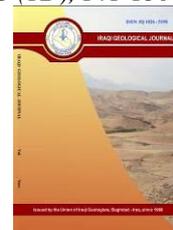




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Tectonic Indications for Thickness Change of Geological Formations in South Eastern Part Area of Safen Anticline, North Eastern Iraq

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Abstract

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The study area is located in the southeastern part of Safen Anticline, northeastern Iraq. The aim of the study is to discuss the listric fault role in the change of the deposition basin topography of Bekhme and Shiranish formations and finally change of their thicknesses. The field data picked up in September of 2020 include bed attitudes and formation boundaries, with their positions. After the drawing of three cross sections and calculating the thickness of Bekhme and Shiranish formations in the studied area, the results showed that the thickness of the Bekhme Formation which represents the reef environment, increases in thickness within the northeastern limb of the fold, While the thickness of the Shiranish Formation which represents the deep environment, increases within the southwestern limb of the fold. These changes were concluded as result occurred due to the reverse movement of the Listeric fault responsible for the growth of the fold synchronously with Bekhme and Shiranish formation deposition.

Keywords: Safen Anticline; Listric faults; Thickness; Formation; Basin

1. Introduction

Series folds of Iraqi foreland region is the outcome of the movement resulting from the convergence and subduction of the crust of the Neo-Tethys Ocean under the Eurasian plate, where the Alpine orogeny started in the Late Cretaceous and led to the subduction of the northeastern margin (Northern Iraq) of the Arabian plate under the Iranian-Turkish plates. As a result of this convergent movement, the normal displacements of the faults formed in the tension phase that preceded that stage turned into reverse displacements, which led to the growth of folds in northern Iraq as a deformation of the sedimentary cover that was deposited within the Neo-Tethys Basin, (Numan,1997 and 2000). Listric faults responsible for the growth of folds were formed in northern Iraq during the Triassic age, where the Arab plate diverged from the Eurasian plate, (Numan and Al-Azzawi, 1993), and its reverse movement during the Alpine orogeny caused the emergence of different forms of folds in northern Iraq. Some folds (such as Safen Anticline) were affected by a complex faulting system that led to a more development of its northeastern limb compared to its southwestern limb, (Al-Azzawi, 2003). Geographically, the studied area is located in the southeastern part of the Safen Anticline in the northwestern part of Sulaymaniyah city in northeastern Iraq. The study area is located between the latitude: 36° 09' 35.39"-36° 12' 47.86"N and longitudes: 44° 38' 04 " - 44° 32' 47.72"E (Fig. 1).

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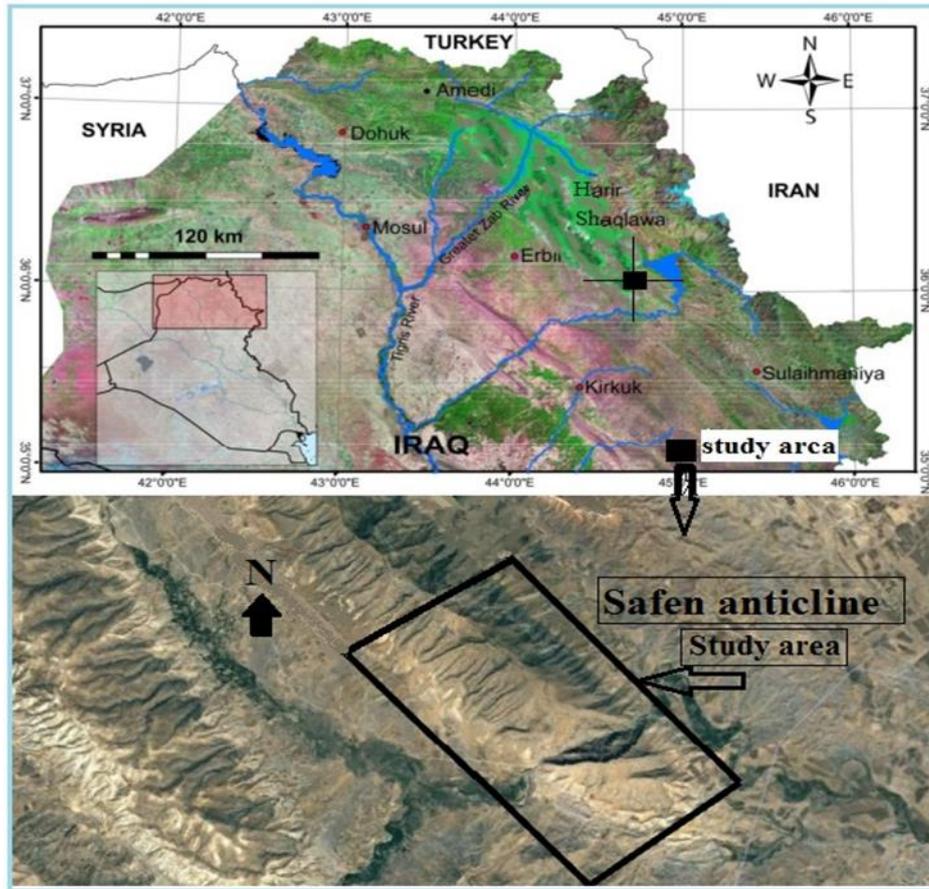


Fig. 1. Location of the study area

Tectonically, the study area is located within the high folded zone of the Iraqi Western Zagros Fold-Thrust Belt (Fig. 2).

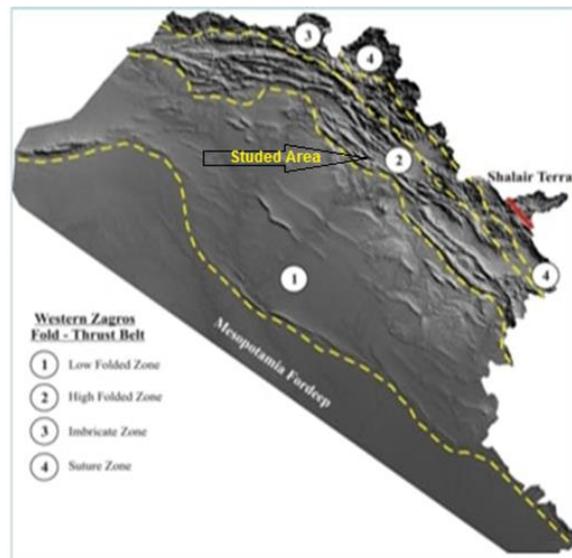


Fig. 2. The tectonic divisions of the Iraqi Western Zagros Fold -Thrust Belt, shows the tectonic location of the studied area (Fouad, 2014)

Stratigraphy, The exposed rocks in the studied area range in age from Early Cretaceous to the Early Eocene. They are represented by four Formations, which are from older to younger according to field observations, Qamchuqa, Bekhme, Shiranish, and Kolosh, (Fig. 3). Deposition of Qamchuqa formation in a shallow marine environment during the Alpien-Hetrovian. Both Bekhme and Shiranish were deposited in shallow reef and deep environments respectively, during the Campanian-Mastrachian age. The Kolosh formation was deposited in a deep marine environment during the Paleocene age, (Jassim and Goff, 2006).

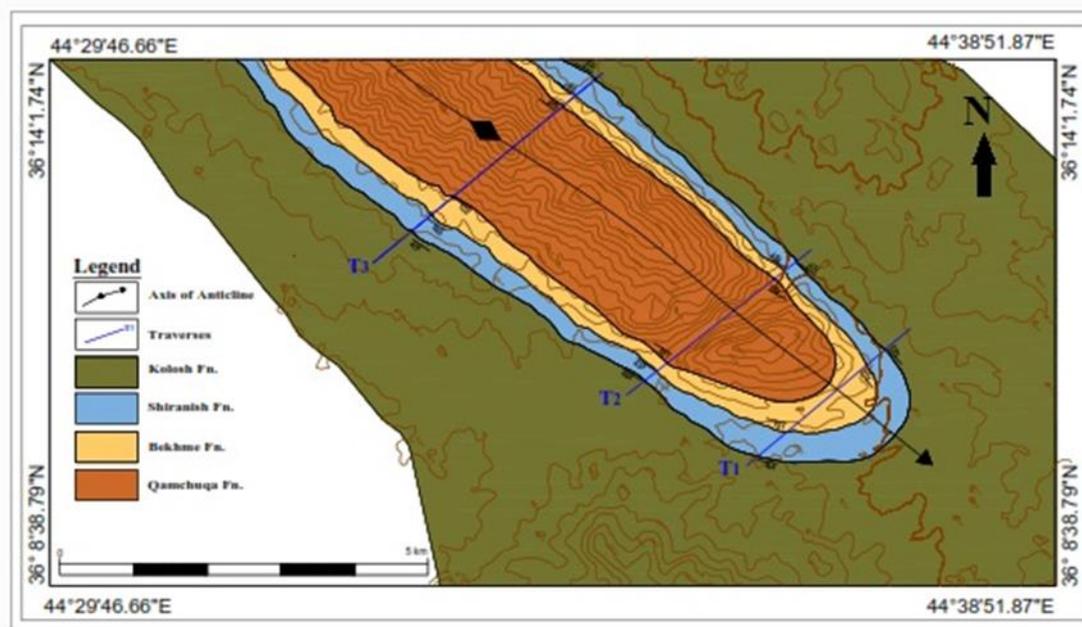


Fig. 3. Geological map of the study area modified from Omer (2005)

2. The Relationship Between Faults and Folds

Folds are a type of plastic deformation, while faults are a type of brittle deformation, so having these two structures together in one place is an exciting thing that interests many researchers in this field. Some structural studies have found an explanation for the presence of these two structures together, which is that the first structure was formed at a different time from the formation of the second structure and under different pressure and temperature conditions (Van der Pluijm and Marshak, 1997). The growth of folds in north Iraq is related faults, (Al- Azzawi, 2003), where these faults may be formed as normal listric faults during previous tension time and showed reverse activation (thrusting) during last compression time, or may be formed as thrust fault during the fold development as result to increasing for the tectonic stress (Numan and Al-Azzawi, 1993). Generally, fault related fold mechanism of the fold thrust belts is divided in the types; detachment fold, fault bend fold and fault propagation fold, (Fig. 4). Fault propagation fold is the dominant mechanism in high and low folded zones of the Iraqi Western Zagros fold-Thrust Belt, (Fouad, 2014). Where the fault propagation fold shows the fore limb steeper than the back limb, and the dip of the back limb is parallel to fault surface that propagated the fold. Moreover, the back limb is high elevation area if compared with the fore limb area of the fold. According to this information's, can be understudied that the change of the elevation in the two limb areas causes different topography for the deposition basin at beginning start of fold growth and finally causes change in the thickness of the formations that deposit synchronously with the fold growth. But in sometimes, the change of thickness sediments may be present or absent because the normal slip that associated with strike slip faults, (Fig. 5).

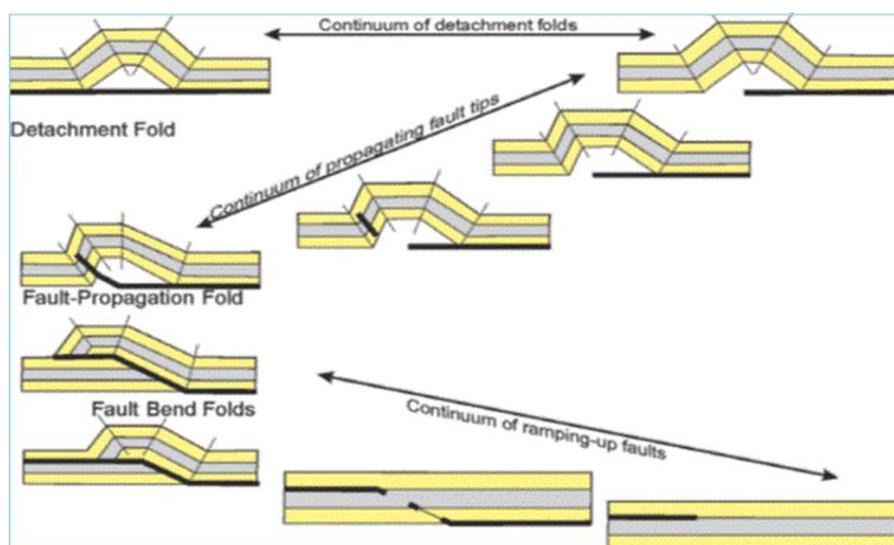


Fig. 4. Different fold related fault mechanism types recorded in Zagros Fold -Thrust Belt (Burberry et al. 2010)

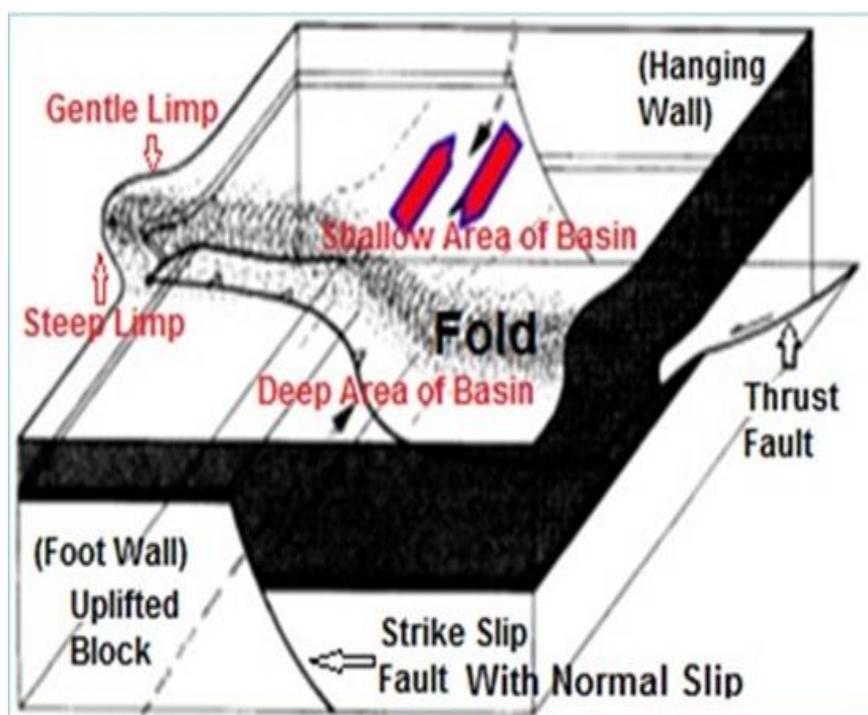


Fig. 5. The effect of faults on the fold growth Modified from Doglioni, (1992), shows the change of sediments thickness between the hanging wall area and the foot wall area.

The growth of folds in north Iraq started in Late Cretaceous (Campanian -Mastrichtian), where this time showed tectonic inversion from tension phase to compression phase and led to presence of thrust slips and strike slips for inherited faults that formed during the tension phase previously. The Late Cretaceous characterized by dominant of strike slips movement, where the sinistral strike slip movement Anah – Qalat Diza cause uplifting for Mosul Block that involve the Safen Anticline if compared by Kirkuk Block that involve Khalakan Anticline, (Fig, 6)

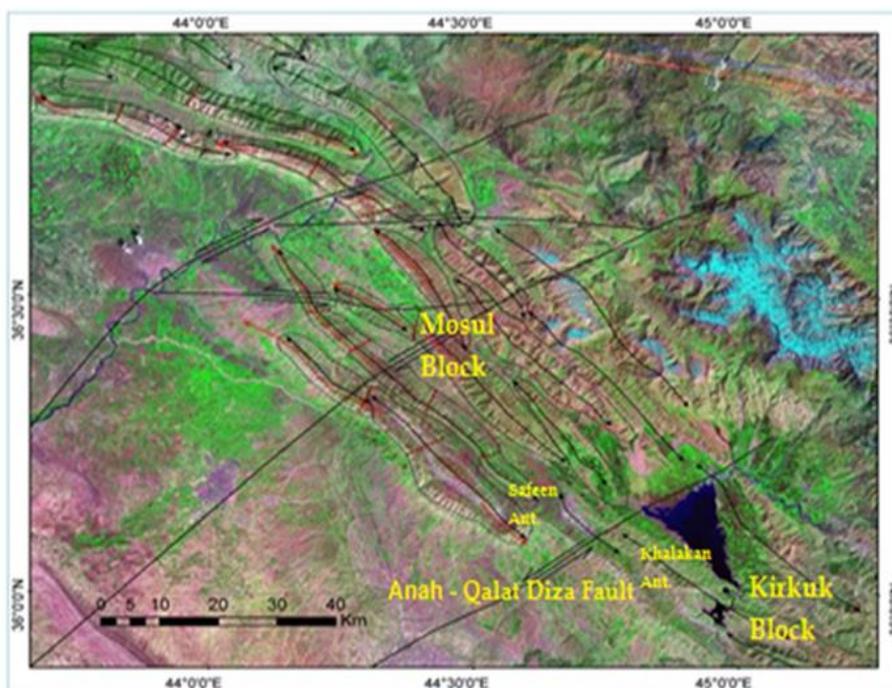


Fig. 6. Satellite map shows the separation between Mosul and Kirkuk blocks by the sinistral movement of Anah Qalat Diza Fault modified from Zebari, (2013)

These uplifting was presented as result to normal slip associated with the strike movement and led to deposition of Bekhme formation in Safen Anticline area and absence of it in Khalakan Anticline area (Znad,2013;Ward, 2019). However, the strike slips movement was the dominant during the Late Cretaceous, some areas of anticlines within the High Folded Zone showed change in the thickness of the Late Cretaceous and Tertiary formations at the two limbs as indication to the thrust movement of the listric (trust) fault that propagated fold, such as Bekher and Shaikhan anticlines (Al- Hubaty, 2008; Al-Khatony, 2009). Based on the surface measurements and the propriety seismic section transformed to depth, Safen anticline showed as fold related NE dipping thrust fault, (Fig. 7).

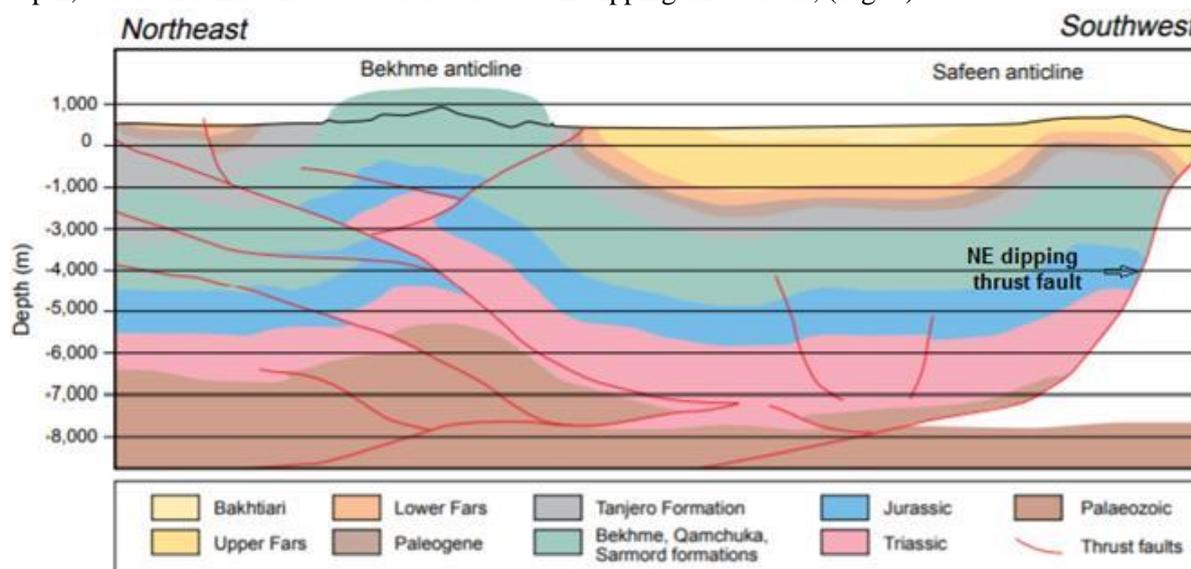


Fig. 7. Geosismic section shows safen anticline as fold related NE dipping thrust fault (Csontos et al. (2012)

3. Calculation of the True Thickness

The Rowland method (Rowland, 1986) was adopted to find the real thickness of the geological formations from the drawn geological sections of the traverses that were identified within the study area. The width of the outcrop of the formations in the sections was calculated, which is represented by the confined distance between the contact surfaces of the formations, as well as the calculation of the dip angle for the layers of the formations, then the method of the trigonometric functions of the formations was applied when the angle of the slope is towards the dip of the layers because it corresponds to the position of the outcrop in the study area, equation and (Fig. 8).

$$\text{True thickness} = \text{horizontal thickness (apparent thickness)} \times \sin \delta \dots \dots \dots (1)$$

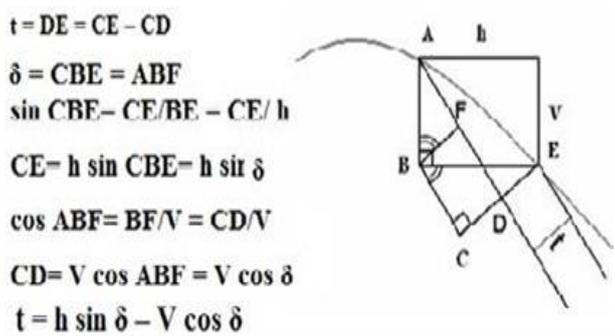


Fig. 8. The method of measuring true thickness of the formation (Rowland, 1986)

4. Results

Three traverse's were chosen in the studied area, and used to drawing of three geological cross sections perpendicular to the fold axis, (Fig. 3). The three sections showed the flowing results: -

4.1. Thickness of the Geological Formations on the First Traverse

The Shiranish Formation varies in the thickness and dip on the two limbs of the fold in the study area, The dip of the formation in the northeastern limb is 44° while it 43° is in the southwestern limb, and the thickness of the formation in the northeastern limb is less than it is in the southwestern limb, with a thickness difference up to 7 meters, (Fig. 9) and (table 1). This discrepancy indicates the existence of a change in the topography of the surface of the depositional basin, which led to a difference in the depth of the basin between the two limbs of the fold due to the thrust movement for the Listric fault that propagated Safen Anticline.

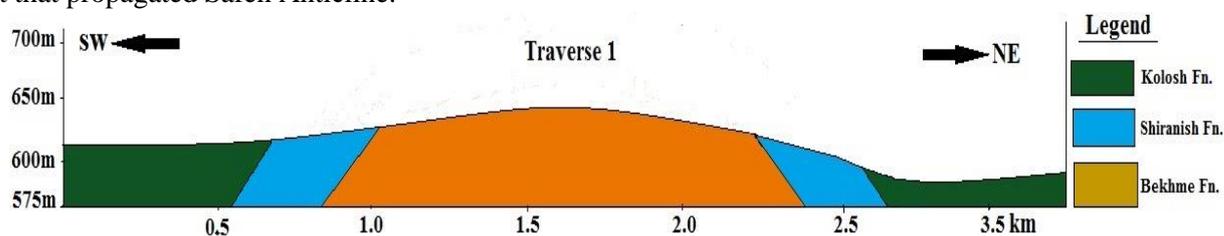


Fig. 9. Geological cross section of the first traverse shows the change of Shiranish fn. thickness in both limb of Safen Anticline

Table 1. The true thickness of the Shiranish formation on the first traverse

Formation	Horizontal thickness in northeast limb from geological section(m)	Layer dip in northeast limb(degree)	True thickness in northeast limb (meters)	Horizontal thickness in southwest limb from geological section(m)	Layer dip in southwest limb(degree)	True thickness in the southwest limb (meters)	Thickness difference (meter)
Shiranish	262	44	182	279	43	190	8

4.2. Thickness of the Geological Formations on the Second Traverse

The measurement of the true thickness of the geological formations exposed in this traverse, represented by the Shiranish and Bekhme formations, showed that there is a discrepancy in the thickness and dip on the two limbs of the fold in the study area of the formations between the two limbs of the fold. The dip of the Shiranish Formation in the northeastern limb is 53° while it 46° is in the southwestern limb, and The dip of the Bekhme Formation in the northeastern limb is 51° while it 43° is in the southwestern limb, As the thickness of the Shiranish Formation in the northeastern limb is less than it is in the southwestern limb of the fold, with a thickness difference of up to 8 meters, (Fig. 10), and on the contrary in the Bekhme Formation, where the thickness of the formation increases in the northeastern limb more than it is in the southwestern limb with a difference Thickness up to 13 meters as shown in the table below, (Table 2). This variation in thickness indicates that there is a change in the depth of the basin and in turn affected the environment of deposition of the two formations within the study area, which led to the variation in thickness in the two limbs.

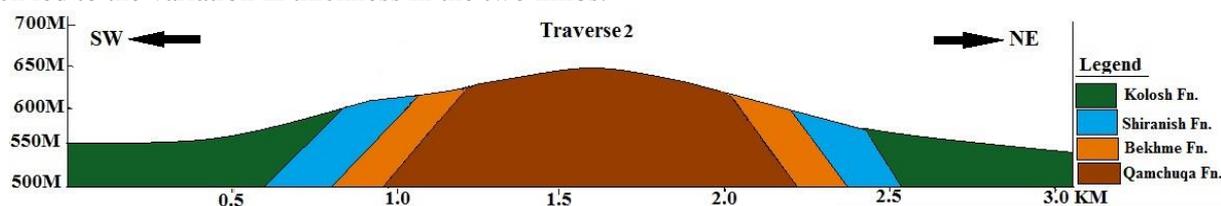


Fig. 10. geological cross section of the second traverse shows the change of Shiranish fn. And Bekhme fn. thickness in both limb of Safen Anticline

Table 2. The true thickness of the Shiranish and Bekhme formations on the second traverse

Formation	Horizontal thickness in northeast limb from geological section(m)	Layer dip in northeast limb(degree)	True thickness in northeast limb (meters)	horizontal thickness in southwest limb from geological section(m)	Layer dip in southwest limb(degree)	True thickness in the southwest limb (meters)	Thickness difference (meter)
Shiranish	165	53	132	195	46	140	8
Bekhme	135	51	105	134	43	92	13

4.3. Thickness of the Geological Formations on the Third Travers

Measuring the true thickness of the geological formations in this traverse, represented by the Shiranish Formation and the Bekhme Formation, it was found that there are difference in the thickness and dip on the two limbs of the fold in the study area of the geological formations. The dip of the Shiranish Formation in the northeastern limb is 55° while it 40° is in the southwestern limb, and The dip of the Bekhme Formation in the northeastern limb is 55° while it 40° is in the southwestern, the thickness of the Bekhme Formation increases in the northeastern limb more than it is in the southwestern limb, with a thickness difference of up to 5 meters, (Fig. 11). This difference refers to the extension of the fault that affected the area in the second traverse and led to the occurrence of the same variation in thickness (Table 3).

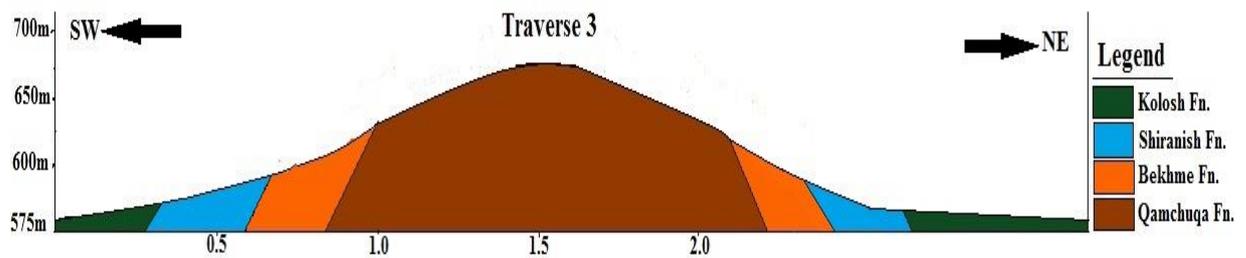


Fig. 11. Geological cross section of the second traverse shows the change of Shiranish fn. And Bekhme fn. thickness in both limb of Safen Anticline

Table 3. shows the true thickness of the Shiranish and Bekhme formations on the third traverse

Formation	Horizontal thickness in northeast limb from geological section(m)	Layer dip in northeast limb(degree)	True thickness in northeast limb (meters)	Horizontal thickness in southwest limb from geological section(m)	Layer dip in southwest limb(degree)	True thickness in the southwest limb (meters)	Thickness difference (meter)
Shiranish	239	55	196	319	40	205	9
Bekhme	194	55	159	240	40	154	5

5. Discussion

By comparison with the SW limb area, the large thickness of the Bekhme Formation in the NE limb area of the anticline may be interpreted as indication to continuance of the normal movement for the listric fault related Safen Anticline synchronously with Bekhme deposition time and led to downing the NE limb area for the fold as hanging wall if compared with the SW limb area, but the increasing of Shiranish thickness in the SW limp area (If compared with NE limb area) may be interpreted as indication to starting of the inverted movement (thrust movement) for the listric fault related Safen anticline synchronously with Shiranish deposition time (Fig, 12).

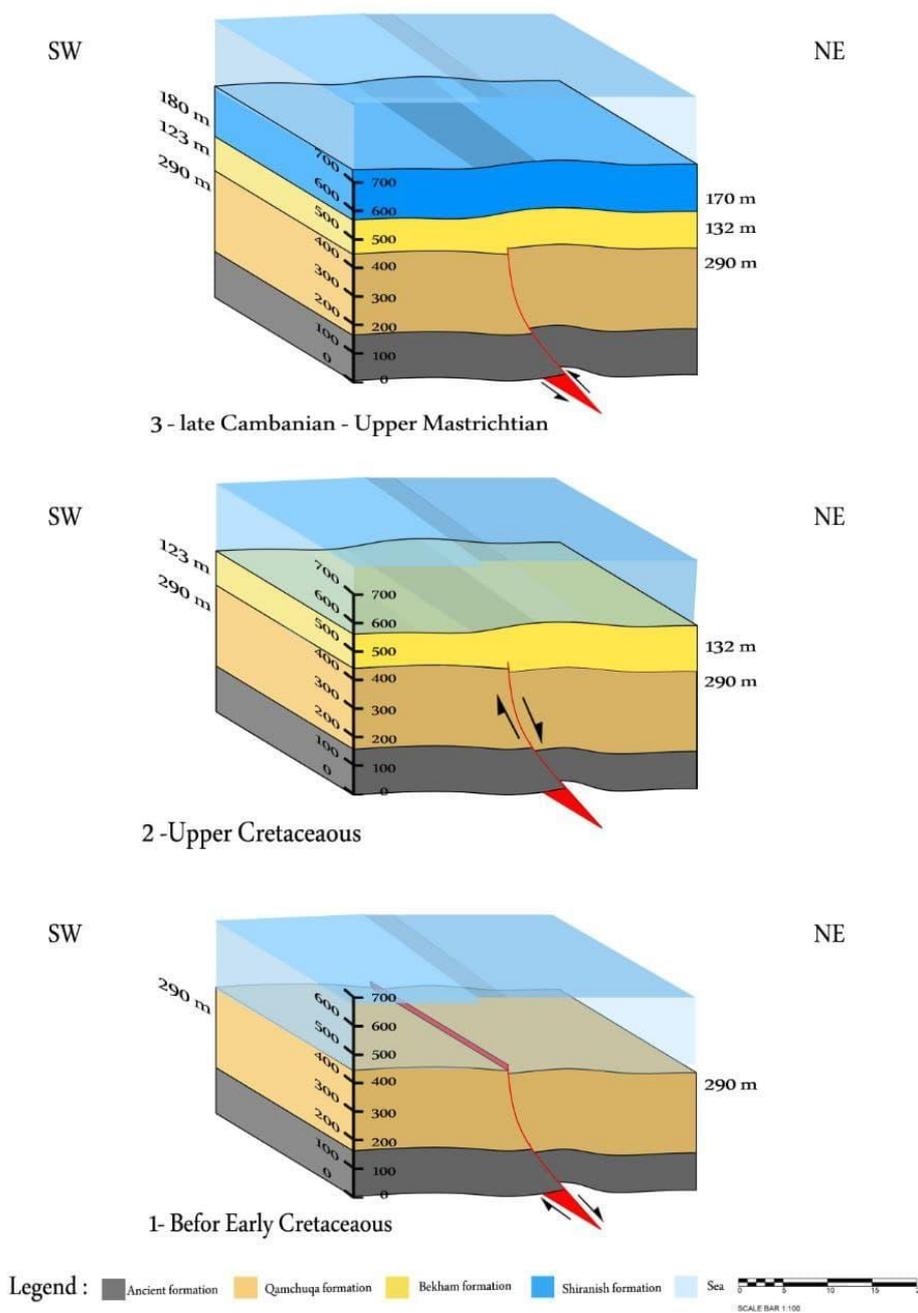


Fig. 12. The proposed tectonic model of the sedimentation basin within the study area

6. Conclusions

- The growth of Safen Anticline related fault and may be started during the Late Cretaceous.
- The fault that propagated Safen Anticline is inherited and formed as listric normal fault NE dipping during tension Triassic phase.
- The normal movement of the listric fault related Safen anticline continued synchronously with the deposition time of Bekhme formation and caused increasing for the thickness in the NE limb area if compared with the SW limb area.
- After Bekhme deposition, the movement of the listric fault related Safen anticline inverted to thrust and caused increasing for the thickness of Shiranish formation in the SW limb area if compared with NE limb area.

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