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Deducing Folding Form in the Qara Chough South Anticline by Using Structural and Geomorphological Indications in Central Part of Iraq

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ABSTRACT

The Qara Chough anticline is a part of the Qara Chough Range, which consists of three parts; the middle one is in the form of a small dome called Makhmour Dome, whereas the northern and southern parts are long and narrow anticlines and are called Qara Chough North and Qara Chough South anticlines. The Qara Chough South anticline is a double plunging with a steeper southwestern limb. The exposed rocks in the anticline are mainly of Oligocene formations, the Euphrates and Fatha formations; however, along with the outer parts of both limbs, rocks of the Neogene formations are exposed with different Quaternary sediments; among them, alluvial fan sediments are the most abundant. The folding form of the Qara Chough South anticline, which is an inverted graben, is deduced through studying and using ESRI World Imagery, Sentinel images, geological maps of different scales, and field data to indicate the structural and geomorphological forms, which can be deduced from the mentioned data. We have also applied different measurements to indicate the type of the fold, and it was found to be a detachment fold. We also have interpreted many geomorphological forms, such as abandoned alluvial fans, fork-shaped valleys, inclined valleys, and radial valleys, and all are reasonable indications for the lateral growth of the anticline.

Keywords: Detachment Fold, en-echelon plunge, Alluvial fans, Aspect Ratio, Fold Symmetry Index, Mountain Front Sinuosity Index, Qara Chough.

1. Introduction

The Qara Chough South anticline is a part of the Qara Chough Range, which consists of three domes, which are called Qara Chough North, Makhmour, and Qara Chough South. The continuation of the range southeast wards is called the Qara Boutaq Range, which consists of two domes, Qara Boutaq 1 and 2, and the lesser Zab River dissects the latter (Fig. 1).

The Qara Chough anticline is surrounded from the north and south by vast flat plains, which are covered by Quaternary sediments. Therefore; the anticline with the neighboring anticlines forms an outstanding mountain, which is an abnormal form within the vast flat plains, which have elevations of (475-530 m, a.s.l.) in the north and (416- 446 m, a.s.l.) in the south.

The Qara Chough South anticline, with the other neighboring anticlines, has been under the focus of oil companies since the middle of the last century. Accordingly; ex-I.P.C. drilled an oil well in 1959 with a depth of 3000 m[1]. Al-Naqib[2] published a report about the geology of the south Kirkuk area and described the exposed formations in the anticline. Al-Sammarai and Al-Mubarak[3] performed geological mapping for an area in which the Qara Chough South anticline was included, and they described the exposed formations and mapped structural forms in detail and presented geological maps at a scale of 1:25000. Fouad[4] carried out a geological structural study of the Qara Chough South anticline and presented his thesis which included detail structural map. Sissakian[5] prepared the Kirkuk Geological map of 1:250000 on a scale (Fig. 2) and presented detailed data about the stratigraphy, tectonics and structural geology, and geomorphology.

The area under consideration is north of Baghdad city by about 270 km, 46 km south of Erbil city, and 6 km NE of Makhmour town (Fig. 1). It occupies the whole Qara Chough South Mountain, and the coverage area is about 125 km^2.

The aim of this research is to indicate the type of the fold of the Qara Chough South anticline by means of using structural and geomorphological forms.

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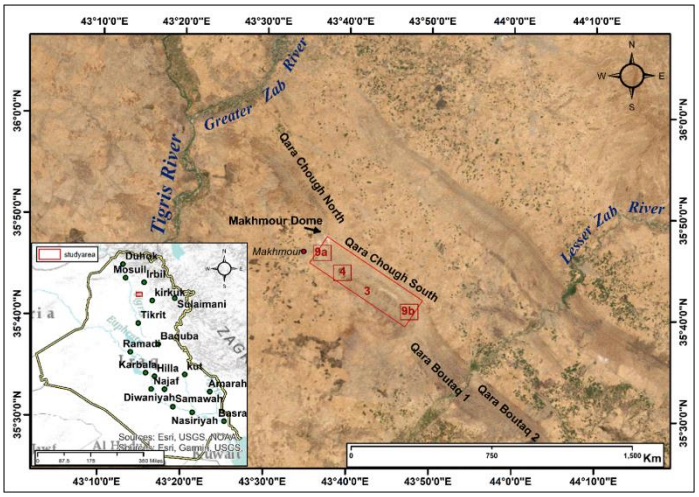

Figure 1: ESRI; world imagery showing the Qara Chough South anticline and neighboring anticlines. Red; rectangles with numbers indicate figure numbers used in the text.

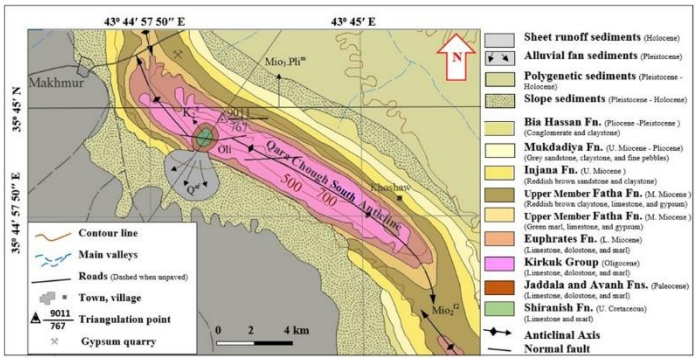

Figure 2: Geological; map of Qara Chough South anticline (From Sissakian,[5]).

2. Materials and Methodology

To indicate the type of the fold (Detachment Fold, Asymmetric Detachment Fold, Fold-Bend Fold) of the Qara Chough South anticline, we; have performed this tectonic-geomorphological study. Satellite images of ESRI World Imagery, Google Earth images, and geological maps were interpreted. Published relevant works of literature were read and evaluated, and fieldwork was performed to confirm the recognized data from the conducted interpretations. We adopted methods of many researchers to recognize significant structural and geomorphological forms and features, such as Fleuty[6], Burbank and Pinter[7], Keller et al. (1999), Ramsey et al.[8], Foosen[9], Zebari and Burberry[10]. We used the measured dip amounts (Table 1), which were recorded during the regional geological mapping of the Qara Chough South anticline[3]. We have measured different aspects of the Qara Chough anticline using satellite images and calculated the data presented in Table (1) based on equations given by Burberry et el.[11] and Bull and McFadden[12].

We have interpreted geomorphological forms such as alluvial fans; some of them are abandoned, wine glasses, and different shapes of valleys. These are indications for the lateral growth of anticlines[7, 8, 13]. Besides; other geomorphological forms, such as flatirons, anticlinal ridges, and dissected slopes.

3. Geological Setting

Three main aspects of the geological setting of the Qara Chough South anticline are concerned. These are Stratigraphy, Geomorphology, Tectonics, and Structural Geology. These three aspects are based on Sissakian and Al-Jiburi[14], Yacoub et al.[15], and Fouad[16].

3.1 Geomorphology

Different geomorphological units are developed in the Qara Chough South anticline (Fig. 4). The most abundant are: 1) Units of Alluvial Origin; within, this unit, the most common forms are Alluvial fans and Abandoned alluvial fans. 2) Units of Structural – Denudational Origin; within, this unit, the most common are the Flat irons, Wine glass, Fork-shaped, and Inclined valleys, Hogbacks, and Questas. Some of the interpreted forms indicate the lateral growth of the Qara Chough South anticlines, such as: Abandoned alluvial fans (AAF), Fork-shaped valley (FV), Radial valley (RV), and Inclined valley (InV) (Fig. 4)[7, 8, 13]. Moreover; a wind gap exists along the southeastern plunge of the anticline. Other interpreted forms are: Wine glass (WG) and flat irons (FI).

3.2 Stratigraphy

The exposed formations in the study area are presented in the geological map (Fig. 2). The exposed formations range in age from the Upper Cretaceous, represented by the Shiranish Formation, to Pliocene – Pleistocene, represented by the Bai Hassan Formation. They are briefly described and presented in a columnar section (Fig. 5).

3.3 Tectonics and Structural Geology

The area under consideration is in the Low Folded Zone of the Outer Platform (Unstable Shelf) within the Arabian Plate. It is also part of the Zagros Fold–Thrust Belt[17]. The Qara Chough South anticline is a double plunging anticline trending mainly NW – SE; however, both plunges change their trends to NNW and SSE, respectively (Figs. 2 and 3). The anticline has a length of 22 km, a hinge line length of 23.90 km, and a width of 5.33 km (Table 1). The anticlines show southwest vergence, and the southeastern; plunge is steeper than the northwestern, plunge (Table 1). Many transverse faults have dissected the northeastern limb and the axis of the anticline; they all are oriented in NE – SW direction (Figs. 2 and 4).

Table 1: Measured; and calculated data in the Qara Cough South anticline.

Average dip mount (º)					Structural and Morphological Data								
Limb		Plunge		Axial surface	L (km)	HL (km)	W (km)	S (km)	FS (km)	AR	FSI	Smf	FFS
NE	SW	NW	SE										
33	52	25	31	47.5 NW	22.1	23.9	5.33	2.4	26.3	4.15	0.90	1.19	1.19

The Qara Chough South anticline, as well as the whole Qara Chough Range, was initially a graben, and it was inverted to an anticline[18, 19]. The structural inversion from graben to anticline of the Late Cretaceous structural troughs occurred during the Pliocene – Pleistocene compression, associated with the final continental collision of the Arabian and Eurasian plates. The inversion is achieved by the reverse reactivation of the trough bounding normal fault; and the extrusion of basin fill, and eventually, the formation of compressional fault-propagation folds above the former troughs[18, 19]. Therefore; the rocks of the Shiranish Formation (Upper Cretaceous) and Jaddala and Avanah formations (Eocene) are exposed (Fig. 2) in a large cirque (wine glass form, Fig. 4) located in the western part of the southwestern limb of the anticline near Azkand Village. Many faults occur in the anticline; the majority of them are normal faults with almost an E – W trend, and some of them dissect the anticlinal axis (Fig. 2). Those; faults have an N 80^{O} E trend with vertical displacement of (10 – 20) m and had displaced rocks of Cretaceous up to Miocene in age[5].

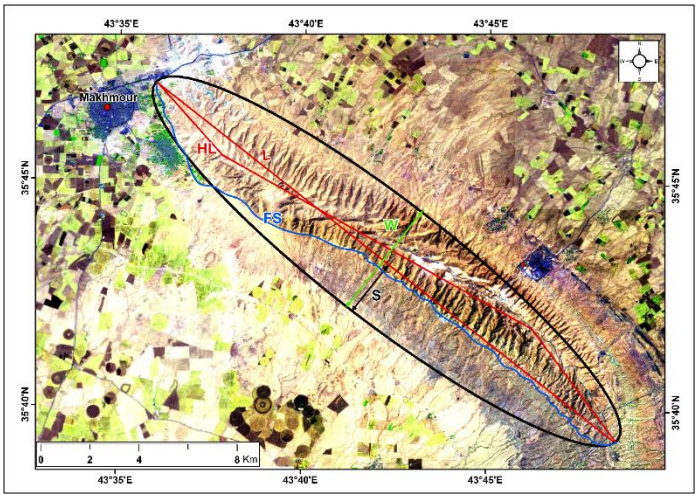

Figure 3: Google; Earth image showing the measured aspects in the Qara Chough South Anticline (based on Burberry et al.[11]).

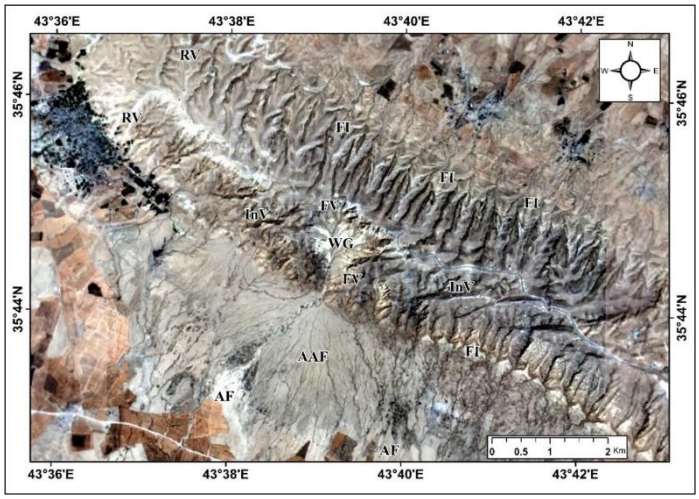

Figure 4: Sentinel; image (B04, B03, B02) showing part of the Qara Chough South anticline with different interpreted geomorphological data and transversal faults (red lines, dashed when uncertain)
For the symbols, refer to Chapters 3 (Geological Setting) and 4 (Results and Discussion)

Formation	Age	Thick (m)	General Description
Bai Hassan	Pliocene – Pleistocene	~ 350	Thick and coarse conglomerate alternated with thick reddish-brown claystone with rare sandstone.
Mukdadiya	Upper Miocene – Pliocene	300 – 400	Grey and coarse sandstone alternated with claystone and rare thin beds of fine conglomerate. Some of the sandstone beds are pebbly.
Injana	Upper Miocene	200 – 250	Reddish-brown and fine sandstone alternated with claystone, and siltstone.
Fatha	Middle Miocene	100 – 150	The Upper Member consist of green marl, limestone, and gypsum. The Lower Member consists of reddish-brown claystone, limestone, and gypsum.
Euphrates	Lower Miocene	50 – 80	Limestone alternated with dolostone and rare marl.
Kirkuk Group	Oligocene	180 – 220	Limestone, dolomitic limestone, and dolostone.
Jaddala and Avanah	Eocene	60 – 70	Limestone, marly limestone, and chert horizons.
Shiranish	Upper Cretaceous	60 – 110	Bluish grey and papery marl underlain by white and well-bedded marly limestone.

Figure 5: Columnar; section of the exposed geological formations in the Qara Chough South anticline (Not to scale).

4. Results and Discussion

The Aspect Ratio (AR) and Fold Symmetry Index (FSI) are used to know the type of folding[11]. The acquired AR and FSI values of the Qara Chough South anticline (Table 1) were plotted in Figure (6); accordingly, we found that the anticline is a "Detachment Fold" (DF). Moreover; we have adopted the opinion of Burberry et al.[11] in detecting the type of detachment fold by plotting the hinge length (HL) in Table (1) versus FSI and AR (Fig. 7, a and b, respectively). Accordingly, we found that the Qara Chough South anticline lies between the domains of "Detachment Fold" (DF), and "Asymmetric Detachment Fold"

(ADF) when considering the FSI (Fig. 7 a), and typical Detachment Fold (DF) when considering the AR value (Fig. 7 b); moreover, it is far from the Fault- bend Fold (FBF) (Fig. 7). The calculated Smf is 1.19 (Fig. 3 and Table 1), this index reflects the balance between erosion forces that tend to cut embayment into a mountain front and tectonic forces that tend to produce a straight mountain front coincident with an active range-bounding fault[20]. The large difference between values of the calculated mountain front sinuosity (Smf) and measured straight length (L) of the mountain indicates extensive erosion.

The detachment layer of the Qara Boutaq fold is most probably the Gotnia Formation, which is about 620 m thick and consists of "bedded anhydrite with subordinate intercalations of brown calcareous shales and thin black bituminous shales, and of recrystallized, fluffy-textured and rare pseudo-oolitic limestones[21]. The formation is not exposed but recorded in drilled oil wells[1]. Moreover; the Aaliji Formation (200 – 350 m thick), which is exposed in the southwestern limb[5], also may be acted as a detachment layer.

We also adopted the opinion of Fleuty[6] in the classification of folds, we applied the average of the dip amount of both northwestern and southeastern plunges, and the dip of the axial surface of the Qara Chough anticline (Table 1) to the classification diagram (Fig. 8). The dip amount of the axial plane was calculated by means of trigonometry method[22], accordingly, the anticline was found to be moderately inclined with a gentle plunge. Fig. 9 shows the world imagery of Qara Chough South anticline.

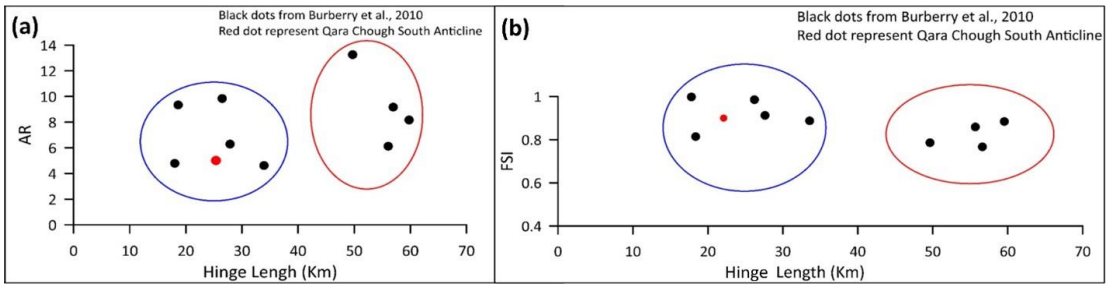

Figure 6: a); AR versus hinge length, b) FSI versus hinge length. The; blue and red clusters represent DF and ADF, respectively. The; red dot represents Qara Chough South anticline.

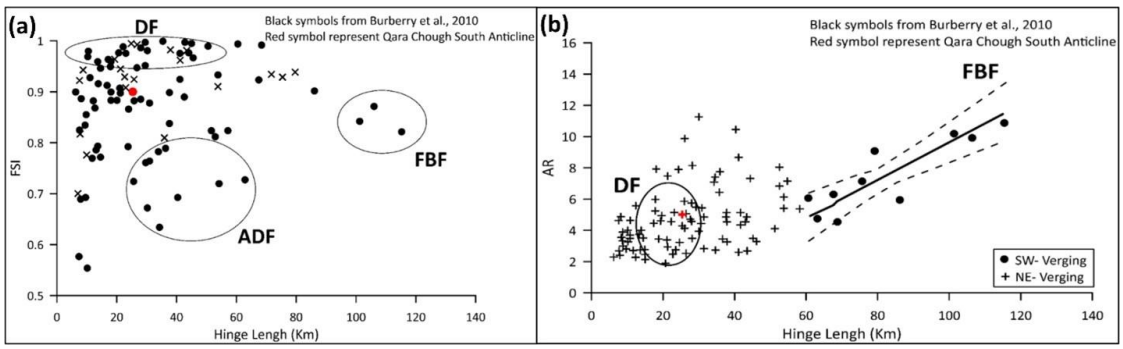

Figure 7: a); FSI versus hinge length, b) AR versus hinge length. Three clusters. The; red dot represents Qara Chough South anticline.

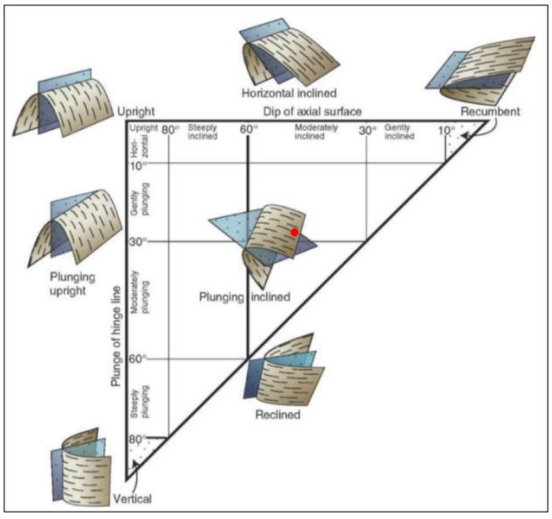

Figure 8: Classification of folds[6]. The red circle represents Qara Chough anticline.

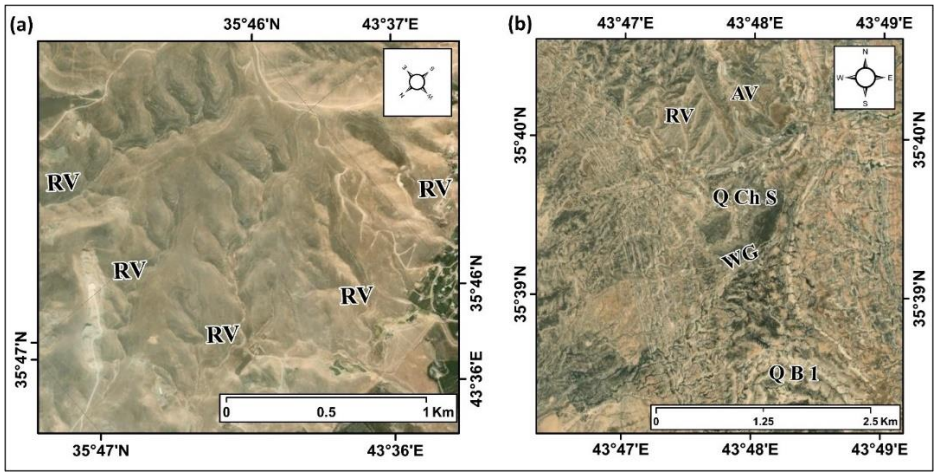

Figure 9: ESRI; world imagery of Qara Chough South anticline, a) Northwestern plunge, not the radial valleys (RV), b) Southeastern plunge, QB 1= Qara Boutaq 1 anticline, WG= Wind gap, RV= Radial valley, AV= Axial

Conclusions

From the presented data, we can conclude that the Qara Chough South anticline is an Asymmetric Detachment Fold as indicated by the calculation of different structural indices, with the moderately inclined axial plane and gently plunging anticline. The recognized geomorphological forms like wind gaps, en-echelon plunges, and differently shaped valleys indicate that the Qara Chough South anticline is exhibiting lateral growth.

Conflict of interests

We declare no conflict of interest as the current article is concerned.

Author contribution

Mr. Sissakian, wrote the first draft. Mrs. Abdullah amended the first version by adding her comments and new data; she also has done the artwork on the images. The; final version was prepared based on the discussions between both authors. Accordingly; the final version was prepared.

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