International Journal Of Enhanced Research In Science Technology & Engineering, Issn: 2319-7463
Vol. 3 Issue 3, March-2014, Pp: (140-148), Impact Factor: 1.252, Available Online At: www.Erpublications.Com

The influence of tectonic movements upon changes in river alignment - The example of the Lower Khazir River

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Abstract: The Lower Khazir River provides a good example of changes in river alignment associated with neotectonic movements. The aim of this paper is to address the two following questions: 1- How big an impact does the river exert upon the process of (fold) anticline growth? 2- Where are the largest geomorphic changes along the lower course of the Khazir River and how are they connected to the sinuosity of the Maqlub and Ain Al-Safra and Makhmoore folds? In order to identify the dry gaps on the anticlines, analyses of two and three dimensional images are performed during the whole research procedure. The growing fold exerts an influence upon the latitudinal displacement of the river bed to the east. Faults and soft rocks play a role in the fold and river morphology. The current gap occupied by the river (water gap) is determined by the flow of the river following the abandonment of the old gap (dry gap) located on the nose of the fold. The morphology of the river changes along with an increase in sinuosity of the Maqlub and Ain Al-Safra folds. The distance over which there is intense morphological change of the old gap reaches 2.5 km, and 3.5 km in case of the water gap on the Maqlub and Ain Al-Safra folds. The morphology of this river is more straightforward in the Makhmore folds than the Maqlub and Ain Al-Safra folds. Considerable changes in the river's morphology continue on the Makhmore folds along the 11.5 km course from the old gap to the water gap.

Key words: dry gap, water gap, digital elevation model, Lower Khazir River.

Introduction

The Lower Khazir River is located in Iraqi Kurdistan (Northern Iraq). The Khazir River crosses three folds from the north to the south (Fig. 1). The growth of the Ain Al-Safra and Makhmoore folds has greatly influenced the alignment of this river, which is now one of the tributaries of the River Great Zap but was formerly a tributary of River Tigris (Fig. 2).

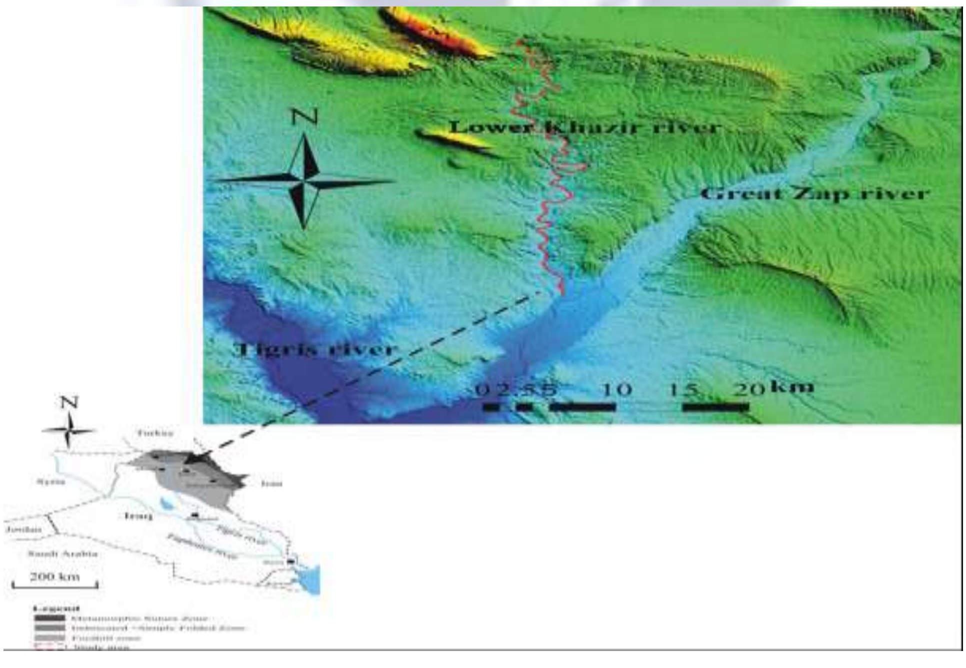

Fig.1 SRTM image of the land relief in the Khazir River Basin

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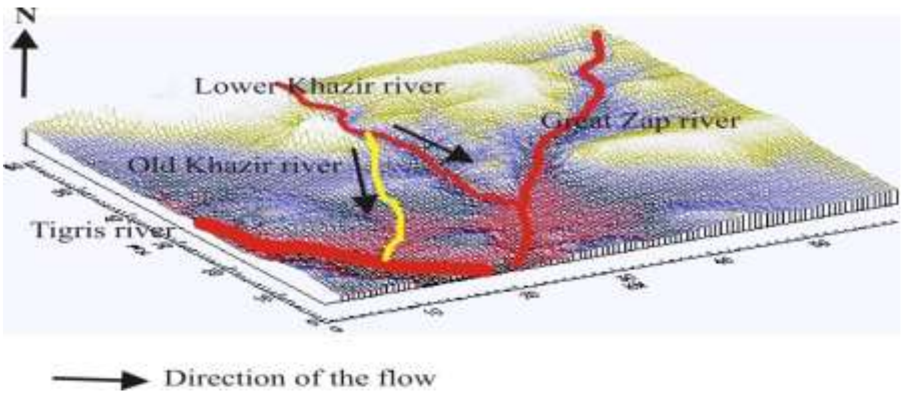


Fig. 2: Three dimensional images of river flow direction- both past and present.

Numerous studies have reported continuing quaternary tectonism (Hapoian, Vejlupek 1977, Burwary 1983, Numan, Bakose 1985) and impacts of tectonic movements upon the evolution of the fluvial landscape (AL-Daghastany, Salah, 1993). However, fewer studies have looked at the influence of tectonic movements upon stream development in such areas as the Zagros Mountains (Ramsey et al., 2008, Bretis et al. 2011). The channelised drainage networks of the mountain belts are probably the most sensitive indicators of horizontal and vertical deformation of the surface. This is true at least for the Holocene time scale (Burbank & Anderson, 2001; Ramsey et al., 2008). Al-Daghastany, Salah (1993) assumes that the meandering of the lower Khazir River is caused by the expansion of the Maqlub and Ain Al –Safra anticlines along their path. Tectonic movement is evident all the way across the river gorge from the north to the south of the study area. The east-west direction of tectonic movements in the Zagros Mountains causes the deformation of the stream to be the more anomalous in places where the stream crosses the anticline. Consequently, the growth of folding takes place on the left side of the old stream and the anticline. Hence, more than one dry streambed is expected to remain on this anticline and dry and water gaps result from the growth of the anticline (Bretis et al. 2011). The aim of this study is to examine the growth activity of the anticline and impact of growth on the river

Data and methods

Erdas software was utilised to produce one image of Landsat 4-5 TM in 7 bands. A relief map of the study area was drawn by SRTM image in ArcGIS software. Three dimensional maps are drawn in River Tools software using SRTM. The curves of the axis of the anticlinal folds are also outlined in River Tools software.

Geological background

Geological formations in the study area include the following: Khurmala, Gercus, Pilaspi, Lower and Upper Fares,Lower and Upper Bakhtairy, and Quaternary (Fig.3). The first three formations are built up of medium and hard rock while the Lower and Upper Fares,Lower and Upper Bakhtairy and Quaternary consist of soft rocks. The Khazir River crosses the area of the Maqlub- Bardarash, Ain Al-Safra and Makhmore anticlines.

Neotectonic setting

According to Numan (1997), the study area lies in the lower folded zone (Fig. 4 A). The regional geology of North Iraq is dominated by the NW-SE trending Zagros Mountains range - a neotectonically active structure. Thus, the movement rate between the Eurasian and Arabian Plates (Fig.4 B) is estimated to be around 1.6^2.2 cm/year (Sella et al., 2002) or 2^3 cm/year (Vernant et al., 2004). The most recent studies estimate the rate of isostatic uplift (vertical movement) in the Alpine Orogentic system in Iraq to be between 1 and 2 mm/year (Adeeb, 2007). The velocity of recent northward / horizontal movement of the Arabian plate in Iraq amounts to about 2.8 cm /year (Hasan, 2008).

Morphotectonic setting

The changes in the river channel are evidenced by the braided throw of low to high sinuosity. The gradient of channel deformation corresponds to the valley slope and power of the flow. This channel is narrow as anomalous meandering reaches upstream in the Maqlub anticline - this is linked to fold and thrust fault activity within the channel. The channel widens abruptly in the line of the Ain Al -Safra anticline under the impact of a fault (Fig.5). The morphology of the stream is straighter with a narrow channel in the Makmoore anticline - the stream meanders both in the Maqlub and Ain Al - Safra anticlines (Fig.1).

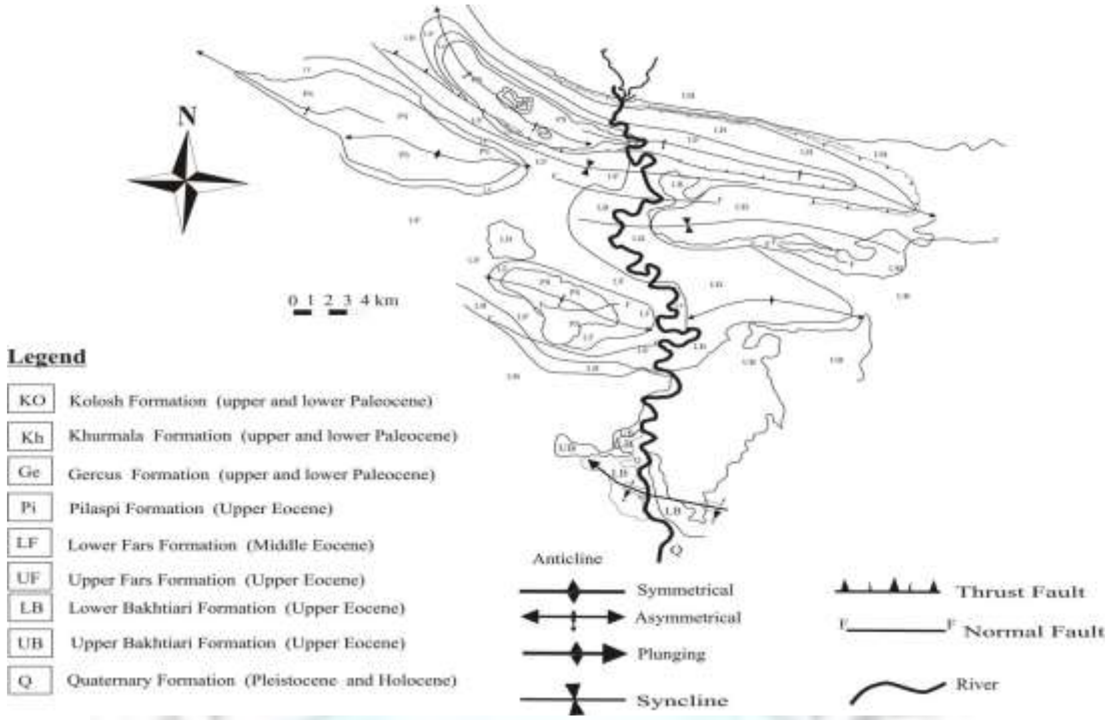
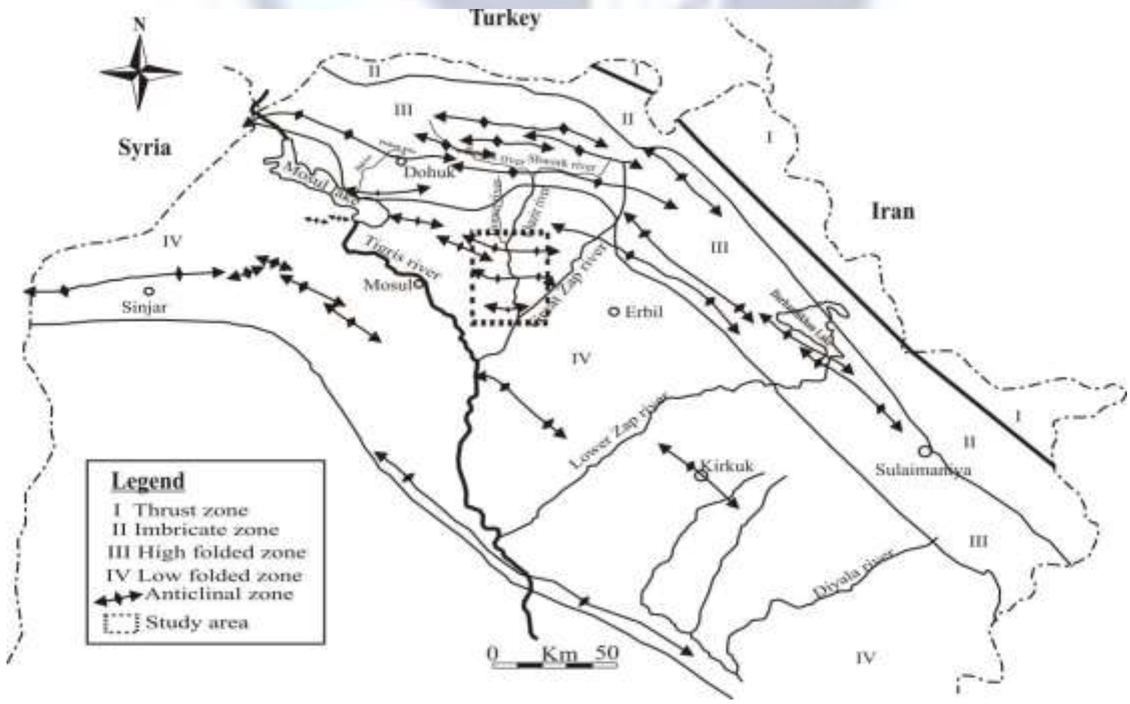


Fig.3: Geological map of the study area following Numan, Bakose, (1985), Al-Daghistany, Salih, (1993) and Geological survey and mining, Bagdad, Iraq, (1995), modified

Reilf et al., 2012 have divided the earthquakes into three groups according to the depths of their focal points. The shallowest and most common group recorded is a group of earthquakes with a hypocentre depth of 0 –30 km, the second, deeper and less common group has a hypocenter depth from 30 up to 150 km hypocenter. Only one earthquake with a hypocentre deeper than 150 km was recorded. Most earthquake magnitudes lie between 4 and 5. The bulk thickness of the sediments is about 8 km in the High Folded Zone (study area) and about 12 km in the Foothill Zone

A



B

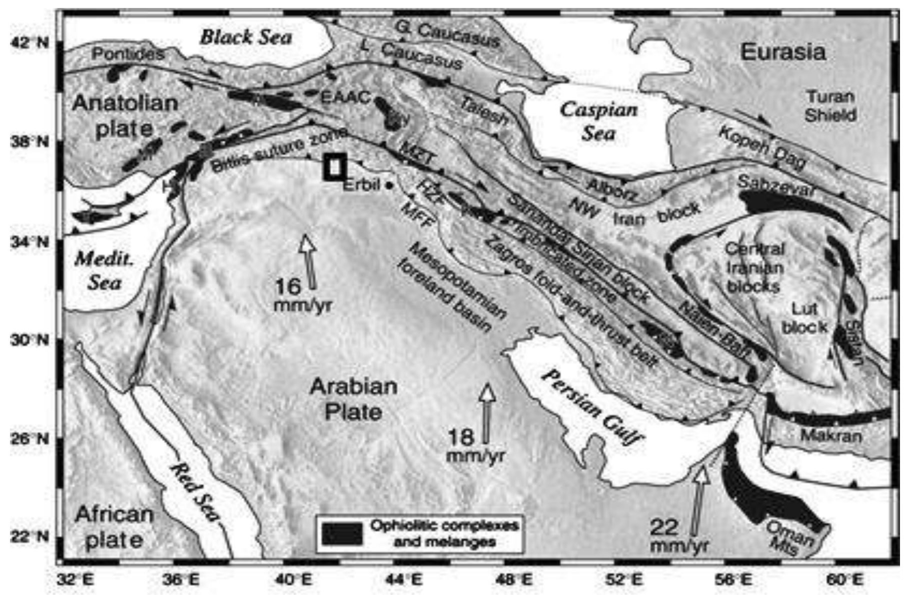


Fig.4 (a) Tectonic subdivisions in Iraqi Kurdistan (Numan 1997) modified, (b) Regional tectonic setting of the Zagros Mountains. MFF (Mountain Front Fault), HZF (High Zagros Fault), MZT(Main Zagros Thrust); the black rectangle shows the area under investigation. Plate movement velocities after Sella et al. (2002), and Homke et al. (2009) modified.

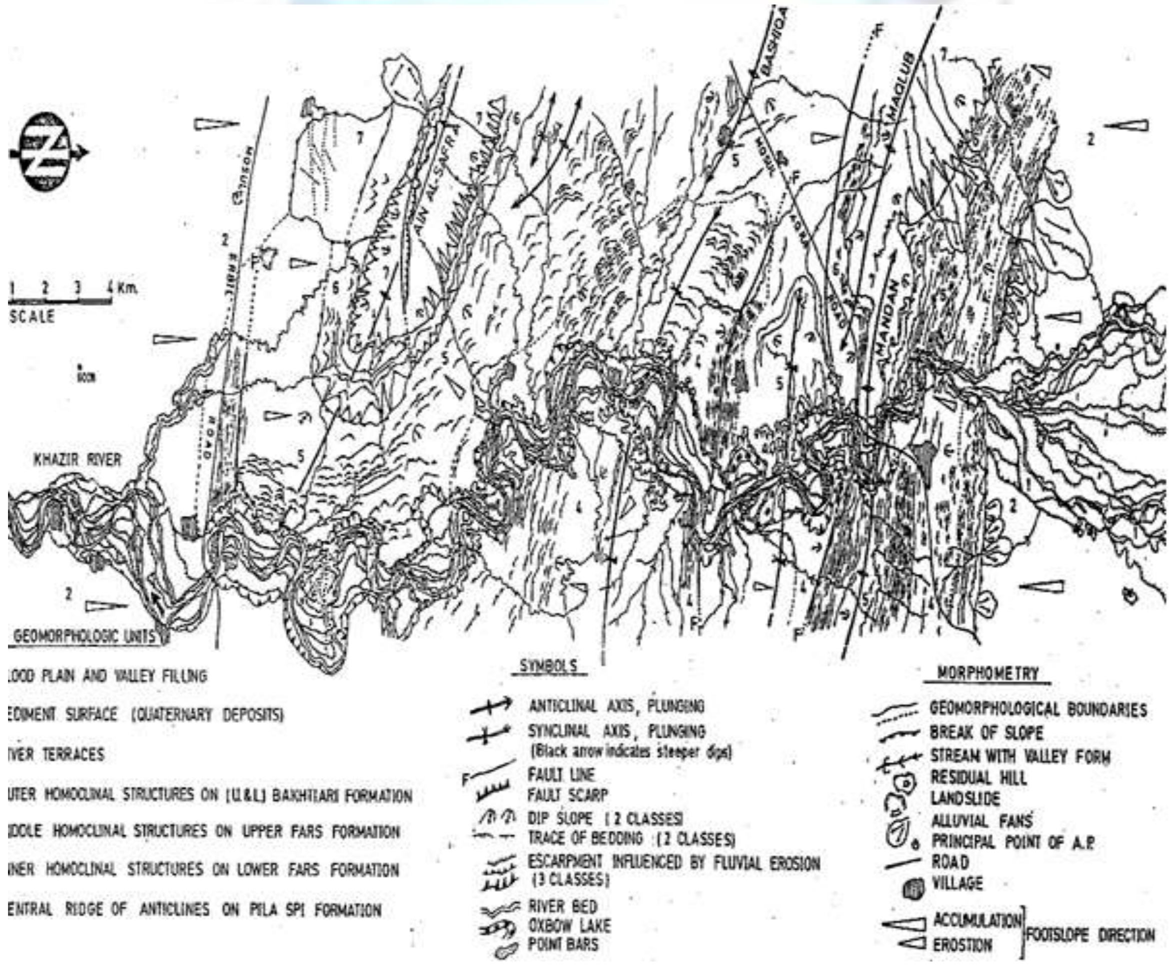


Fig.5: Morphotectonic map of the study area by Al-Daghistany, Salih (1993)

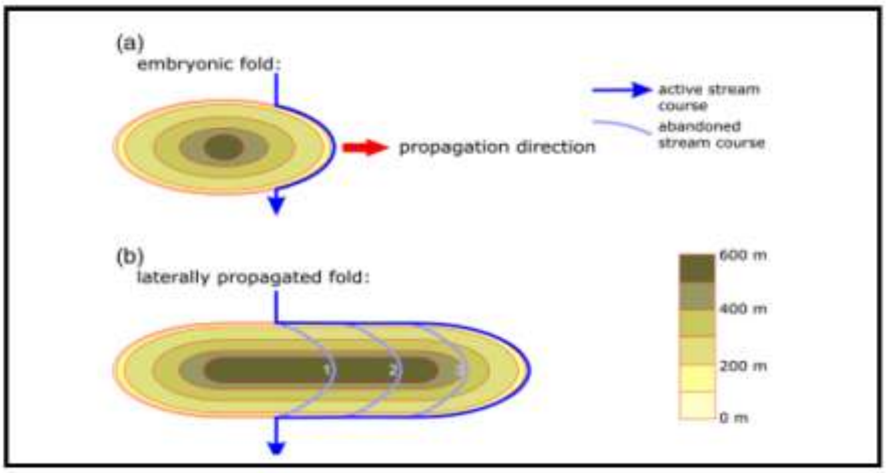


Fig. 6 (a) Map view with contour lines of an idealized embryonic cylindrical fold with an elliptical base and convex-up Lanks hat deflect a river around the fold nose. (b) A series of curved dry gaps have formed due to the very fast propagation and high tectonicuplift of a fold growing in length, mimicking the fold nose by Bretis et al. (2011)

The Lower Khazir River crosses three anticlines from the north to the south and is described below.

Maqlub- Mandan anticlines

The Maqlub-Mandan anticlines are nearly 42 km long and take an asymmetrical form. Two segments are shown along these anticlines. Wind gaps lie across the nose of Maqlub-Mandan folds (Fig.7 a). Four dry gaps are located on the south western nose of the Maqlub anticline in the upper part of the river (Fig. 7. c). An old dry gap is located at an altitude of 500 m.a.s.l (along a distance of 3 kilometres and a younger dry gap is located at 350 m. a.s.l (along a distance of 5 km). The water gap is present at 300 m.a.s.l and along a distance 5.5 km river moved (Fig.7 d).

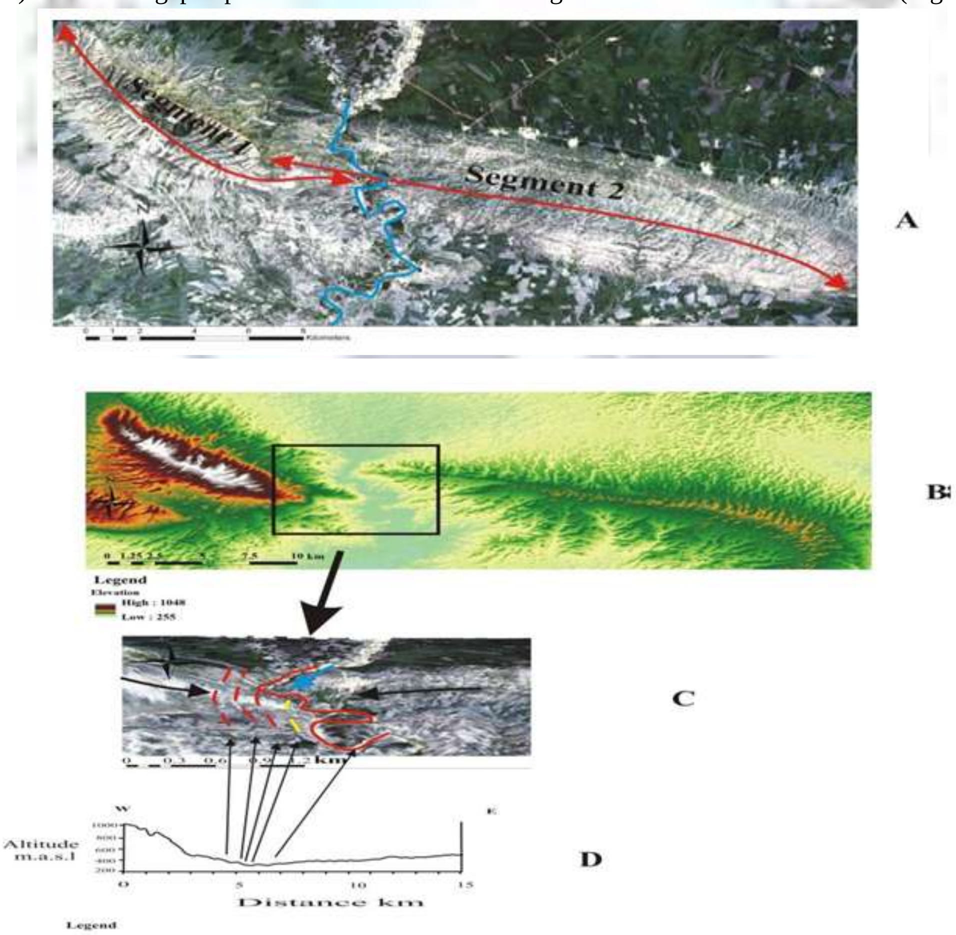


Fig.7 (a) Direction of growth of the fold segment towards the NW and SE, (b) ASTER (elevation) false colour overview of the Maqlub and Mandan Anticlines. (c) Location of the dry and water gaps and direction of anticline growth.(d) Topographic profile along the nose of the growing fold.

This displacement has resulted in a distance of 2.5 km between the old dry gap and the water gap on the nose of the Mqlube anticline. Fluvial terraces are located on both sides of the main channel and the active flood plain of the channel (Fig.8 a,b).

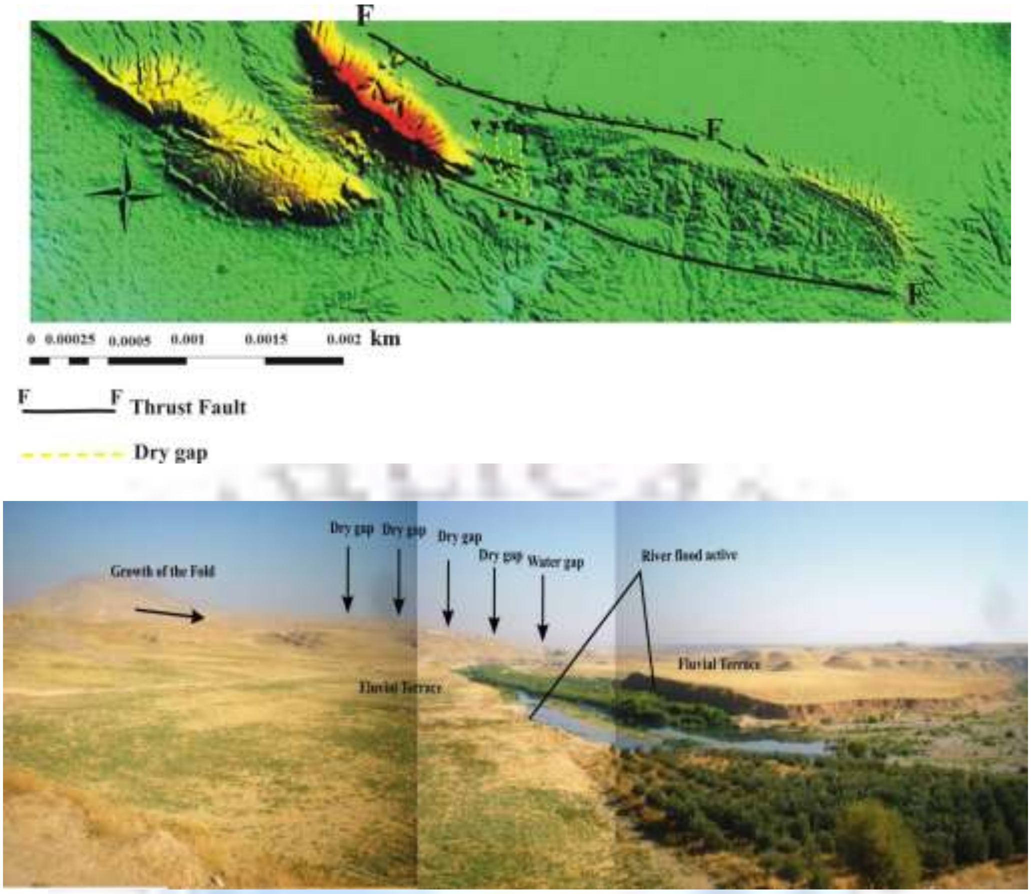


Fig.8 (a) 3D view of the Maqlub and Mandan Anticline and curved dry gaps, (b)Field trip photo of the upper river shows the dry gaps and water gap (location of the photo is shown in a).

Ain Al-S afra anticline

Two segments are shown in this anticline (Fig 9.a). Ain Al–Safra is a double plunging structure. The length of its axis is about 8 km. The southern plunge extends to the Lower Khazir river (Numan, Bakose 1985). There is another of very low amplitude which runs along the axis of the Ain Al-Safra anticline, but on the other side of the Lower Khazir river (Burwary 1983). Three dry gaps are located on first segment of the Ain Al-Safra anticline (Fig.9 c). The older dry gap is located at an altitude of 320 m. a.s.l (along a distance of 7 km) and the younger dry gap is located at 280 m.a.s.l (along a distance of 10.25 km). The water gap is present at 260 m.a.s.l and along a distance of 10.5 km river moved (Fig.9 d).

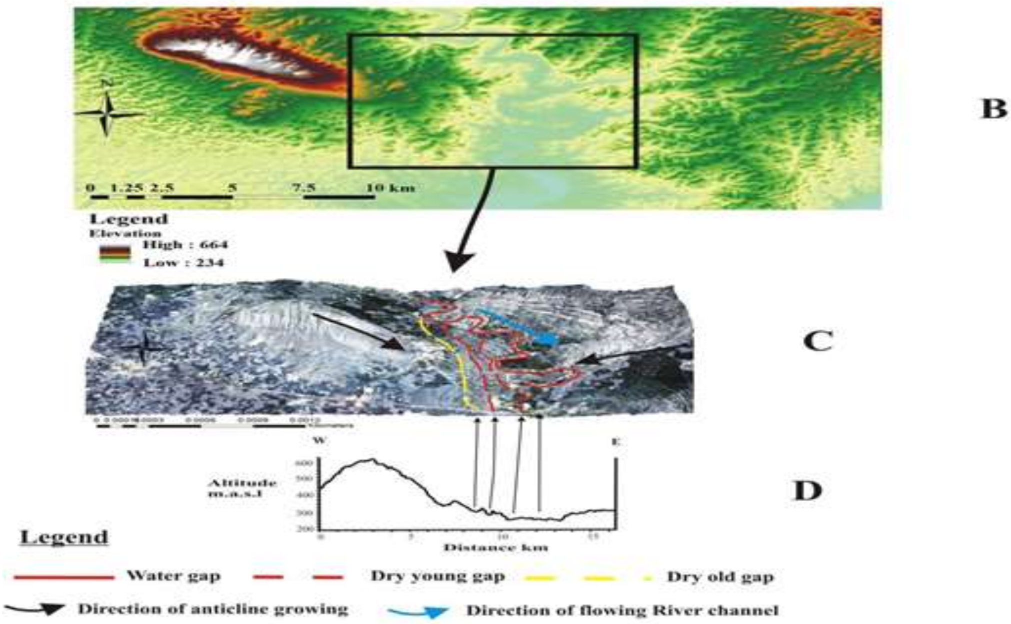


Fig.9 (a) Direction of growth of the fold segment towards the NW and SE, (b) ASTER (elevation) false colour overview of the Ain Al-Safra Anticline. (c) Location of the dry and water gaps and direction of anticline growth. (d) Topographic profile along the nose of the growing fold.

The distance between the old dry gap and water gap on the limb of the Ain Al-Safra anticline is 3.5 km. Fluvial terraces and hill slopes are indicated on both sides of the river channel (Fig.10 a, b).

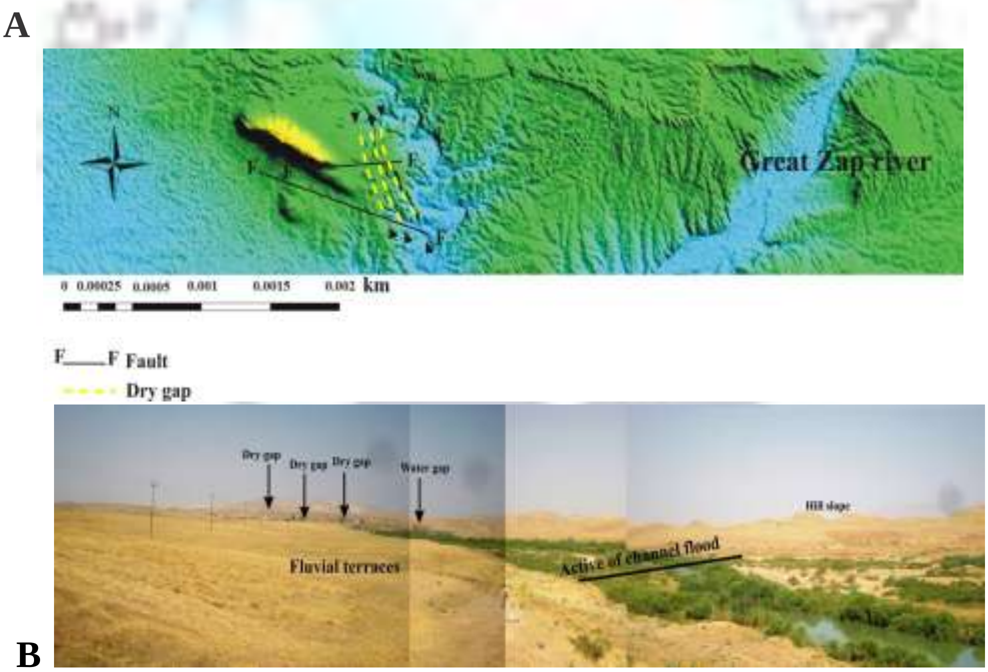


Fig.10 (a)3D view of the Ain- Al Safra Anticline and curved dry gaps ,(b)Field trip photo of the middle river shows the dry gaps and the water gap (location of the photo is shown in a).

Makhmoore anticline

Three segments are shown along the growth of the Makhmoore fold (Fig.11). The total length of the fold axis is 19 km. Three dry gaps are located on the nose of first and second segments of the Makhmoore fold(Fig.11 c). The old dry gap is located at an altitude of 285 m. a.s.l (along a distance of 4 km from the western limb) and the young dry gap is located at 275 m.a.s.l (along a distance of 10 km). The water gap is present at 235 m.a.s.l and along a distance of 10.25 km river moved (Fig. 11 d). The resulting distance between the old dry gap and water gap on the limb of the Makhmoore anticline equals 7.5 km. Fluvial terraces are found on the right side of the channel (Fig.12 a,b).

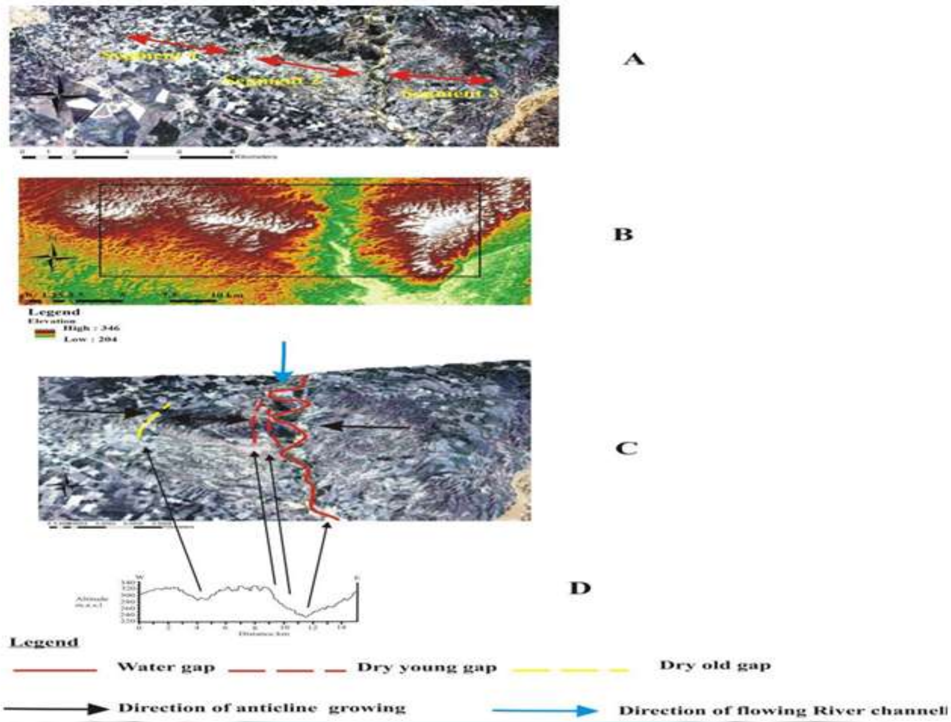


Fig.11 (a) Directions of growth of the fold segment towards the NW and SE, (b) ASTER (elevation) false colour overview of the Makhmorre Anticline. (c) Location of the dry and water gaps and direction (d) Topographic profile along the nose of the growing fold.

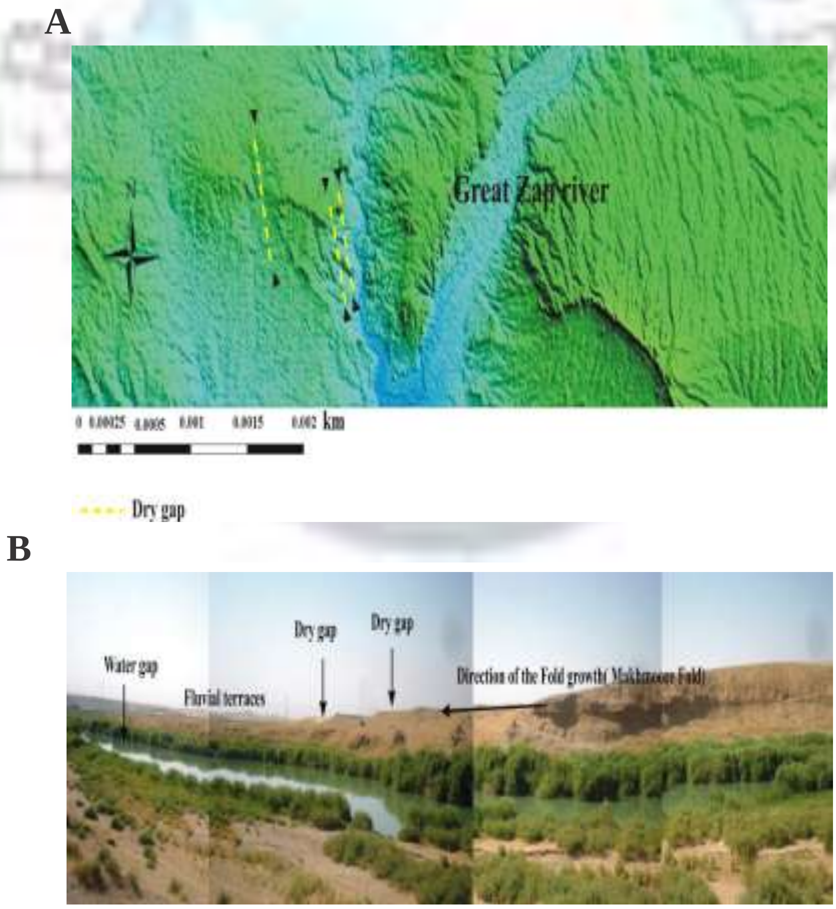


Fig.12 (a) 3D view of the Makhmoore aniticline , (b) Field trip photo of the river shows the dry gap and water gap (location of the photo is shown in a).

Results

Geomorphological investigation of fold growth in the study area suggests one scenario for fold linkage and summarised according to the conceptual models by Bretis et al. 2011. In the Maqlub-Mandan, Ain Al-Safra and Makhmorre folds en echelon-linkage occurs when embryonic fold segments that are aligned en echelon to the shortening direction link to form a continuous structure (Fig.13b).This process leads to the development of fold structures, which record a marked curvature of the fold axis and axial plane and resemble Type 2 refold structures (Ramsay,1967) (Fig.13). Obviously, there is a smooth transition between linear-linkage and en echelon-linkage. In both cases, geomorphological criteria are probably the most useful and efficient tools for distinguishing between different fold segments, by deciphering the growth directions and linkages of the fold. The Maqlub-Mandan anticline (fold train) and Ain Al-Safra are characterised by en echelon-linkage of two fold segments, causing marked bending in the fold morphology. The Makhmorre anticline is characterised by en echelon-linkage of three fold segments. The morphology of the river is characterised by higher sinuosity on the nose of the Maqlube and Ain Al- Safra anticlines. The river valley becomes straighter in the Makhmoore anticline while the biggest changes in the river's direction are found in the Ain Al-Safra and Makhmoore anticlines. The dry gap increases in the middle and lower part of the river. The explanation of this morphology may lie in the river course, which crosses one anticline in in its middle and lower section. As a result, the river rips deep into the Makhmoore anticline and the changes from the western part of this anticline continue along 11.5 km.

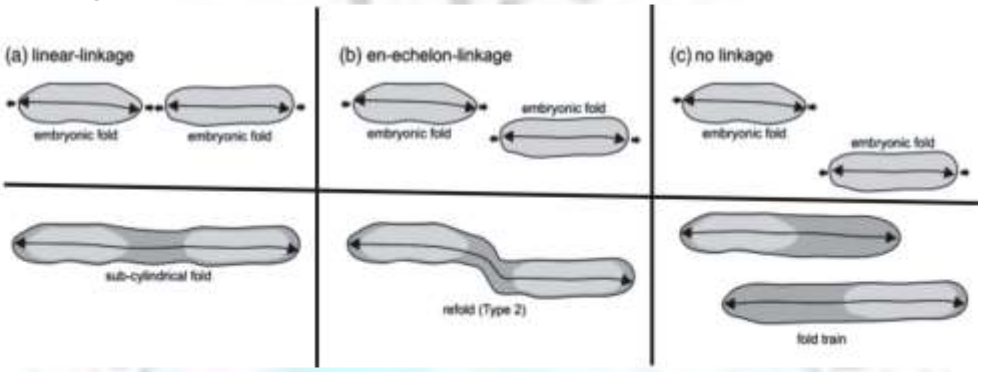


Fig.13.(a) Linear-linkage - linearly aligned embryonic fold segments join laterally into a sub-cylindrical fold, forming Type 1 refold structures. (b) En echelon-linkage - en echelon aligned embryonic fold segments are linked leading to the development of a fold structure with a marked bending of the fold axis and axial plane forming Type 2 refold structures; (c) No linkage between fold segments resulting in long fold trains (Bretis et al. 2011)

Conclusion

Geomorphological changes on the Lower Khazir River are evident in its middle and lower sections and have been caused by the growth of anticlines. Tectonic uplift and anticline movements play a vital role in the lower section of the Khazir River. These movements are clearly visible in the morphology of the bed of the valley as they induce river meandering. Anticline growth influences changes in the river bed course and sinuosity. Faults also play a role on the nose of the anticline and become observable in the whole morphology of the river. The biggest changes in the movements and river direction occur in the Makhmoore anticline. A displacement of 7.5 km is present between old dry gaps to the water gaps.

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