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Role of facies changes in shifting trends of anticlines in the Zagros Fold-Thrust belt: Examples from Sulaimani area, Kurdistan Region, Northeastern Iraq

Kamal Haji Karim[1*], Polla Azad Khanaqa[2], Khalid Mahmmud Ismail[2]

[1]*University of Sulaimani, College of Science, Department of Geology*
[2] *Kurdistan Institution for Strategic Studies and Scientific Research, Sulaimani city, KRG, Iraq*
[*]*Corresponding author's e-mail: kamal.karim@univsul.edu.iq*

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Abstract

The Zagros Fold Thrust Belt extends for more than 1500 kms from Oman to Turkey and passes through Kurdistan Region, northern Iraq where the studied area is located. The belt is about 200 kilometers wide and the main anticlines axes have the trends of 300°-325° in the studied area. The present study focused on a local disturbance of the above trends in the Chwarta–Mawat area. The disturbance is expressed by 20-30° of clockwise rotation (toward north) of axes of the local anticlines relative to trend of the non-rotated main anticlines of the Zagros belt. The rotation occurs in the lateral boundary between the Early Cretaceous Balambo Formation (thin bedded limestone and marly limestone) and Qamchuqa Formation (massive limestone and dolomite). These two formations are consisting of incompetent and competent rocks whereas shifting is occurred at their lateral boundary. The reasons for this tectonic disturbance is discussed and analyzed according to the direction of stress in the area and boundary conditions that are associated with the axes rotation. The study attributes the disturbance to lateral facies changes from competent, in the northwest, to incompetent rocks in the southeast. Furthermore, the facies change is associated with presence of massif block (Mawat Massif) which is responsible for transferring of the northeast Zagros tectonic stress toward southwest direction into areas of anticlines disturbance. Due to this transfer , the rate of the stress propagation, being directed by the massif, is faster in the incompetent units in the southeast which rotates the massif clockwise and forcing the axis of the neighboring anticlines to shift northward about 25 degrees. The massif is a large block (26 km × 8 km) and according to previous studied consists of metamorphic and igneous rocks in addition to conglomerates. The block is located between rotated folds (the local disturbance) and the Main Zagros Thrust. Due to southwest pushing of the massif by the Main Zagros Thrust (or reverse Fault), the surrounded rocks are folded and aligned parallel to the massif. The rotated folds are localized at the interfaces between the massif and incompetent rocks. The record of this local disturbance is important for analysis of the dynamic evolution of Zagros since the local events can be used for interpretation of regional ones.

1. Introduction

Geographically, the studied area is located at the north and northwest of Sulaimani city in Kurdistan region, northeastern Iraq (Fig.1 and 2). According to tectonic subdivision of Zagros belt in Iran, it is located in both the Simply Folded and Thrust Zones (Sanandij-Sirjan Zone). According to published maps of the belt by Berberian and King, (1981) [1], Alavi (1994) [2], Mc Quarrie (2004) [3a] and Emami et al (2010[4]), Zagros belt has width and length of 300 and 2000 kilometers. It covers a part of Middle East between Oman, at the southeast and Turkey, at north and passes through western Iran and northeastern Iraq. It is nearly a straight belt of high mountains but disturbed more or less by Dezoful and Kirkuk embayments (Vergés et al. 2011) [5]. The shortening rate, measured by GPS, of the Zagros belt, in the southwest Iran, is 16 mm/ year and its direction is nearly normal to the trend of the belt while in local place shows obliquity. Hessami et al. (2006) [6]; Vernant and Chery (2006) [7] have indicated matching of the Zagros kinematics to an oblique convergence between Iranian plateau and the Arabian plate at nearly 7 mmyr−1 near Arabian Gulf. They added that the belt is characterized by almost frontal convergence in the SE Zagros and oblique (45◦) in the NW part of the range (near the studied area). They further added that the Main Recent Fault (MRF) bordering the Iranian plateau accommodates all the tangential motion. According to Alipoor *et al*. (2012) [8], the Main Zagros Recent Fault (strike slip fault) passes at about 37 km to the northwest of the studied area and 20 km to north of the Main Zagros Thrust Fault. The present study aims to discuss the reasons behind local northward shifting of many small anticlines axes relative to the main anticlines of the Zagros belt.

1.1. Geology of the area

According to previous studies the northern part of the area is stratigraphically occupied by ophiolite (Late Cretaceous) and Naoperdan Series (Eocene) thrust sheets and these sheets are thrusted over Paleocene-Eocene Red Bed Series (Buday 1980[9]; Jassim and Goff, 2006) [10]. They added that the northeastern part is covered by the Qulqula Radiolarian Formation (Early Cretaceous). While the carbonates of the Early and Late Cretaceous ages are exposed in the south and southwest of the study area. Between the Red bed and carbonate, Shiranish (Campanian), Tanjero and Aqra (Maastrichtian) Formations are cropped out in the middle part of the area (studied area). Tectonically, the studied area represents the northeastern margin of the Arabian Plate (Fig.1 and 2), where the previous Early Cretaceous platform had transformed to a foreland basin during the Late Cretaceous due to thrust loading the platform by radiolarites (Karim, 2004) [11]. The studied area located in the Imbricated Zone of Buday (1980) [9], Buday and Jassim, (1987) [12]. This zone is equivalent to Balambo-Tanjero Zone of Kadhimi eta al. (1996) [13]; Jassim and Goff (2006) [10].

1.2. Method of the study

The study depends on the field mapping for recording the ductile and brittle deformations in the studied area. These deformations are well exposed along the deep valleys sides and high mountains. In the field the attitude of the strata and the trends of main and secondary fold axes are recorded by GPS and compass. In the field, they are photographed and plotted on suitable maps with differentiation of the relevant stratigraphic units by lithology and fossils content with the aids of previous studies. The compass data are plotted on lower hemisphere of equal area stereo net by using the software of Stereonet 9.5 that is prepared by Allmendinger, et al. (2012) [14] and Cardozo and Allmendinger, 2013) [15]. The bedding and fold axes attitudes are fed in to the program according to the option of right hand rule.

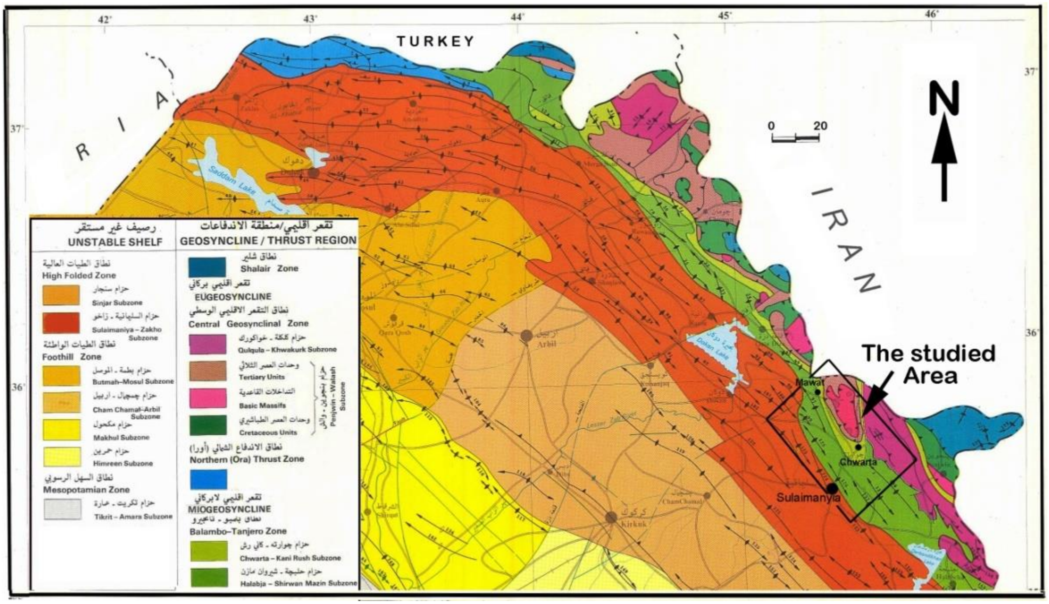

Fig. (1) Tectonic map of the northern Iraq (Al-Kadhimi, et al. 1996) [13] on which the studied area is shown

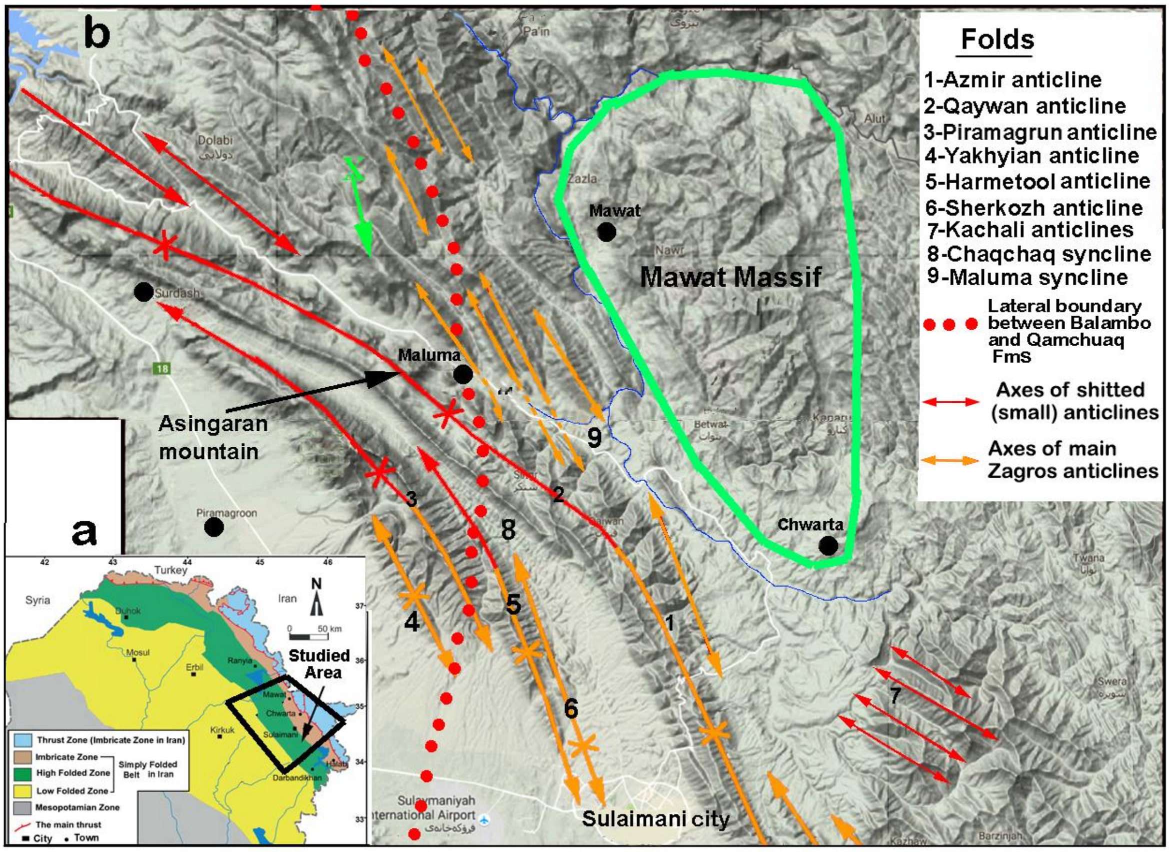

Fig. (2) The location (a) and topographical map of the studied area (b) shows the tends of main (red arrows) and north shifted (orange arrows) anticline axes

2. Result

2.1. Zagros anticlines pattern

According to Mc Quarrie (2004) [3a] The Zagros belt is known for its spectacular fold series, believed to be detached on lower Cambrian salt and resistant limestone anticlines control the characteristic morphology of the region. Alan (1969) [16] has cited many NW-SE folds, which are elongating parallel and formed due to the collision between Arabian and Iranian (Eurasian) plates. The anticlines are arranged in en echelon (Alavi, 1994) [2] and the belt consists of thousands of large and small anticlines, which are linked transversally and longitudinally by complementary synclines (Fig.3). This pattern, require bifurcating of the synclines and anticlines and thus each anticline is bounded from all sides by synclines.

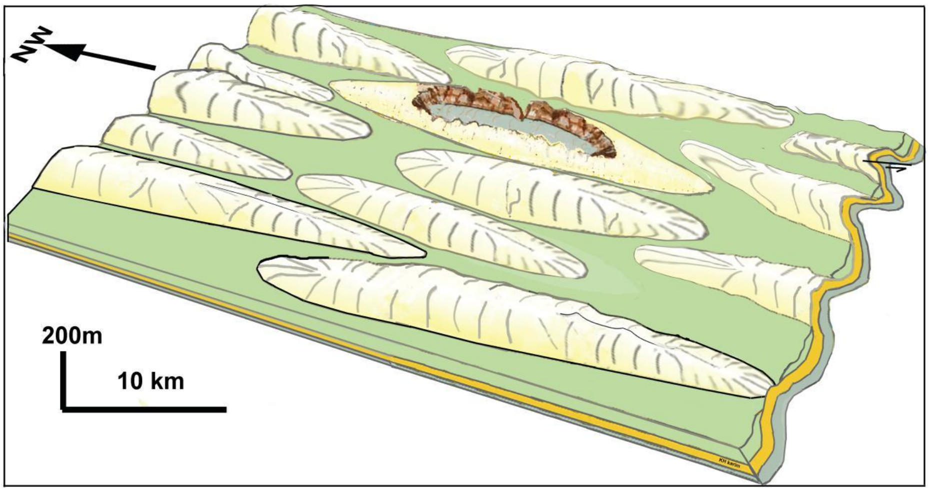

Fig. (3) In the Zagros Fold-Thrust belt the anticlines are arranged en-echelon pattern where they are surrounded by complementary synclines

2.2. Facies change in the studied area

The above-mentioned change of anticline axes is associated with major facies change of the lithology in the studied area and spatially related to the position of the axes changes. Directly to the south and southwest of the zone of axes change, reefal and massive dolomitic limestone facies of Qamchuqa Formation change to pelagic and well bedded marly limestone and limestone of Balambo Formation which extends and thickens in the area of the shifting anticline axes. These two formations belong to Early Cretaceous age and they were deposited contemporaneously on the Arabian platform and on the basin floor of the Neo-Tethys Ocean respectively. The facies change is documented by Dunnington (1958, [17] fig.4), Buday (1980) [9], Ameen (2008) [18]. In the latter paper, the area of the facies change is indicated and called “Transitional Zone between Qamchuqa and Balambo Formation”. Rheologically, these two formations are classified as soft and stiff facies or lithologes respectively and they deform differently in response to external stress.

The soft facies (pelagite and hemipelagite of Balambo Formation) deposited in the south and east of the studied area (Fig.4) and located between two massive and stiff lithologies of Qamchuqa Formation at the south and west and Mawat Massif at the east and northeast (Figs.5 and 6). This massif consists of different rocks such ophiolite (gabbro, peridotite, dunite and volcanic rocks), marble and conglomerate of Red Bed Series (Al-Mehaidi, 1975[19]; Othman and Gloaguen, 2014) [20].

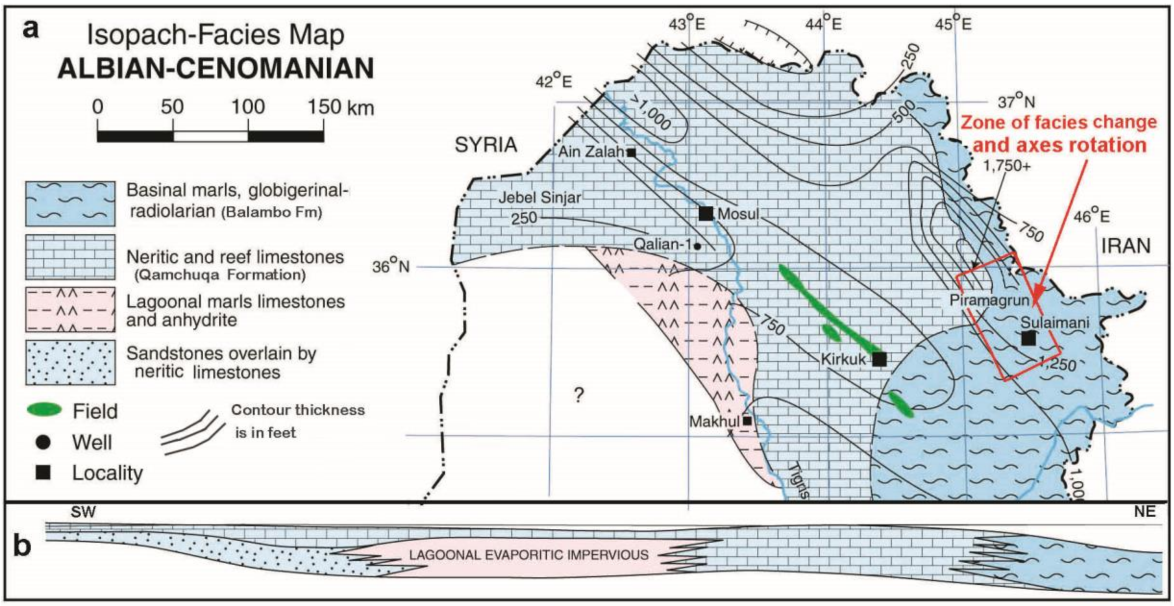

Fig. (4) A map of the Cretaceous facies change (Dunnington, 1958) [17] on which the studied area and rotation of anticline axes are indicated

2.3. Northward rotation (shift) of axes of the local anticlines

This study has grouped the anticlines into two types, the first is those that their axes have general (common) trend of the Zagros belt that are indicated on the structural map of Al-Kadhimi et al.(1996) [13] and they are called “Zagros Main Anticlines: ZMA” which are shown in red arrows in the figure 2. The other type is those that are shifted (rotated) clockwise northward and called “Shifted Anticlines: SA”. In the whole Zagros belt the common azimuthal trends of the ZMA are 300°-325° degrees, while the mean azimuth, in the studied area is 315° degrees but the SA shift more than 20^o northward and change nearly to 340^o (Fig. 2). The oblique anticlines are relatively small and cutting or obliquely modulating the ZMA. These modulations can be seen clearly around Singer, Qaywan, Gomazal, Garade, Galala, Gapilon and Safra villages (Figs. 7, 8, 9, 10 and 11).

In these areas the SA are lined obliquely to the main anticlines of Zagros trend and they may bifurcated from them with difference of about 20 degrees of axes trends. It is clear that the SA is younger in age than the main ones. This is evident from hosting of the shifted anticlines by main ones and their relation appear as clear cross cutting of the later anticlines by former ones. Another evidence is more exhumation of the main anticlines, as compared to SA ones. The northward rotation is not restricted to independent anticlines but include rotation parts of large anticlines such as southeastern parts of Piramagrun and Azmir anticlines (Figs. 2, anticlines no.1, 2, 4, 5 and 6) at the north and northwest of Sulaimani city.

2.4. Mawat Massif

Mawat Massif (Jassim et al. 1983) [21] is composed of mixture of igneous, metamorphic and Meta-volcanic rocks that has 20 and 30 kms of width and length respectively, Jassim and AL-Hassan (1977) [22]; Buda and Al-Hashimi (1977) [23] and Al-Mehaidi (1975) [19]. The latter author studied petrography and origin of the massif under the name of Mawat Nappe and outlined it at northeast of Sulaimani city between the upstream of the Lesser Zab River along the Iranian border in the north and the of Chwarta town in the south (Figs.2 and 5).

From north and northeast bordered by Qulqula Radiolarian Formation (Zagros Radiolarites) while in the east, southeast, south and southwest surrounded by Cretaceous pelagite and hemipelagite (Balambo, Kometan and Shiranish Formations). The most important geological characteristic of this massif is its competence as compared to the surrounding sedimentary rocks. Another characteristic is its elongation exactly parallel to the present axes of shifted anticline (Fig.5). This parallelism can be seen between the axes of the SA (shifted anticlines) and southwestern boundary of the Mawat massif.

The deformational structures of massif and its surrounding areas are agrees with transpressional deformations that cited and modeled by Milia and Torrente (2000) [24]; Vaughan et al (2012) [25], Yin (2012) [26] (Fig.5b) and Sarkarinejad and Azizi (2008) [27]. In the present study, the whole model is rotated for directional matching of stress direction in the model (red arrow in fig.5b) with main tectonic stress direction of Zagros belt.

After matching, of the stress model with that of Zagros, the model revealed origin of many structures of the studied study. From the figure 5a, the two normal faults indicated by Karim (2006) [28] are nearly coinciding with the two normal faults in the model of transpression deformation (Fig.5b5). The Main Zagros Thrust, anticlines and shear fractures in Mawat area (Buday, 1980[9] and Jassim and Goff, 2006) [10] are matching with those of the model of the figure (5b1, 2, 3 and 5). Even the finite stress ellipsoid (FSE, see fig.5b6) is nearly similar to Mawat Massif in shape and direction of elongation (deformation).

The geological setting of the nape by (Mehaidi, 1975) [19] (Fig. 6) and all the later authors envisaged surficial thrusting of the nappe toward the southwest. Although there are strong attitudinal status between the nape and SA structures, but its thrusting cannot be responsible for the deep deformation and shifting of small anticline. This is due to presence of SA in deep valley (e.g. valley of Safra-Zaron, about 500 m below the level of nappe. Therefore, we think that the Mawat area is not a nape but it has deep root in the area which generates deep shifted structures in it's west and south vicinities (Figs. 2, 5, 7, 8,9, 10 and 11). In literature, analogous to deep root is discussed in detail by Azizi et al. (2013) [29] who refuse nape setting of the Mawat Ophiolite complex (Mawat Massif) and considered the complex as an intrusion of mantle plume into an extensional tectonic regime on the thinning of the lithosphere of the Arabian passive margin (Fig.12). Therefore, according to the observation of the present study about deep root of the Mawat Massif and that of the latter article, the heat that associated with the massif may affected neighboring rocks and more or less effected the differential deformation by softening the mechanical properties of the stratigraphic units.

Recently Karim and Al-Bidary (2020) [30] and Karim (2020) [31] concluded that the Bultaf and Mawat Massifs (Complexes) are originally consist of metamorphosed volcaniclastic sandstone (greywackes) and refused presence of Igneous rocks on the two complexes. They added that these sediments are buried deeply and regionally metamorphosed as metamorphic core complexes. They further added that these cores are uplifted during Miocene-Pliocene. Therefore, presence of Mawat Metamorphic Core Complex and its nearly vertical uplift may be responsible for shifting of the axes of the SA, especially the core complex is pushed more or less southwestward by the force of the Main Zagros Thrust (Zagros compression stress). This vertical uplift agrees with the intrusion idea of Mawat Massif by Azizi et al. (2013) [29] and the observation of the present study that the axes shifting of the small shifted anticlines (SA) is generated by deep force not thrust.

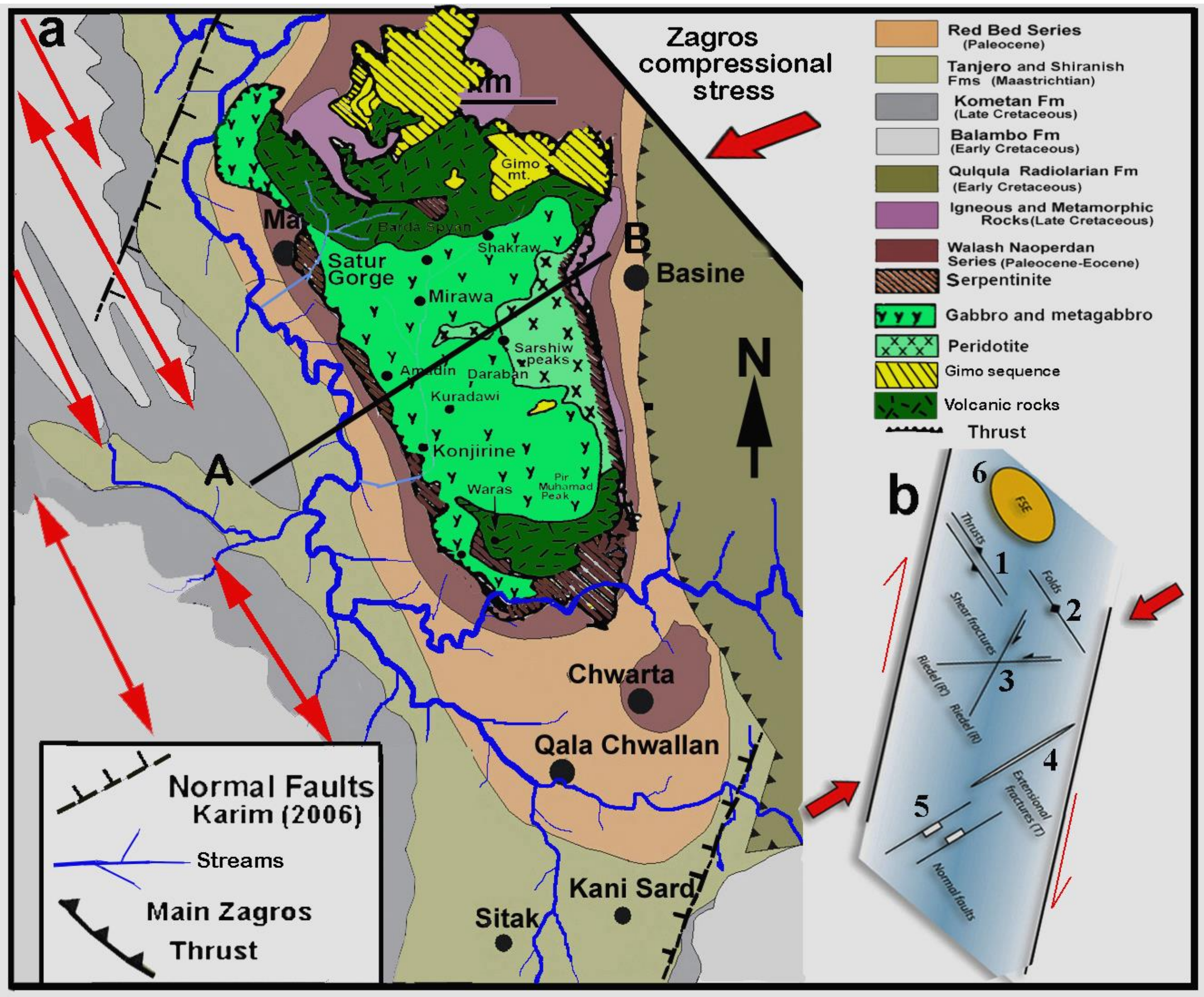

Fig.(5) a) Geological map of the Mawat massif (Al-Mehaidi, 1975) [19] shows parallelism of its southwestern boundary to the SA (shifted anticines) b) A transpression strucures such as normal fault, folds, thrusts and conjugate fracturing (Vaughan et al, 2012[25] and Yin, 2012) [26] Which are applicable to the studied area.

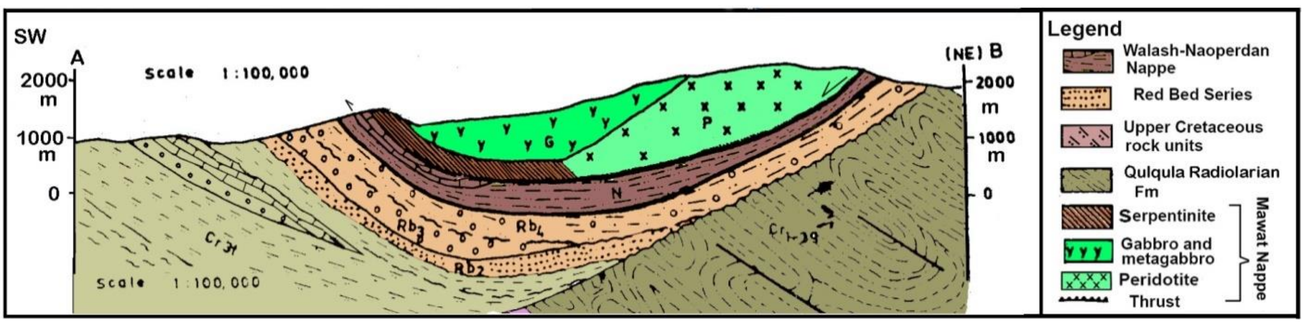

Fig.(6) cross section (A—B in the figure 5) of the Mawat nape (Mawat Complex) by (Al-Mehaidi,1957) [19]

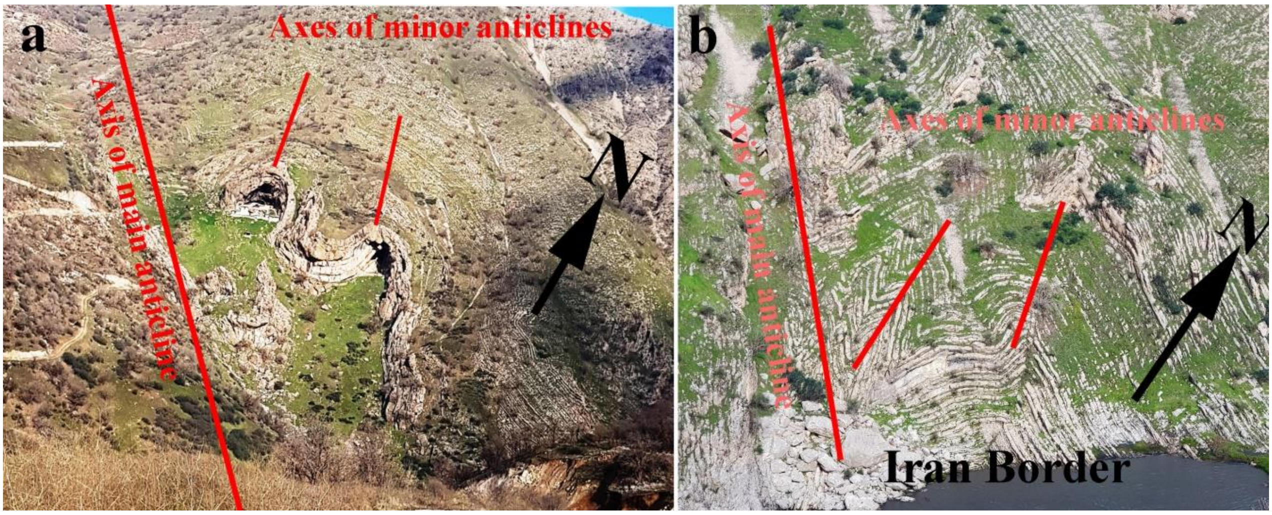

Fig. (7) a) Small shifted anticlines (trending 350^{o}) in Safra-Zarun Valley at 2 km north of the Gallala Village at the 10 km west of Mawat town, b) photo of the south of Qaytool village on the border of Iran at the end of the Sara_zarun valley show northward shifting of two SA anticlines relative to main anticline (red bold line).

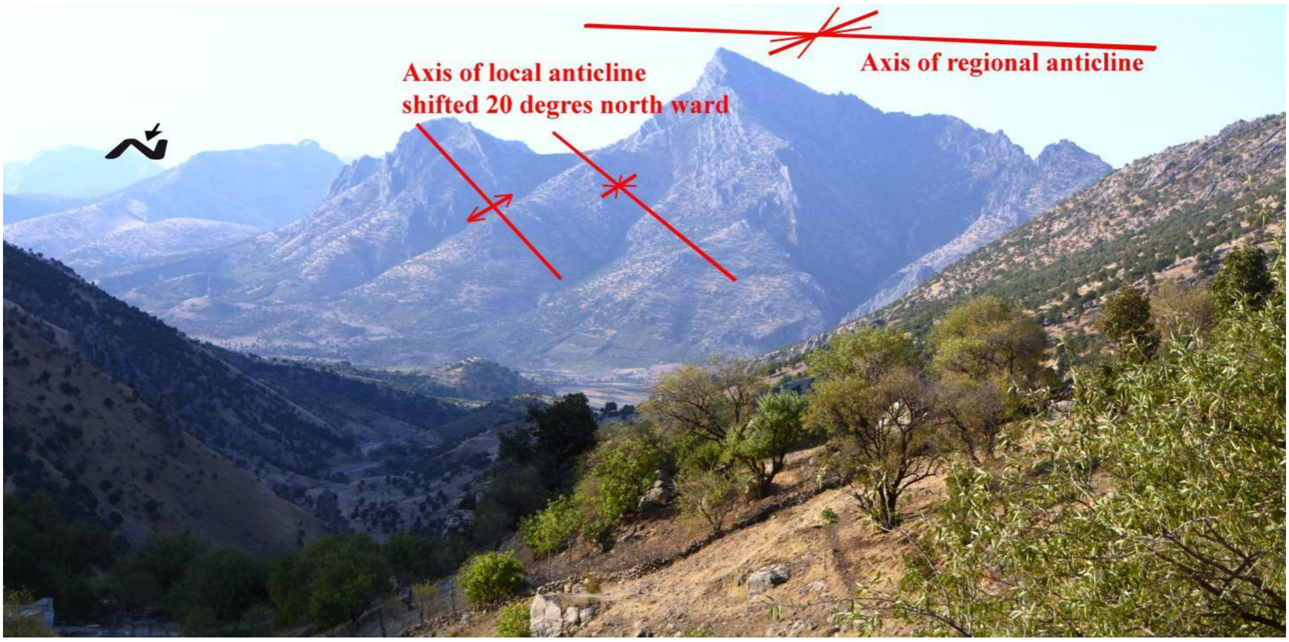

Fig.(8) Shifting (toward north as compared ZMA) of two minor folds on the Asingaran mountain, the photo is taken from the peak of the Gomazal mountain in the Jafayaty valley.

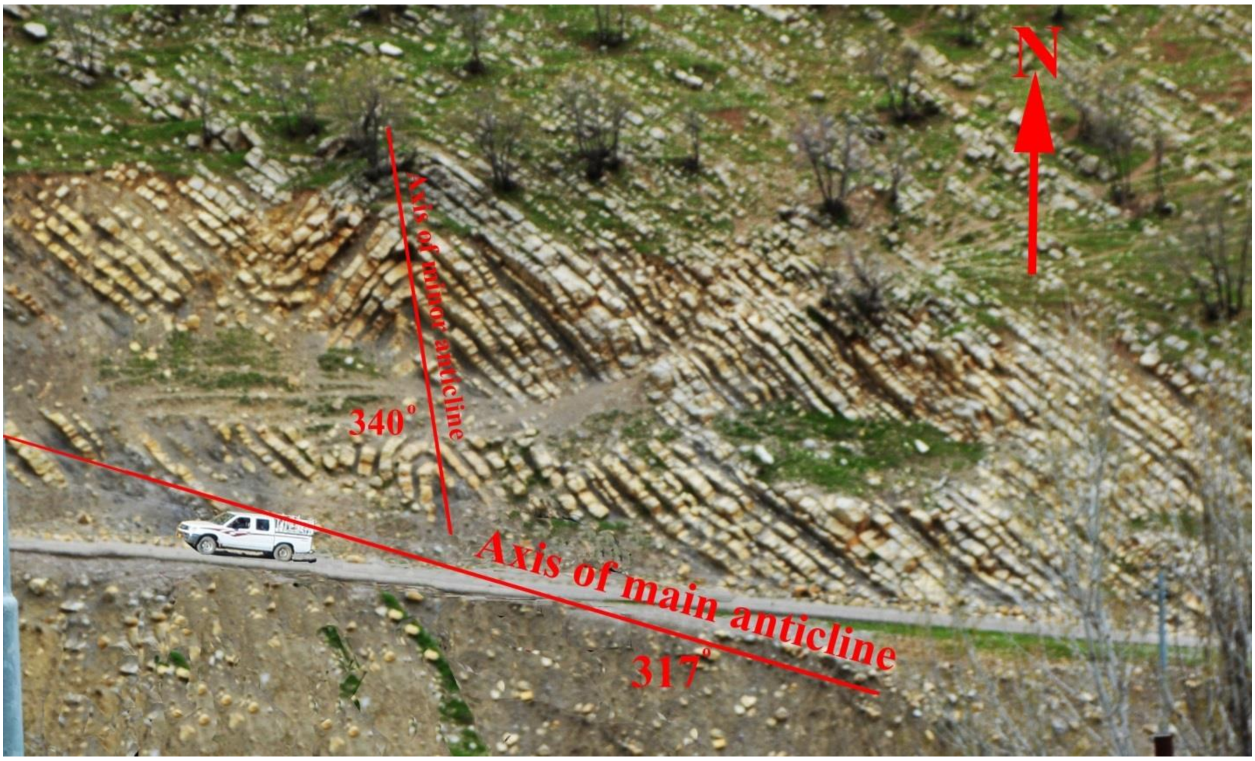

Fig.(9) a) 20 degree obliquity of a minor anticline (SA) to axis of the main anticline (ZMA) near Qaywan village.

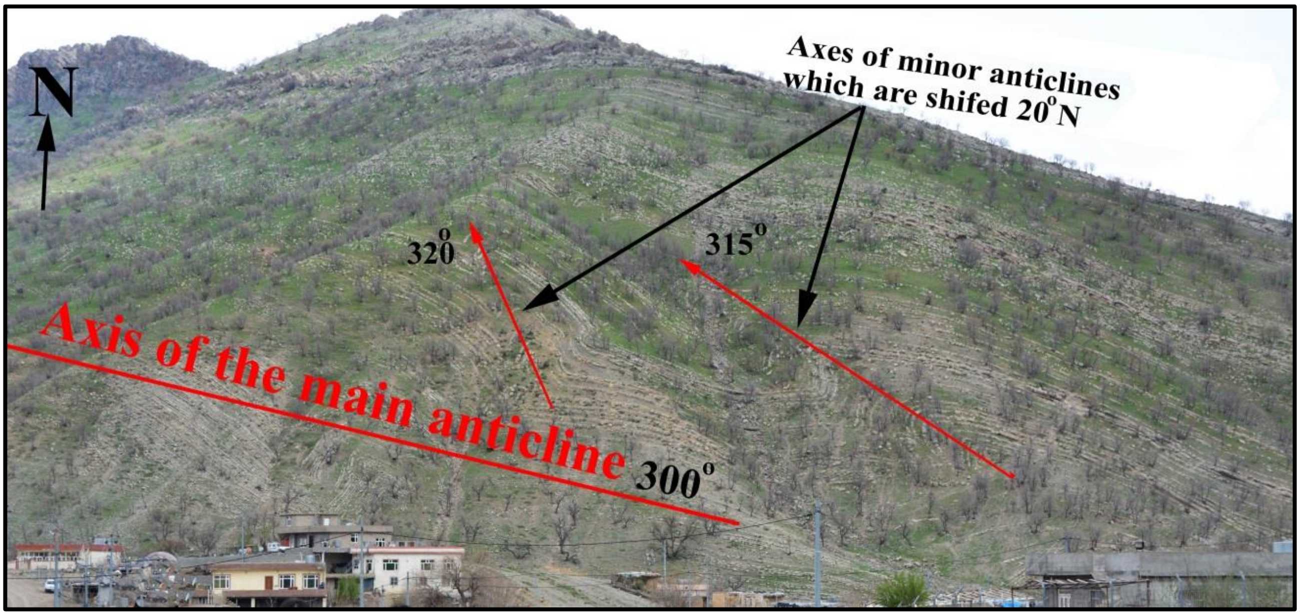

Fig.(10) a) Main Qaywan anticline as one of the ZMA axes (red thick line) and shifted axes of the minor anticlines (SA) (red thin arrows) inside Singr village

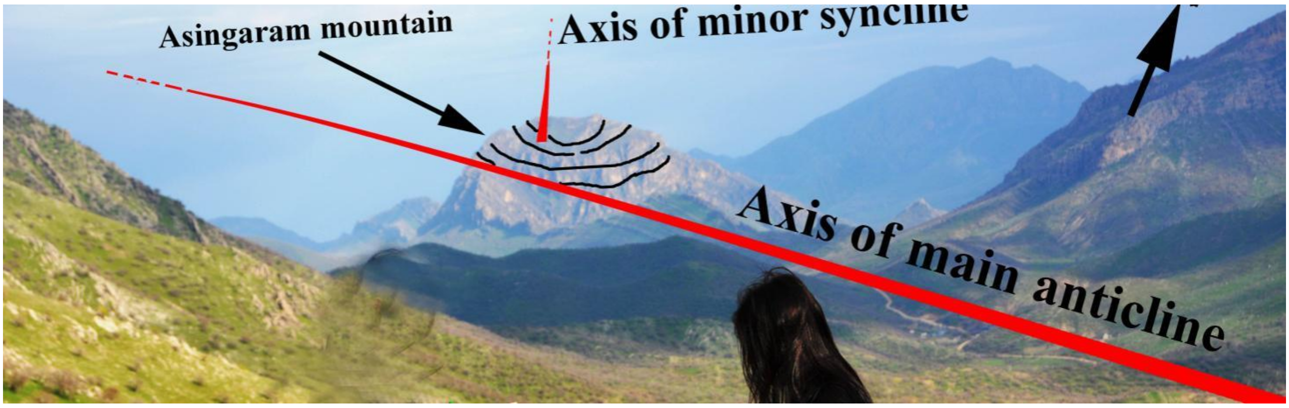

Fig.(11) a) Jafayaty valley shows axis of the main anticline and a minor syncline which is shifted (toward north) on the Asingaran mountain.

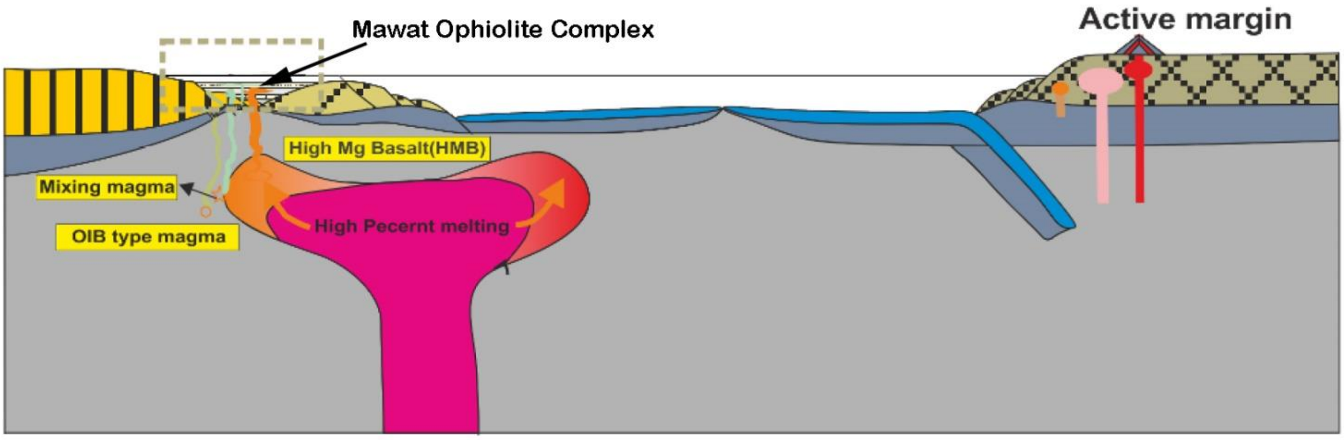

Fig.(12) The Mawat Ophiolite complex (Mawat Massif) considered as an intrusion of mantle plume into an extensional tectonic regime on the thinning of the lithosphere of the Arabian passive margin Azizi et al. (2013) [29].

3. Discussion

The documentation of the local shifts (changes) of anticline axes is valuable for interpretation of the attitudes of local and regional deformational pattern of Zagros belt. These attitudes are attributed by Cotton and Koyi, (2000) [3b] to the type of the decollement, where weak, the overlying deformation front propagates farther and faster than the adjacent deformation above a detachment with high friction (Fig.13). The pattern of the anticlines in this latter figure and their rotation toward north is very similar to that of the present study as shown in the figures (2, 6, 7, 8, 9, 10 and 11).The deformation inside Qamchuqa Formation is very similar to friction decollement which mean deformation in massive coherent rocks while ductile decollement is similar to deformation inside Balambo and Sarmord formation in which each thin and relatively soft bed act as easily deformed and perform as ductile medium or discontinuity surface.

In the model of latter author, there is strike slip fault while according to Karim (2006) [28] and Karim et al. (2009) [32] a normal fault extends from the northwest to the southwest of Mawat Massif and it coincides with normal fault of Cotton and Koyi, (2000) [3b] (Fig.13 **a** and **b**). However, now the authors think that the normal fault not a pure dip slip fault but may be actually oblique slip normal fault to accommodate rotation of the Mawat massif clockwise in the area.

The reasons for this tectonic deformation is discussed and analyzed which are attributed to the stratigraphy architecture of the area including lateral facies change from competent to incompetent stratigraphy. Furthermore, the facies change is associated with presence of massif block (Mawat Massif) at its adjacent north-eastern border. This association is responsible for local anticline axes rotation and transferring of the northeast tectonic stress in privilege condition to the incompetent rocks (Balambo

Formation) at the southwest of the studied area while Qamchqa Formation as competent body more resisted to deformation and relatively remained more or less in its location without considerable rotation in the west and northwest of the Massif. Consequently, the elongation (length) of the Mawat complex aligned nearly parallel to axes of the structures SA (shifted fold axes) (Fig. 5). The deformation of the studied area was inhomogeneous due to facies inhomogeneity of the studied area at the west and south of Mawat complex. Rayan et al. (2014) [33] summarized the effect of lateral lithologic change on structure in orogenic belt and mentioned that lateral facies changes in the stratigraphy of mountain systems may be important drivers of long-strike variations in structural style.

While the model of Cotton and Koyi, (2000) [3b] agrees with the present one, the model of Csontos et al. (2012) [34] gives the completely opposite results (Fig.14). In this figure, the trends of the Early Miocene anticlines (older anticlines) in Iraqi Zagros were more northward (about 338^{o}) than the recent ones (younger anticlines) trending 318^{o} (Fig.14a and b). The results of the present study prove that the younger anticlines are more shifted northward than the older ones (Fig.15). Therefore, the present study has significant result since it uncover local disturbance of the structure of the Zagros Fold-Thrust belt in addition to opposing historical alignment of the anticlines in some previous studies.

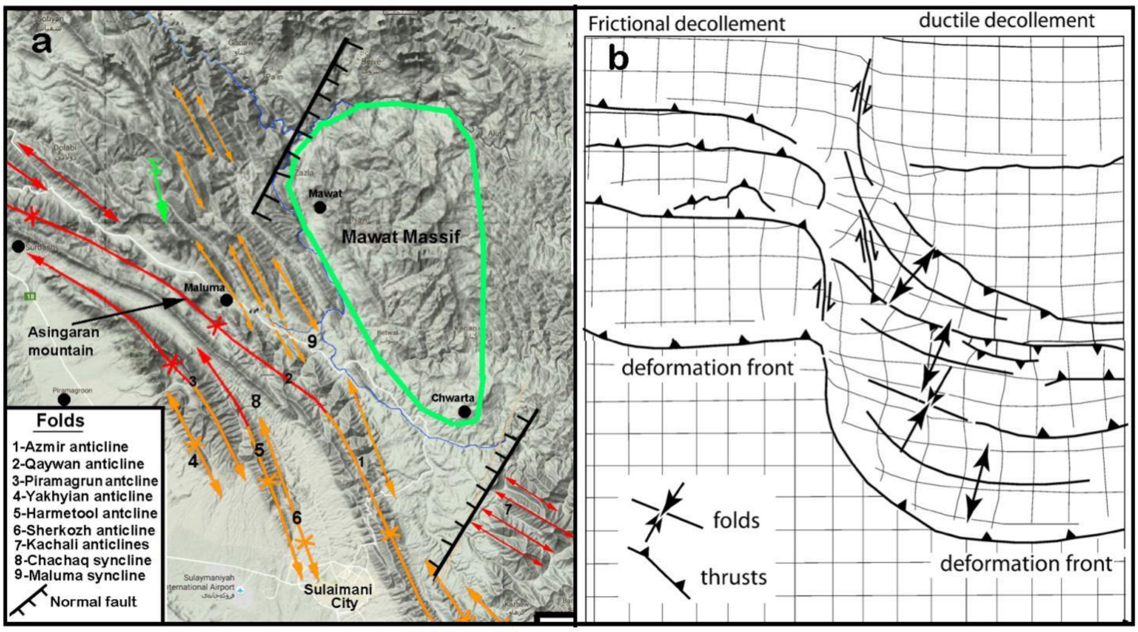

Fig.(13) Comparison between structures of the Mawat area (a) and structures of the model of Cotton and Koyi, (2000) [3b] (b). It can be see that the two models contain two types of rocks, normal faults, tectonic fronts and rotation of axis of anticlines.

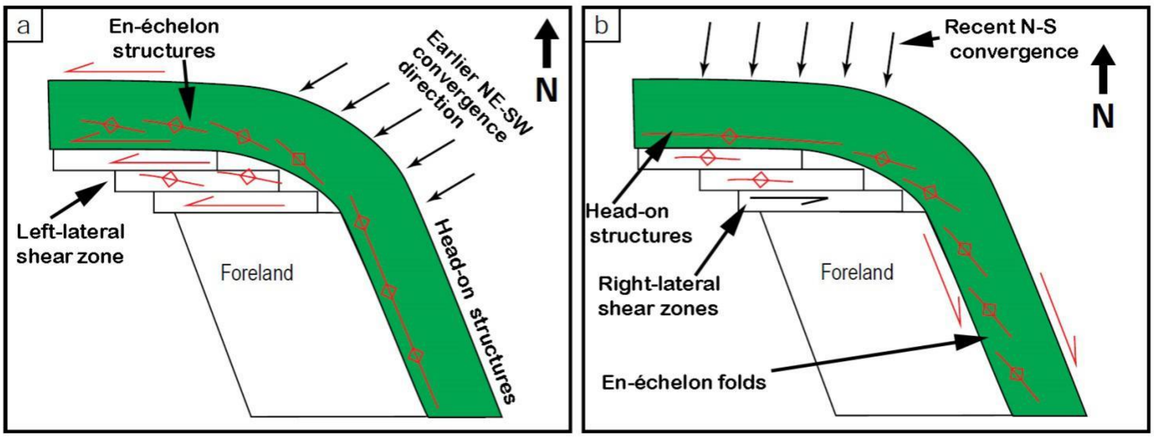

Fig. (14) Models for the historical structural development of the studied area Csontos et al. (2012) [34]. Green stripe marks the Fold-Thrust Belt of Zagros. Small black arrows indicate main directions of Eurasia-Arabia convergence. (a)

Earlier (Early Miocene) NE-SW convergence direction generates "head-on" folds trending nearly 338o in NW-oriented segments (b) Recent N-S convergence direction generates en-échelon folds that trending 318^{o} .

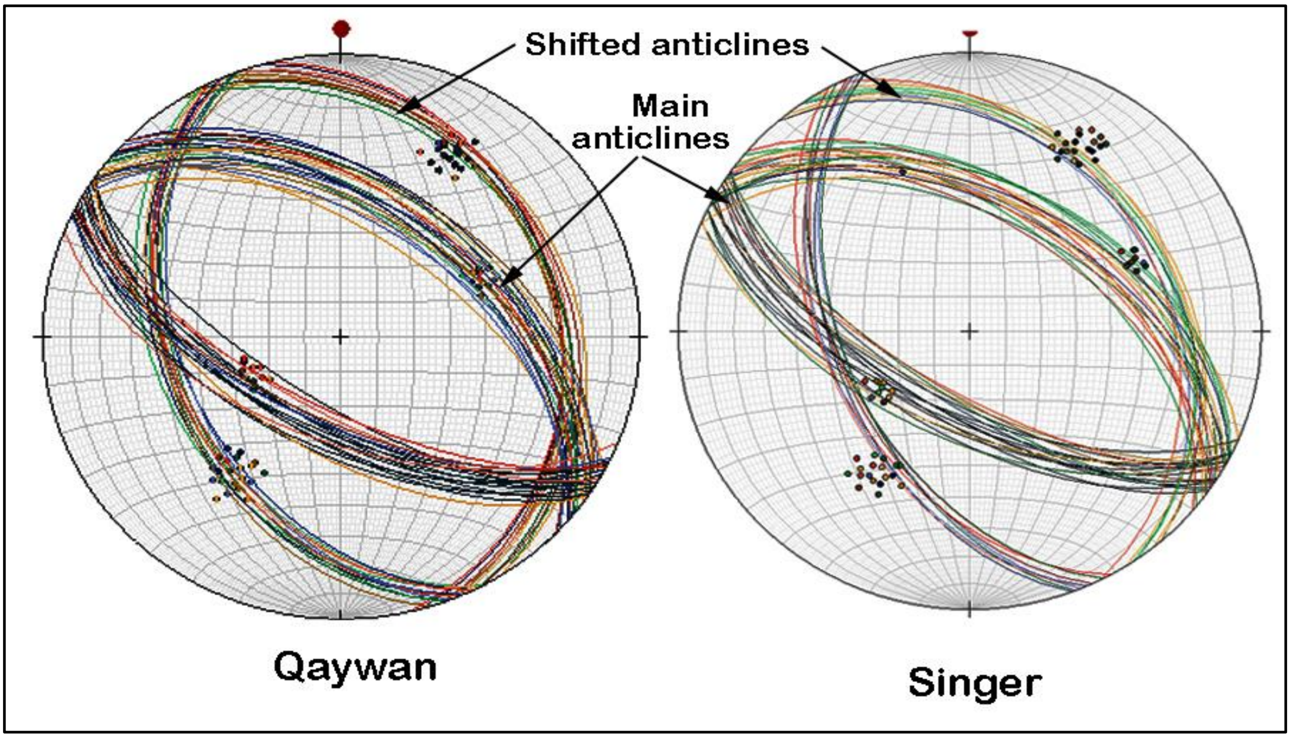

Fig.(15) Stereonet of the attitudes of the limbs of the several main and shifted anticlines in two different localities in the studied area

4-Conclusions

1-For the first time local disturbance of axes of local anticlines is found in Zagros of Kurdistan Region which modulated the axes of the main anticlines.

2-The disturbance is represented by northward shifting of the minor anticline (small anticlines) in the area between Sulaimani city and Mawat town

3- A recording of shifting of minor anticlines in the studied area for about 20 degrees relative to the regional trend of axes of main anticlines of Zagros Belt.

4-The reason for the shifting is attributed to the presence incompetent and incompetent facies in the studied area in addition to possible vertical uplift of the Mawat Massif and its southwestward push of main Zagros thrust. 5-It is expected that the shifted (minor) anticlines are younger than the main ones due to cross cutting relation and generated during upper Miocene -Pliocene.

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