans bound between Pulkhana and Qumar anticlines serves good example for the case;

(4) Flood plain. The wide flood plain presence along narrow valleys is another indication that the valley abandoned from its original course. Tuz Chai during crossing Pulkhana anticline (Fig. 8) is good example, where the original course is a nowadays nar-

row stream. The wide flood plain can't be developed by the nowadays narrow stream.

DISCUSSION

We have studied three anticlines called Jambour, Pulkhana, and Qumar in the central north-eastern part of Iraq to deduce their lateral growth using drainage analysis and their sinuosity. We found many interesting indications confirming their lateral growth.

The recorded aspect ratio (Table 1, Fig. 13) indicates that the three studied anticlines show tectonic activity, consequently indicating lateral growth of the folds. However, Jambour, Pulkhana, and Qumar anticlines showed difference in their activity, which is a normal case.

The sinuosity of the three studied anticlines (Table, Figs. 14, 16). The recorded fold sinuosity indices showed that the three folds are active; consequently, indicating their lateral growth.

Fig. 14. SRTM image showing fold front sinuosity (FFS).

Fig. 15. Satellite image facing south fork-shaped valleys (FV) in Pulkhana anticline.

Fig. 16. Geomorphological attributes of: (a) Jambour, (b) Pulkhana, and (c) Qumar anticlines, illustrating overall lateral propagation to the NW: annotated digital elevation mapper (DEM), image locations of water gap (Wg) and wind or dry gap (Dg) marked on the profiles of the anticlines.

The three studied anticlines show tens of water gaps and wind (dry) gaps (Figs. 7, 9, 11, 16). The presence of water gaps and wind gaps in folds is excellent indication for their lateral growth anticlines [11, 18, 27].

The heights of the wind gaps and water gaps (Fig. 15) in Jambour and Pulkhana anticlines are decreasing north-west ward indicating that the lateral growth was towards north-west. However, the last water gap in

Pulkhana anticline (Fig. 16) is lower than the other water gaps. This can be attributed to Diyala River, which is larger than the existing streams crossing the anticline. Therefore, its eroding ability will be higher; consequently, the water gap will be in lower height as compared to the other existing water and wind gaps in Pulkhana anticline.

Fork-shaped valleys are good indication for the lateral growth of anticlines [11, 18, 27]. In the studied three anticlines, tens of fork-shaped valleys were recognized (Fig. 15). They are well developed in hard rocks within the Fatha Formation, like thick limestones, however, in soft rocks like claystone and sandstone the fork-shaped valleys are hardly developed and preserved.

CONCLUSIONS

(1) The studied Jambour, Pulkhana, and Qumar anticlines show clear indication towards northwest. The lateral growth is confirmed by studied parameters, such as aspect ratio, fold front sinuosity index, recorded values confirm their activity and lateral growth consequently.

(2) The presence of tens of water and wind (dry) gaps also indicates their activity. Moreover, the decrease in their heights towards northwest indicates that their growth was towards northwest.

(3) The abnormal behavior of streams dissecting the studied anticlines also confirms that the anticlines were active, especially those streams which were feeder streams of alluvial fans. The activity is also indicated by the presence of tens of alluvial fans with different shapes and sizes. The growth of some of the alluvial fans was ceased by the growth of the facing anticlines. Moreover, some streams show wide flood plains, which indicate that the original course of the streams and/ or valleys was abandoned and a new course is followed nowadays.

(4) The presence of fork-shaped valleys in some hard rocks is also good indication for the lateral growth of the studied anticlines.

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