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Determining Regional Shortening of the Taurus Foreland Folds-Northern Iraq

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ABSTRACT
This study presents a structural profile for determining the regional shortening that extends south-North for(55 km.) from the southern limb of Dahkan anticline (30 km.) North of Mosul city to the border between folded and thrust zones, to the North within Duhok governorate. The cross-section cut six anticlines and five synclines. The amount of regional shortening of the Taurus fold and the depth of detachment surface as well of each fold were quantified on the basis of simple geological trend and measurements of mathematical approaches.
Consequently, encourage results show that the regional shortening is nearly (15.9 %) and the depth to the detachment surface calculated for Bekhair anticline is (6.28 km.) .
Keywords**:** *Regional Shortening, Taurus , Detachment Surface, Northern Iraq.*

I. INTRODUCTION

The method for measuring the amount of shortening is the balanced cross section . Balanced cross section calculations assume that the section has been deformed by a plain strain (Hossack,1979).It was first used to estimate the depth to the decollement underlying concentric folds (Chamberlin,1910, Bucher, 1933, Dahlstrom,1969).The balanced geological cross section can drawn with the assumption that the area of the section has not changed during deformation (Hossack,1969).In order to make the cross section possibly correct, one must be able to restore the beds in it to their original Hat –lying geometry without creating or destroying rocks. Suppe (1985) considered the method as retro deformation with fundamental assumptions like conservation of mass, volume and bed length. Al-Azzawi(2008) used a simple mathematical method for determination of the depth of detachment surface and the amount of local shortening of Qara Chauq and Bekhair anticlines in foreland folds-Northern Iraq .Al-Azzawi(2004) depend on the principle of busk method to construct the cross section using data available from a map. Al-Shali(1992)determined the regional amount of shortening along four traverses in foreland folds in Northern Iraq. Mjahid(2013) found the regional shortening amount and the depth to the attachment surface for Akre section and Shaklawa section within the high folded zone in Zagros fold – thrust belt. Contreras(2002) use FBF which is a software package for the construction of balanced cross section and to simulate thrust and normal faulting in cross section .Schelling(1991) used balanced cross section across the sub Himalayan siwalik hills in Nepal to calculate tectonic shortening .

In the present study a simple mathematical techniques was used to measure the amount of shortening of regional trend of Taurus fold in northern Iraq as well as the local shortening of each fold in the study area cut by the cross section depending on real field data .The cross section transverse six anticlines and five synclines. It includes Dahkan , Duhok , Bekhair , Sadya , Mangesh and Matin anticline with the synclines between them .The cross section extends for (55km.) from the South to the North .Fig (1).

Figure (1) . The study area

II. METHODOLOGY

To determine the amount of shortening of any fold depend on the amount of the total mass which was uplifted or subsided in anticlines and synclines during rock folding .The cross section choose in the study area cross six anticlines and five synclines within Duhok governorate .It started from the Southern limb of Dahkan anticline at station (N: 36° 44' 35" ; E: 43° 02' 00") and ended at station (N: 37° 12' 65" ; E: 43° 01' 56") near the boundary between the folded zone and thrust zone .The section was taken to be nearly perpendicular to the fold axis of the cutting anticlines and parallel to the tectonic transport direction . The length of the cross section is extended(54319m.) north-southerly. The measurements had taken a long a cross sectional area of an anticline between two inflection points of the same strata that have the same stratigraphic positions (Al-Azzawi, 2003), (Pila Spi Formation had been chosen to be the key strata for measurements because it appear on all the anticlines , easy to measure the dip and strike of the beds at any point, competent layer and maintained constant thickness during foldin, So that this layers folded in the model of 1B class according to Ramsay (1967)) . For every limb of the anticline , three measuring points were taken on the Pila Spi Formation started from the boundary between it and the Al-Fatha or Injana Formation as it appeared in the area . At each point several readings for the attitude of the bed was measured by silva compass and location by GPS. The distance between the three points on the same limb depends on the slope of the limb. Fold function had been determined by applying the(X and Y) coordinate values of the fold profile to the Lagrangian polynomial interpolation method .The theory of the method is given in Gerald and Wheatly (1984).Then the mean profile of the fold was drawn by connecting between fold profile of both limbs via the interpolating points .

Measuring percentage of shortening:

To measure the percentage of shortening , We need line balancing .It requires that the length of each contact between pinning points be the same before and after deformation and the deformation has not changed the thickness of units in stratigraphic section (no internal ductile deformation).In Iraq ,the Pila Spi Formation are of flexural flip folding ,so there is no change in thickness . For this reason Pila Spi Formation was chosen. .The procedure was to separate the cross section into parts by pin lines where by anticlines and synclines can be separated from each other. In this study ,the sectional length of six anticlines and five synclines were measured to find the percentage of the local shortening for each fold and the total shortening for the foreland fold.

The initial section has an arbitrary length (L0) and the ends of the section are fixed at points where there is no inter bed slip .The points are planes normal to the regional dip in the undisturbed beds of the foreland fold (Dahlstrom,1969a) . The final length of the section after shortening is (L1) . the lengths were calculated by curvimeter .

% of shortening = (L0 – L1) / LI * 100%

Calculation of the depth to the detachment surface:

It is one of the important parts of balancing techniques .It measured in the area affected by folding with a presence of one marker stratum which is cohesive within the succession (Ramsey and Huber,1987).The area between two pin points have to be measured by planimeter .In this study we found the depth to the detachment surface for Bekhair anticline and the total shortening of the section .

Depth to the detachment surface = Area/Lo – L 1 .

How to find fold function by applying the (X and Y) coordinate value of fold profile to the lagrangian polynomial interpolation method:

Table (1) :Example : South limb of Dahkan Anticline :

Lat.	Long.	No.	F(X)*100m. elevation	X*100m. distance
N: 36 44 35.2	E: 43 02 00	X0(pin point)	4.84	0
N: 36 44 38	E: 43 02 00	X1	5.00	0.85
N: 36 44 40	E: 43 02 00	X2	5.16	1.60

L (X0) = (X-0.85)(X-1.60) / (0-0.85)(0-1.6)
= (X^2 – 2.45X + 1.36) / (1.36)
= (0.735X^2 – 1.8X +1)

L (X1) = (X-0.00)(X-1.60) / (0.85-0.00)(0.85-1.6)
= (X^2 – 1.6X) / (-0.6375)
= (-1.5686 X^2 + 2.51X)

L (X2) = (X-0.00)(X-0.85) / (1.60-0.00)(1.60-0.85)
= (X^2 – 0.85X) / (1.2)
=(0.833 X^2 -0.71X)

F(X) = 4.84 (0.735X^2 – 1.8X +1) +5 (-1.5686 X^2 + 2.51X) + 5.16 (0.833 X^2 -0.71X)

F(X) = (0.0076 X^2 + 0.246 X + 4.84) (Fold function) .

Table(2) : Fold function for the folds in the study area .

Dahkan Anticline (South Limb)	F(X) = (0.0076 X^2 + 0.246 X + 4.84)
Dahkan Anticline (North Limb)	F(X) = (-0.0064 X^2 + 0.0919 X + 4.80)
Duhok Anticline (South Limb)	F(X) = (0.0015 X^2 + 0. 2083 X + 6.09)
Duhok Anticline (North Limb)	F(X) = (0.0192 X^2 + 0.125 X + 7.00)
Bekhair Anticline (South Limb)	F(X) = (-0.0055 X^2 + 0.3878 X + 6.40)
Bekhair Anticline (North Limb)	F(X) = (0.0123 X^2 + 0.1013 X + 9.17)
Sadya Anticline (South Limb)	F(X) = (-0.008 X^2 + 0.152 X + 8.67)
Sadya Anticline (North Limb)	F(X) = (-0.06 X^2 + 0.3302 X + 8.20)
Mangesh Anticline (South Limb)	F(X) = (0.0815 X^2 + 0.2237 X + 9.17)
Mangesh Anticline (North Limb)	F(X) = (0.271 X^2 + 0.073 X + 8.37)

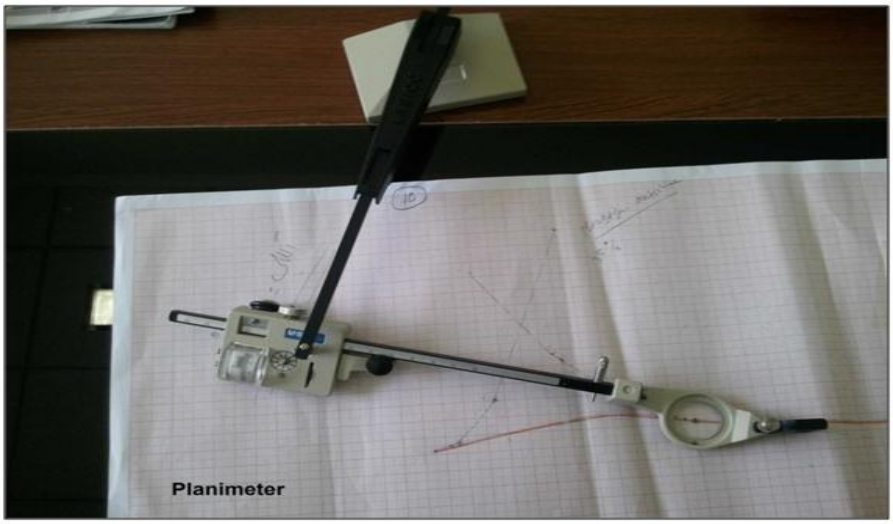


Figure (2) Planimeter instrument

III. RESULTS

1. Structural Analysis of the folds:

In the foreland belt of Iraq, the folds are manifested by the Pliocene paroxysmal phase of the Alpine orogeny (Numan and Al-Azzawi,2003 , Jassim and Golff,2006 ,Al-Adeeb,2007).The study area consist some of folds of foreland belt which constituted the area of continental collision or area of compression environment. The study area consists of six anticlines and five synclines in between . The structural analysis of each anticline was found by using stereo net-window program and each fold was classified on the basis of fold axis and axial plane and interlimb angle depending on Fluety ,1964 classification .

Dahkan Anticline:

The fold extends for (30km.) East-West with Pila Spi Formation as the oldest formation in the core and Al-Fatha and Injana formations on the limbs .The fold is asymmetrical has steeper southern limb (40°)and gentler northern limb (24°) . The results obtained by analyzing the fold by stereo net-window program , show that the fold axis is (266/07°) and the axial plane is (265/82°) which means that the fold is upright /sub horizontal, and the interlimb angle is (117°) which means that the fold is open according to Fleuty's , 1964 classification. (Fig 3).

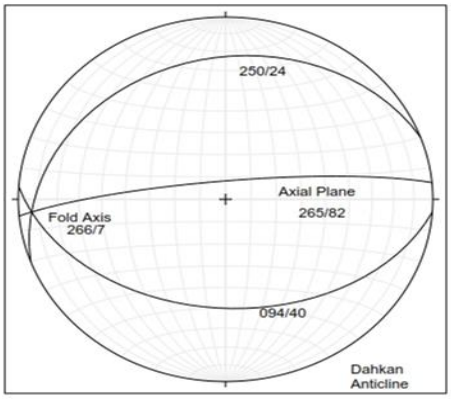


Figure (3) . Stereonet of Dahkan anticline

DuhOk Anticline:

The fold extends for (23km.) from Aloqa westward with Pila Spi Formation as the oldest formation in the core and Al-Fatha and Injana formations on the limbs. The fold is trending East – West and asymmetrical with gentler southern limb (30°)and steeper northern limb (70°) .The northern limb is vertical to locally overturned. The results obtained by analyzing the fold by stereo net-window program , show that the fold axis is (091/03°) and the axial plane is (090/70°) which means that the fold is steeply inclined /sub horizontal, and the interlimb angle is (80°) which means that the fold is open according to Fleuty's , 1964 classification (Fig 4). The syncline between Duhok and Dahkan anticlines is 5869 m.consist of layers of Upper Fars Formation.

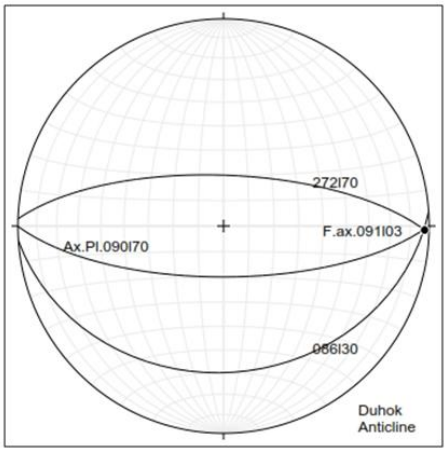


Figure (4) Stereonet of Duhok anticline

Bekhair Anticline:

The fold extends for (83km.) from Dairabeen northwestward to Zawita southeastward. It consist of three segments separated by two saddles(Ameen, 1979). The segment within the study area has, generally, trend (NW-SE) with Shiranish and Bekma formations in the core making Speriz mountain and the limbs consist of (Kolosh , Khurmala , Gercus ,Avana , Pila Spi , Al-Fatha and Injana) formations.The fold is asymmetrical has steeper southern limb(46°)and gentler northern limb (24). The results obtained by analyzing the fold by stereo net-window program. It shows that the fold axis is (100/04°) and the axial plane is(280/79°) which means that the fold is steeply inclined /sub horizontal, and the interlimb angle is (110°) which means that the fold is open according to Fleuty's , 1964 classification. (Fig 35)

The syncline between Bekhair anticline and Duhok anticline is 2300 m.It consists of layers of Lower Fars and Upper Fars and soil .Duhok city located through this syncline.

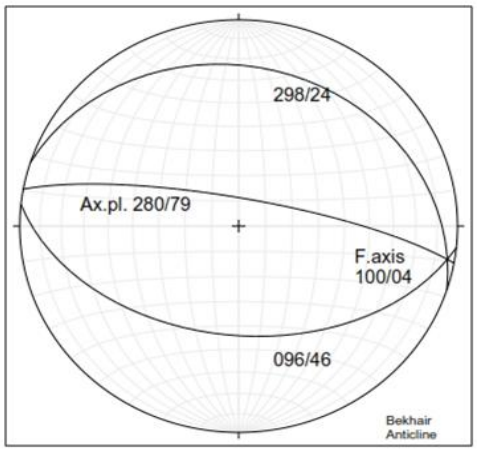


Figure (5) Stereonet of Bekhair anticline

Sadya Anticline:

It is a small anticline extend for (14 km.) northwest – southeast. It is not mentioned in previous studies, so here is called as Sadya anticline with Pila Spi Formation forming the core of the anticline and Al-Fatha and Injana formations on the limbs .The fold is asymmetrical has steeper southwestern limb (28°)and gentler northeastern limb (20°) . The results obtained by analyzing the fold by stereo net-window program , show that the fold axis is (288/00°) and the axial plane is (288/86°) which means that the fold is upright /sub horizontal, and the inter limb angle is (132°) which means that the fold is gentle according to Fleuty's , 1964 classification. (Fig 6) The syncline between Sadya anticline and Bekhair anticline is 3100 m.It consists of Upper Fars Formation.

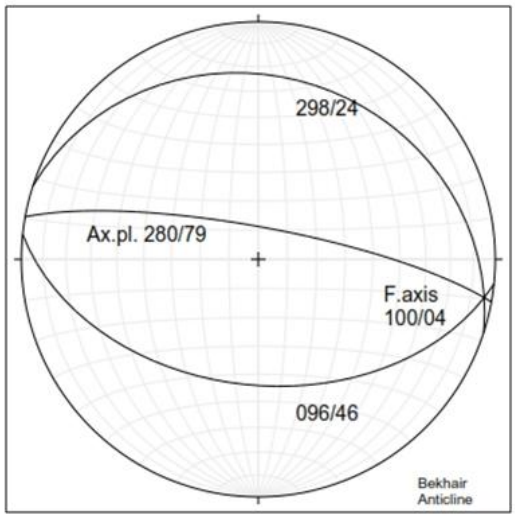


Figure (6) Stereonet of Sadya anticline

Mangesh Anticline

The fold extends for (32 km.)Northwest – Southeast with Pila Spi Formation as the oldest formation in the core and Al-Fatha and Injana formations on the limbs . The fold is asymmetrical has steeper Southwestern limb (32°)and gentler Northeastern limb (20°) . The results obtained by analyzing the fold by stereo net-window program , show that the fold axis is(091.5/01°) and the axial plane is (271.6/84°) which means that the fold is upright /sub horizontal, and the inter limb angle is (128°) which means that the fold is gentle according to Fleuty's , 1964 classification. (Fig 7)

The syncline between Mangesh anticline and Sadya anticline is 4600 m.consists of Upper Fars Formation.

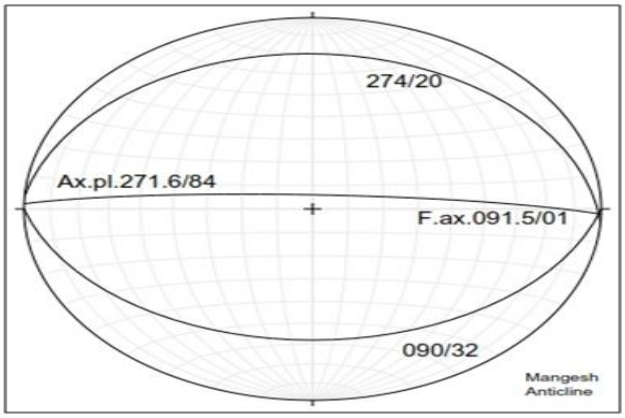


Figure (7) Stereonet of Mangesh anticline

Matin Anticline:

In the study area which appeared a part of this anticline ,The fold extends southwest – northeast with Gercus Formation as the oldest formation in the core and Pila Spi , Al-Fatha and Injana formations on the limbs . The southwestern limb of the fold has attitude (240/50°)and northeastern limb is overturned due to the thrust fault in the area (260/85°) .The results obtained by analyzing the fold by stereo net-window program , show that the fold axis is (262/24°) and the axial plane is (251/67°) which means that the fold is steeply inclined /gently plunging, and the interlimb angle is(39.4°) which means that the fold is close according to Fleuty's , 1964 classification.(Fig 8).

The syncline between Matin anticline and Mangesh anticline is very wide 18900 m. consists of Upper Fars Formation.

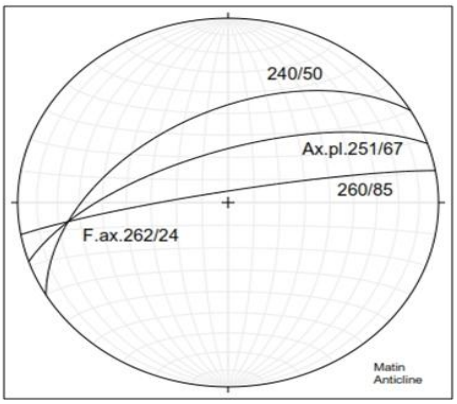


Figure (8) Stereonet of Matin anticline

2.local shortening of the folds :

The local shortening of the anticline folds (Dahkan , Duhok , Bekhair , Sadya , Mangesh , Matin) are found to be (4.3 % , 6.35 %, 20.8 % , 3.0 % , 22.9 % ,and 37.5%) respectively and for the synclines between them respectively (3.0 % , 4.34% , 3.2 % , 7.6 % and 27%).

3. Regional shortening of the foreland fold :

The regional shortening of the Tuarus foreland folds was found to be (15.9 %) .

4. Depth to the detachment surface :

The depth to the detachment surface measured for Bekhair anticline (Fig 9) was found to be (6.26 km) . The calculation is as below :

Reading of planimeter = 11673

Area = reading of planimeter * c-factor (in cm.)

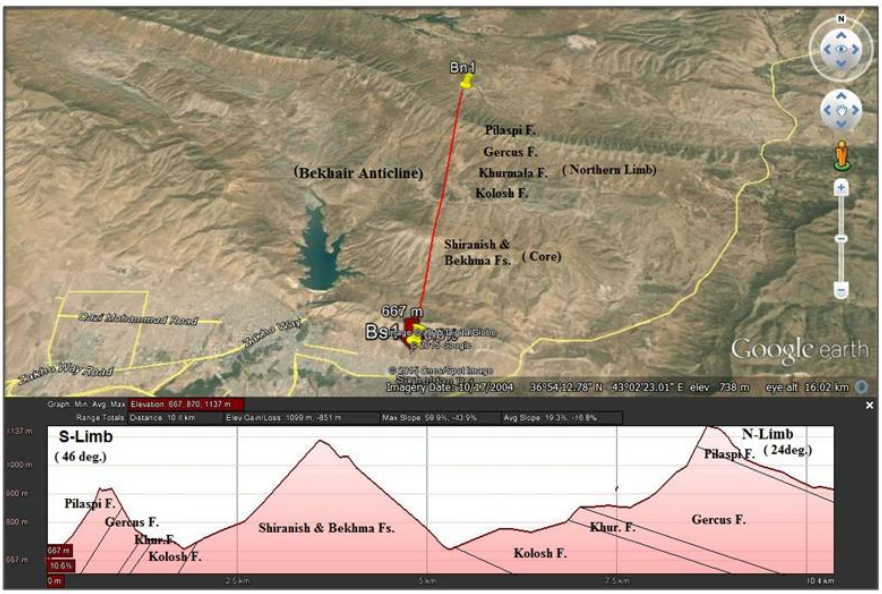
Area = 11673 * 0.11 cm^2

Scale = 1 / 10000

L o –L 1 = 20.5 cm.

Depth = Area / L o –L 1 = 11673 *0.11 * 10^4 / 20.5 * 10^2 = 62.6 * 10^2 m.

Depth = 6.26 km.



Figue(9) . Cross section through Bekhair anticline

IV. Discussion and conclusions

Balanced section calculations are an important tool for the geologists because it is possible to estimate in a simple manner the orogenic contractions across a large area of the earth crust (Hossack.1977).

In this study a structural analysis and balanced section calculation was made for the Taurus foreland folds –northern Iraq. It include (Dahkan , Duhok , Bekhair , Sadya , Mangesh and Matin anticlines) with synclines between them.The study depends on field data were collected from all the folds in the study area. A structural analysis was made for all anticlines using stereo-net window program.The results show that all anticlines are asymmetrical extending (E –W) or (NW – SE) with vergency towards the south except Duhok anticline which has vergency toward the north and strata of the northern limb are nearly vertical to overturned in many locations .Also the northern limb of Matin anticline which is adjacent to the thrust zone was overturned due to the southern thrust fault in the area (Al-Brifkani, 2008). According to Fluety's ,1964 classification , most anticlines classified as upright to steeply inclined axial plane and sub-horizontal depending on fold axis .While classification according to the interlimb angle show that they are open to gentle,buy Matin anticline classified as steeply inclined axial plane , gently plunging fold axis and close according to inter limb angle .Figs (3-8).

For determining the amount of local shortening of the folds and the regional shortening of the Taurus foreland folds , Two mathematical methods were used in this study .The results of local shortening are (4.3 % , 6.35 %, 20.8 % , 3.0 % , 22.9 %) for anticlines (Dahkan , Duhok , Bekhair , Sadya , Mangesh) while the local shortening for the synclines between them are (3.0% , 4.34 % , 3.2 % , 7.6 %).The regional shortening for the foreland folds (33400m.) was (10.03%) .

The local shortening for Matin anticline near to the thrust zone was (37.5 %) and for the syncline between Mangesh and Matin anticlines was (27 %). So the total regional shortening for the Taurus foreland fold (54319 m.) till the boundry with thrust zone was found to be (15.9 %).

Al-Shali(1992) determined the regional amount of shortening along four traverse on northern and northeastern Iraq using data from prepared cross section done by (Ameen, 1979). The shortening was found to be (5 % , 8 % , 20 % , and 6.5 %) .Al-Azzawi (2008) found local shortening for Qara chauq Anticline in NE Iraq and Bekhair anticline in N-Iraq which was (18.9 % and 26 %) depending on drawn cross sections .

Mjahid (2013) found the regional shortening amount for Akre section(20-29 %) and for Shaklawa section within high folded zone in iraq to be equal to (12 %), The regional shortening for Jura mountains were (48 %) and (58 %) for Rocky mountains (Jackson, 1980) . Hossack (1980) found that shortening percentage for parts of orogenical belts near plate tectonic margins between (35 – 54 %) .Wilson (1988) found shortening percentage for central Appalachian as (34 %) .

When we compare the local shortening percentage of Bekhair anticline of this study (20.8 %) with Al-Azzawi,2008 for the same anticline (26 %) , it seems to be less than that due to the way of getting data and also ,he add a new factor which was the additional tectonic uplift that may have an influence the amount of shortening .

The regional shortening for this study was (15.9 %) which is less than the regional shortening for a cross section similar to an extent to this study done by Al-Shali, 1998 which was (20 %) . The reason behind that may be due to the difference in the location of the two sections and Al-Shali cross-section cut six anticlines , two of them (Gara and Sari Amedi anticlines) are big anticlines and near to the thrust zone. The local shortening for Matin anticline was (37.5 %) is high because it is near to the thrust zone and the strata are orerturned due to the thrust fault in the area , and it is near to the results mentioned by Hossack, 1979 (35 – 54 %) for the orogenic belt near to the plate tectonic margins .

The depth of the detachment surface calculated for Bekhair anticline was found to be (6.28 km.) . Al-Azzawi(2008) found the depth for the same anticline to be (7.75 km.) which is more than the depth for this study .Al-Azzawi (2008) depend on Injana Formation (700 m. thickness) as a remark formation for the calculation while in our study , Pila Spi Formation was taken as remark formation which is beneath Injana and Al-Fatha Formations .

Mjahid (2013) found the depth to the detachment surface for Akre section to be (4 km. or greater) and (5.5 km. or greater) for Shaklawa section in the high folded zone in Iraq..

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