Structural analysis of the Azmir – Goizha anticline, north and northeast of Sulaimani city, Kurdistan Region, Northeast Iraq

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Abstract

The Azmir–Goizha anticline (AGA) is located directly to north and northeast boundary of Sulaimani city, Kurdistan Region, NE Iraq. The anticline originally consists of two main connected anticlines (Azmir and Goizha anticlines) with many smaller anticlines along southwest and northeast limbs. In the studied area, it has length and width of about (10 and 4) kms, respectively, with height of 1600 m (a.s.l). It extends from Weladar village, from southeast to Khamza village at the northwest and further extends outside of the studied area. The anticline has very complicate structural setting and recently few structural analyses were conducted by different workers. The present study is an attempt to discover the actual structural setting of the anticline and try to review the previous studies critically by using data collected in the field with aid of precise stratigraphic analysis. Structurally, the previous pigy-back thrust imbricated fan is changed to nearly isoclinal detachment fold, which is detached in the form of either lift-off detachment fold or multi-detachment fold or multi-detachment faulted fold. In the core of the anticline, the accommodation of the shortening is preserved as second-order folding or second-order conjugate faulting. The competent cover (outer layers) of the anticline consists of Kometan and upper part Balambo formations. Core Azmir and Qaywan anticlines are occupied plastic incompetent layers of Sarmord Formation and lower part of Balambo formations while that of Azmir Bichkola and Naugirdan (or Goizha) anticlines are occupied. These units are deformed as disharmonic buckle folds in the cores. The main detachment had occurred in the lower part of the Sarmord Formation (Lower Cretaceous) and inside Jurassic rocks. All the mapped strike-slip and reverse faults, in the previous studies are not recorded in the present study. Furthermore, this study recommends excluding the anticline from the Imbricate Zone and including it within the High Folded Zone.

Keywords: Azmir anticline, Goizha anricline, Structural analysis, Sarmord Formation, Balambo Formation, Kometan Formation, Gulneri Formation, Dokan Formation.

1-Introduction

The Azmir and Goizha are two connected mountains located to the north and northeast of Sulaimani city, respectively. In nowadays, the boundary of two mountains nearly coincides with limits of the city (Fig.1). The two mountains form a small NW – SE mountain range; looking over the city and exhibit magnificent scene to the city, being interesting touristic site.

Structurally, each of the two mountains consists of a large anticline and together is called Azmir – Goizha anticline (AGA). With these two anticlines, the Azmira Bichkola and

Qula Rash anticlines are studied too, which are located northeast of AGA (Fig.1).

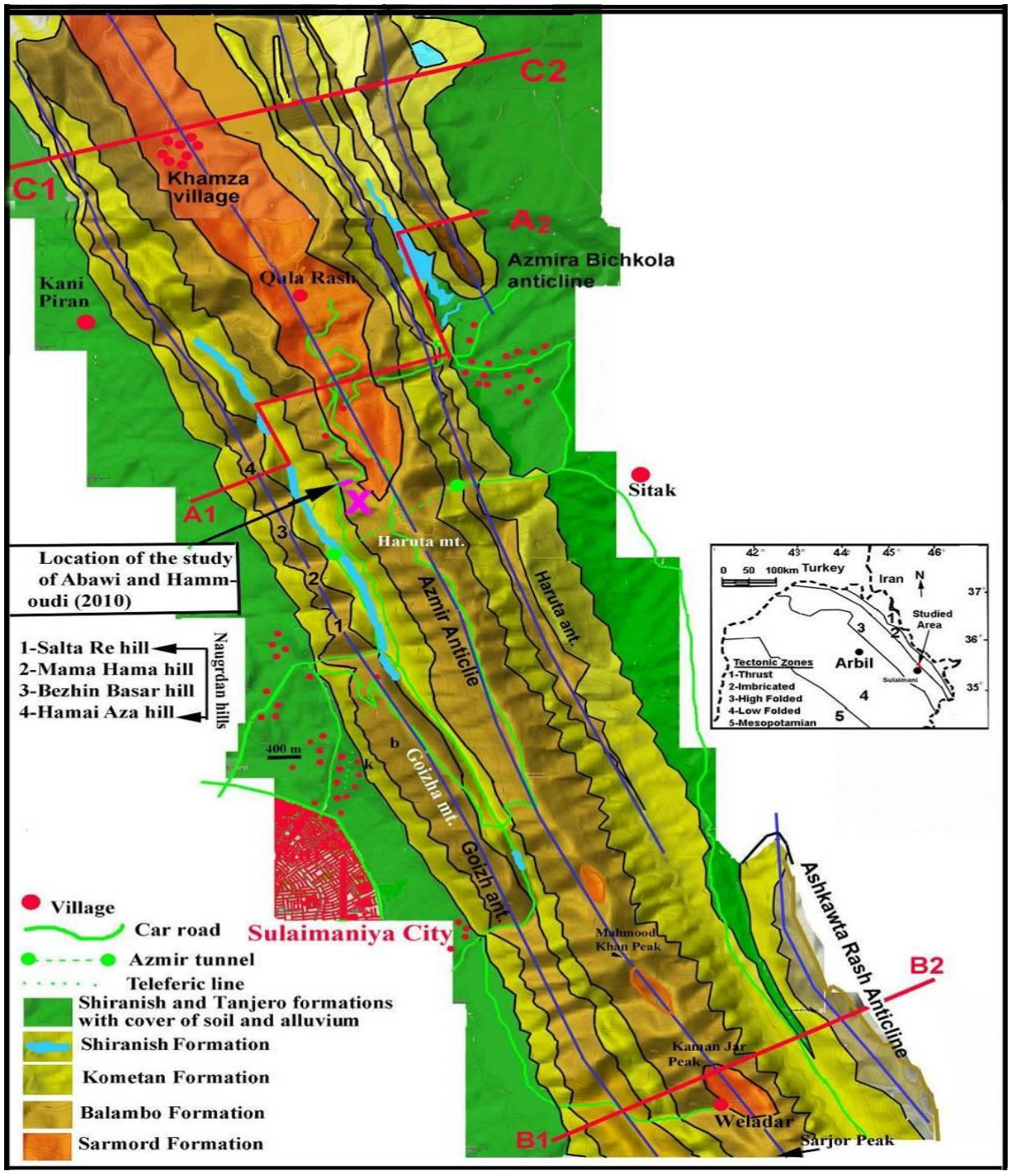

Fig. (1): Geological map of Azmir-Goizha anticlines (modified from Karim *et al*., 2013) [1]

These four anticlines (with complementary synclines) contain many parasitic folds in their core and along their limbs. The northwestern end of the Goizha anticline is dissected by four streams by mean of which it got shaped of four pyramidal hills that are called Naugirdan hills (Fig.1). Recently, several detailed studies were conducted on AGA; among them are Al-Jumaily and Adeeb (2011) [2], Omer (2011) [3] and Al-Hakari (2011) [4].

Structurally, the development of the anticline is a controversial. Lawa (2004, p.213 and 222) [5] in the model of basin analysis of Kolosh Formation showed that the anticline was the source area for the Kolosh Formation during Early Paleocene and called it "Azmer Orogenic Belt". Al-Hakari (2011) [4] showed by a correlation chart the same idea of Lawa (*op ct.*) [5], which stated that Azmir –Goizha anticline was uplifted and acted as a terrestrial land between Red Bed Series and Kolosh Formation during Paleocene.

In contrast to the aforementioned idea, both Karim (2004a) [6] and Al-Barzinjy (2005) [7] concluded that the anticline was not existing during Maastrichtian and Paleocene, respectively, and its position was a sea in which sediments of the both aforementioned ages were deposited as concurrent and lateral facies changes. Karim *et al,* (2008) [8] concluded, on the basis of sedimentology and hydrodynamics of the Zagros Foreland Basin, that the first development of the anticline had occurred during Middle Eocene and prevented the influx of the clastic sediments to reach Pila Spi basin. Ibrahim (2009, p.137 and 143) [9] gave two different ages for the first development of the anticline, which are Paleocene and Late Eocene. Aziz and Lawa (2000) [10] called the anticline "Azmir anticlinorium" and Al-Hakari (2011) [4] used the same name too.

The aims of the present study are documentation and updating the actual structural and tectonic setting of AGA. The study depends on field work, using hand lenses (10 X and 30 X) for recognizing the stratigraphic units, their internal structure and their fauna. The attitudes of the bedding are measured by compass and plotted on a stereo net. The locations of the measurements were indicated by GPS on the geological map and three detailed geologic cross sections were drawn, which show the types, sizes and relations of anticlines with stratigraphy and geomorphology (Figs. 2, 3 and 4). For the geological mapping, the study has depended partly on the study of Karim *et al*. (2013) [1] who differentiated both Kometan and Sarmord Formations from Balambo Formation for the first time (Fig.2). They also proved the occurrence of the age equivalents of Gulneri (marl and marly limestone, not black shale as defined by Bellen *et al*., 1959) [11] and Dokan formations. Another result of their study is that the lithology of Kometan Formation and the upper part of Balambo Formation are very similar in lithology. All previously mapped faults were all other structures, which were concluded in previous studies are re-studied and discussed in detail.

Structure of the Azmir – Goizha Anticline (AGA)

The structure of the AGA, as well its stratigraphy, is very complex due alternation of competent and incompetent rocks; in addition to sudden facial changes in the area.

According to tectonic subdivision of Jassim and Goff (2006) [12], the boundary between High and Imbricated Zones is nearly pass along the axis of Amir Anticline.

Due to a recently conducted accurate geologic mapping (scale 1:50000) and stratigraphic differentiation by Karim *et al.* (2013) [1], a new structural analysis and modification is possible in the present study. In the recent geological map, three elongated outcrops of Balambo Formation are shown (Fig.1) instead of one; as it was the case in the

previous studies (Omer, 2011[3], Al-Hakari, 2011[4]; Al-Jumaily and Adeeb, 2011[2]) (Fig.5). These three outcrops are good indicators for existing of three anticlines (in the studied area). From the size of the outcrops of the Balambo Formation, it can be realized that the central one, among the three, is the largest anticline and the southwestern one is the smallest; (Figs. 3 and 4). Al-Hakari (2011) [4] divided the studied area into four anticlines; naming them, Azmar Bechkola, Haruta (Qula Rash), Main Azmar and Goizha and he concluded that they are forming piggy-back thrust imbricate fan.

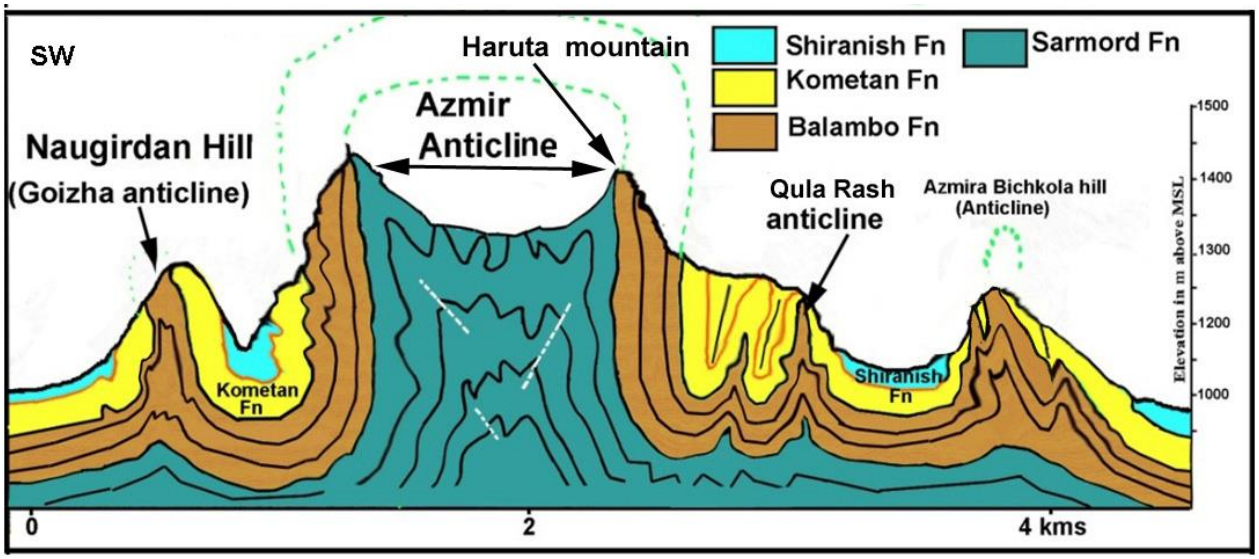

Fig.(2) Geological cross section of Azmir – Goizha anticline of the present study (see A1----A2 line in Fig. 1). (Folds that are smaller than 50 m are not shown) (Modified from Karim et al. 2013) [1].

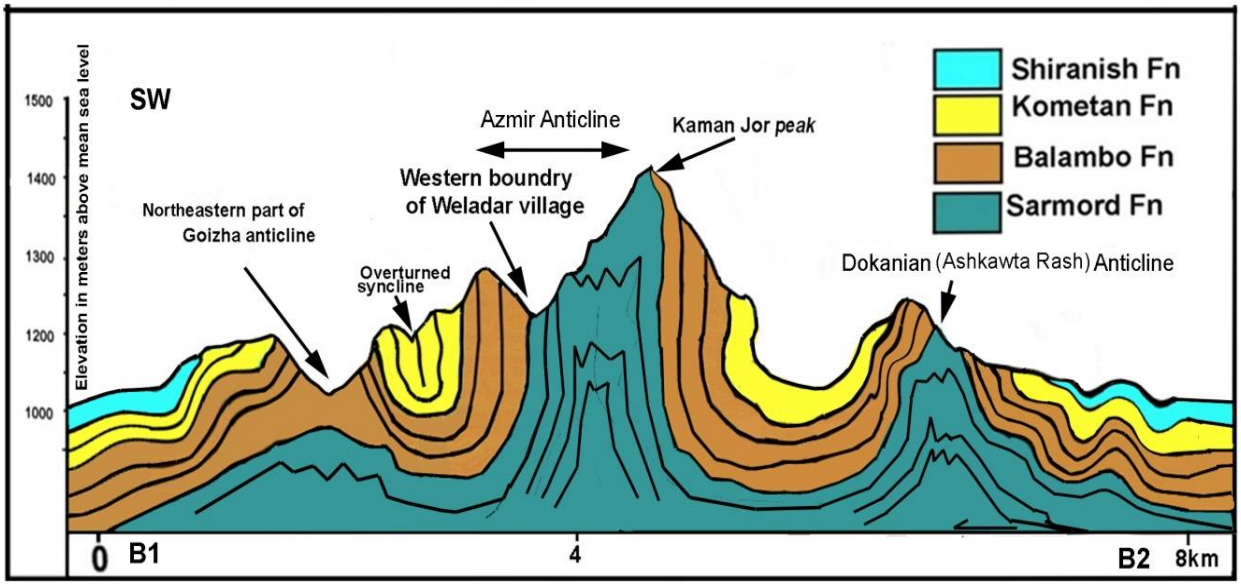

Fig.(3) Geological cross section of Azmir–Goizha anticline passing through Weladar village (See B1---B2 line in Fig.1), the minor deformations are not shown.

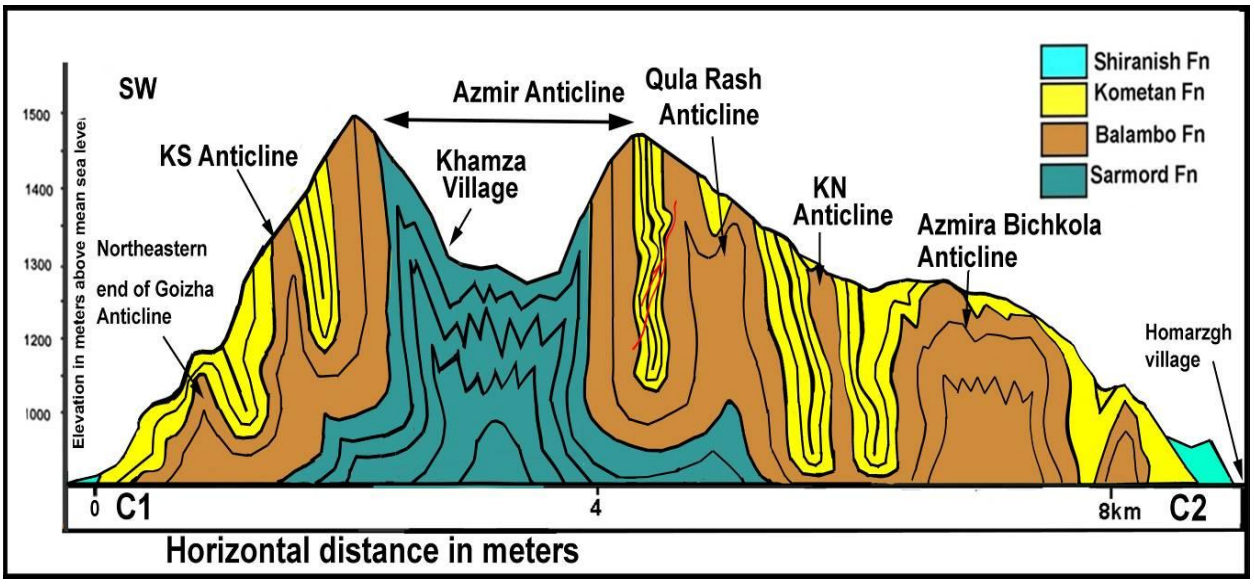

Fig.(4): Geological cross section of Azmir–Goizha anticline passing through Khamza village (See C1---C2 line in Fig.1), the minor deformations are not shown.

1-Azmir Anticline

It is the largest anticline in the studied area, it extends for about 91 km and its northwestern and southeastern plunges are located near to Dokan Town and Chanakhchian villages, respectively. The anticline has width of (1–4.5) km and has many local names along its length, from northwest to southeast, such as: Sara, Daban, Qayiwan, Azmir, Sarjor, Kharajyian anticlines (or mountains). According to Karim *et al.* (2013) [1], its core is occupied by Sarmord Formation, while Balambo and Kometan formations form the rocks of both limbs. Many smaller parasitic folds exist on the limbs; some of which are differentiated in this study (Figs.2, 3 and 4).

Al-Hakari (2011) [4] mentioned that the Azmir anticline is tight fold, but the measured attitudes and drawn cross sections, in the present study, shows that it is more or less close to isoclinal fold (Fig.2). This is because the dip angle of the limbs of the anticline is slightly variable. Locally, in some place, the anticline shows double vergen limbs and in others has isoclinal or close interlimb angles (Fig.2, 3 and 4). The mean attitudes of the northeastern and southwestern limbs are 326 /85^{O} and 145/87^{O}, respectively with the trend of the fold axis being 325 degrees. The recently acquired result does not confirm the "Anticlinorium", which was applied by Aziz and Lawa (2000) [10] and Al-Hakari (20011) [4], because the anticline is a normal one; in most places.

2-Azmira Bichkola Anticline

In the studied area, this anticline is about 1k wide and 3km long and extends outside the studied area (Fig.1). Due to dissection of the anticline by many streams (valleys), it forms three pyramidal hills which are more than 300 m high from the surrounding areas. Al-Hakari (2011) [4] mentioned that it is an open anticline and has been forked (separated) from Azmir anticlinorium and formed a surface anastomosing pattern of the folds. The present study has inferred that it is independent and nearly straight anticline and its southeastern

and northwestern plunges are located at the limits of Modern Sitak village and 1km to the southeast of the Mokaba Bridge, respectively, its total length is 9 km. The core of the anticline is occupied by Balambo Formation not Kometan Formation; as mentioned before (Figs.2, 3 and 4). The anticline consists (or modulated by) of more than two smaller anticline. Second-order folding and second-order conjugate faulting (Epard and Groshong, 1995, Fig.6) [13] are observed in some of small anticlines of the Azmira Bichkola Anticline. The mean attitudes of the northeastern and southwestern limbs are $320/40^{O}$ and $148/60^{O}$, respectively, with the trend of the fold axis being in 328^{O}.

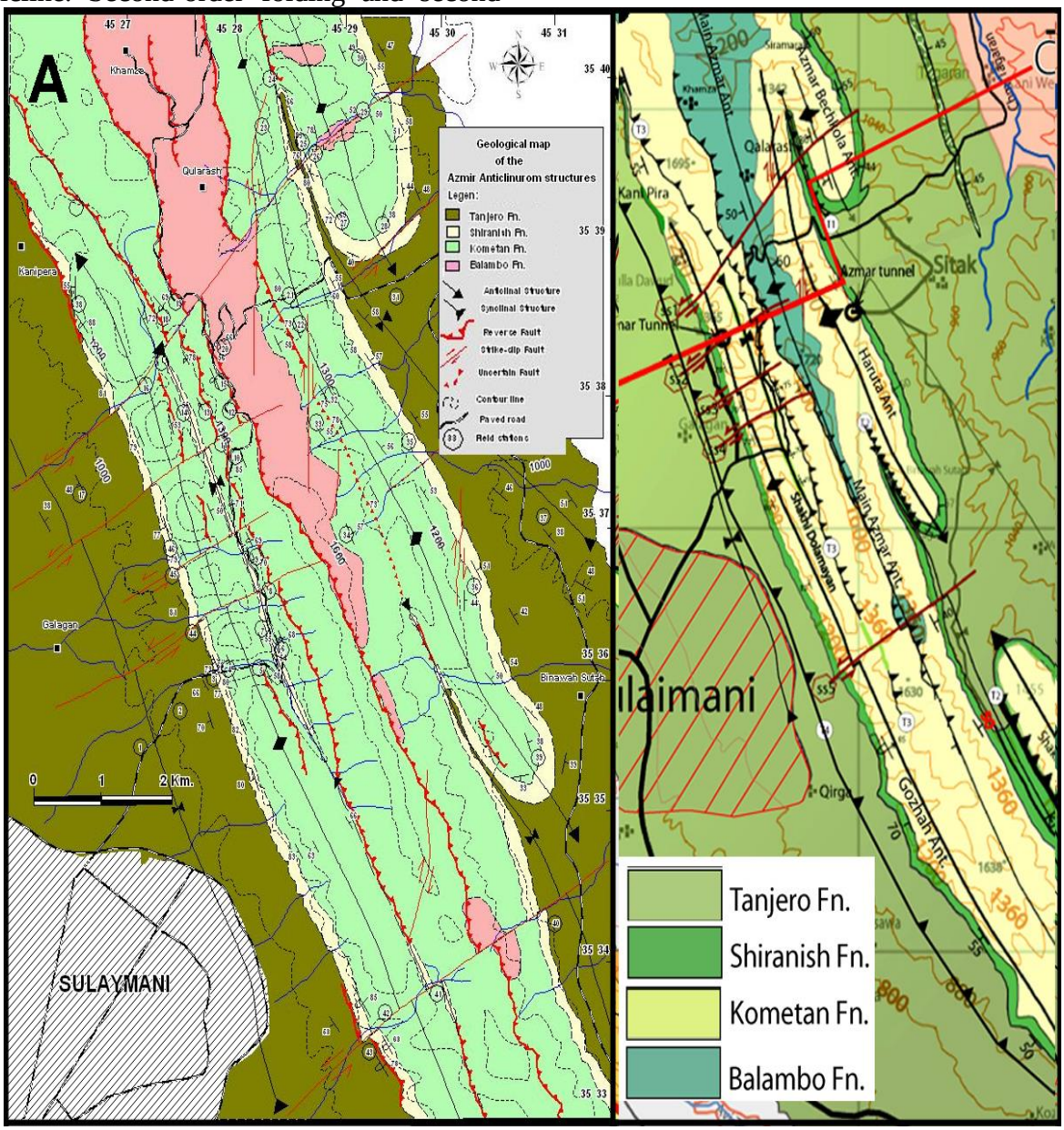

Fig. (5) Geological map of the studied area, A) Omer (2011) [3] and Al-Jumaily and Adeeb (2011) [2], B) Al-Hakari (2011) [4].

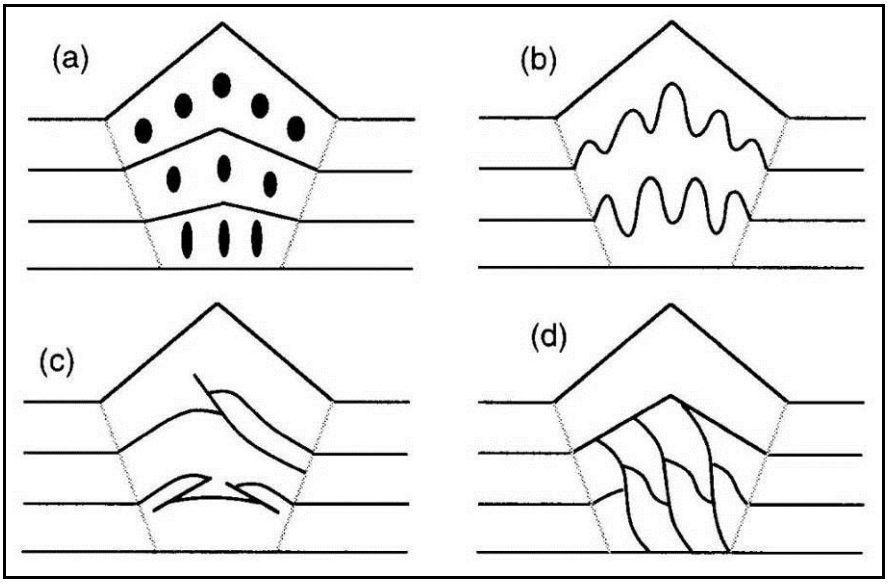

Fig.(6): Schematic detachment folds with alternative shortening accommodation mechanisms. (a) Homogeneous strain. (b) Second-order folding. (c) Second-order conjugate faulting. (d) Duplex. (Epard and Groshong, 1995) [13].

3- Qula Rash Anticline

This anticline is called Haruta anticline by Al-Hakari (2011) [4] while in the present study, the name is changed. This is because the Haruta Mountain from which the name is taken by the latter author constitutes the northeastern limb of Amir Anticline (Fig.1). The latter author has mentioned that Qula Rash (Haruta) anticline forks from Azmir anticlinorium and forms a surface anastomosing pattern of the fold. The present study has inferred that it is an independent and nearly straight anticline. Its northwestern plunge is located far outside the geographical extent of Azmir anticline, which extends from Sharsten village (its southeastern plunge) to near Gapelon village, where its northwestern plunge is located. On the road to Chwarta, the anticline has width of about 200 m, while it becomes 800 m northeast of Khamza village (Figs.2 and 7). Its core is occupied by Balambo Formation not Kometan Formation, as mentioned in previous studies. This anticline is associated with smaller anticlines, which are not included in this study. It is separated by wide and narrow synclines from Azmira Bichkola and Azmir anticlines, respectively. Inside the wide syncline, Shiranish Formation is exposed, while it is eroded inside the narrow one. In the southeastern part of the studied area, the Qula Rash anticline is a closed fold, while becomes isoclinal anticline towards the northwest; at 1km northwest of Khamza village (Figs.4 and 7). The attitudes of the limbs are changing from place to another, but the mean attitudes of the northeastern and southwestern limbs are $329/60^{O}$ and $146/75^{O}$, respectively with the trend fold axis being in 326^{O}.

Goizha (Maindol) Anticline

This anticline is facing over Sulaimani city from the northeast and its southeastern and northwestern plunges are located to the north of Arbat town and northeast of Kani Mekail village, respectively. It has the length and width of 29 km and 500 m, respectively. At North of Sulaimani city, it is dissected (by streams) into four typical pyramidal hills;

known as Naugirdan Hills (Fig. 1). To the east of Sulaimani City, between Kazjwa modern village and Arbat town, the Goizha anticline has weak geomprphological expression on the surface; due to erosion and intense deformation. However, it is can be easily identified in the valleys between the modern village and the town. Its core is occupied by Balambo Formation which is exposed in the consequent valleys that are looking over the Ibrahim Ahmad neighborhood (eastern part of Sulaimani city) (Figs.8, 9 and 10). The core is deformed to accommodate shortening mechanism in the form of homogeneous strain folding and second-order folding (Fig.9 and 10). The mean attitudes of the northeastern and southwestern limbs are 322/57^{O} and 144/ 75^{O}, respectively with the trend of the fold axis being in 325^{O} (Fig.9).

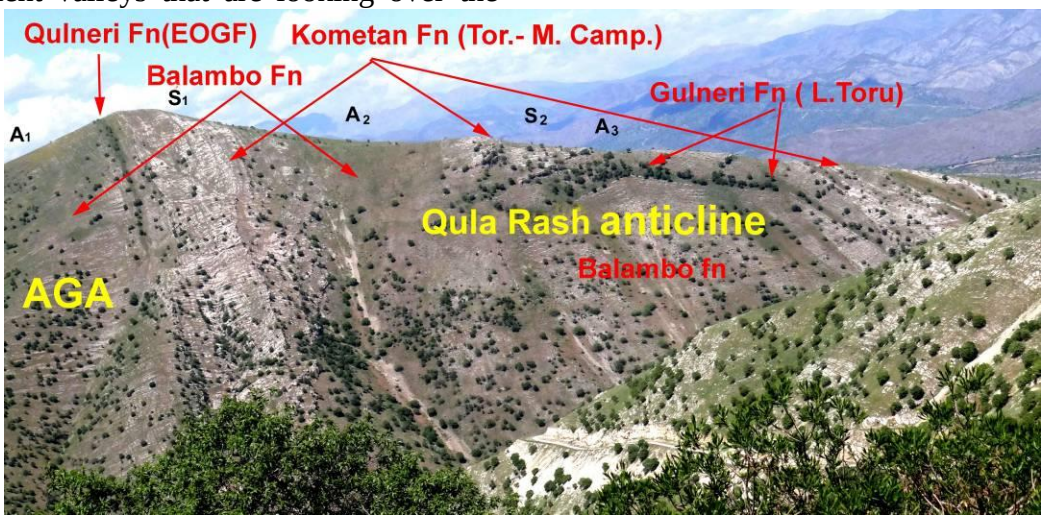

Fig. (7): Structures at the northeast of Khamza village, A_1) Azmir anticlines, A_2)KS anticline, A_3)Qula Rash anticline, S_1andS_2 are two complementary synclines

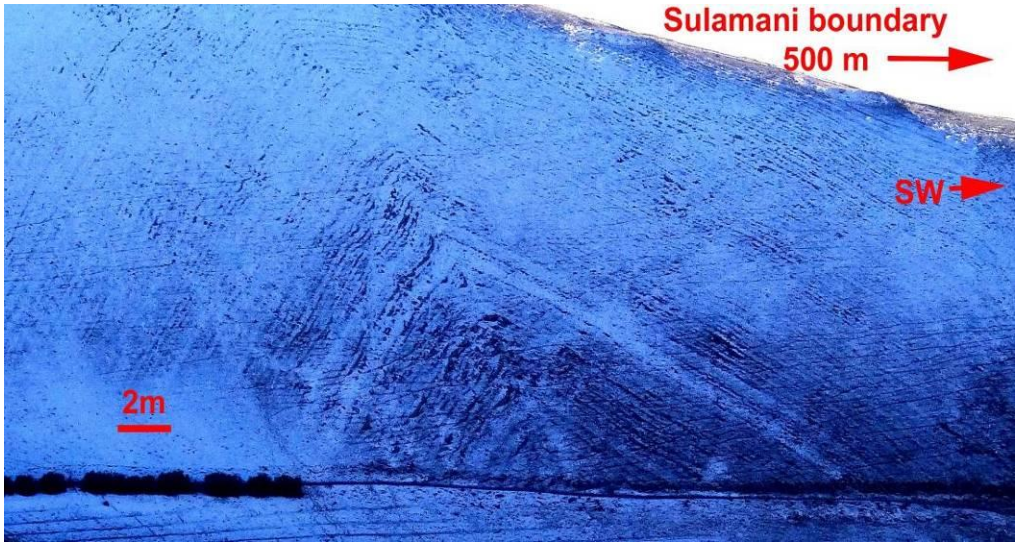

Fig. (8): Goizha anticlines 500m east of Kazywa Modern village show northwest vergen, the photo is taken after snow fall.

Fig. (9): Anticlines and synclines in the core of Goizha anticline (Balambo Formation), at two kms north of Sulaimani City, on the paved road between the Azmir tunnel and Kurdsat TV center on the eastern side of the paved road.

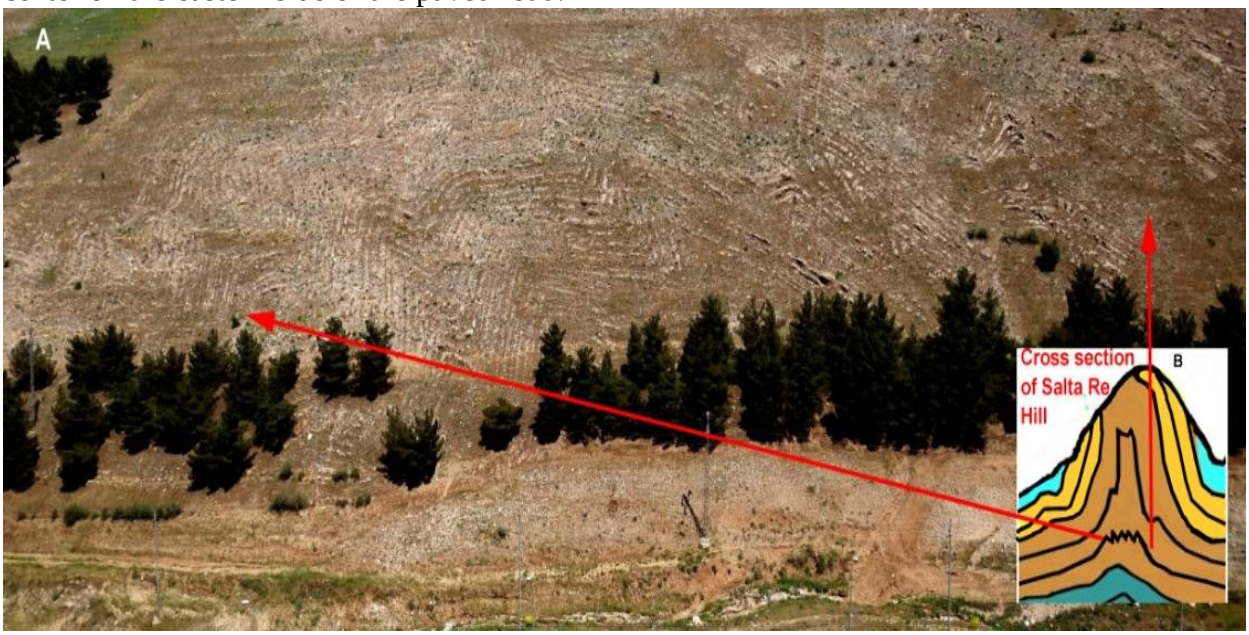

Fig. (10): Disharmonic folding in the intensely deformed core of the first Naugirdan hill (Salta Re hill), B) cross section of the hill with competent beds of Kometan and Balambo (its upper par) formations (orange) and incompetent (core materials, brown) lower part of Balambo Formation (see figure 2 for legend)

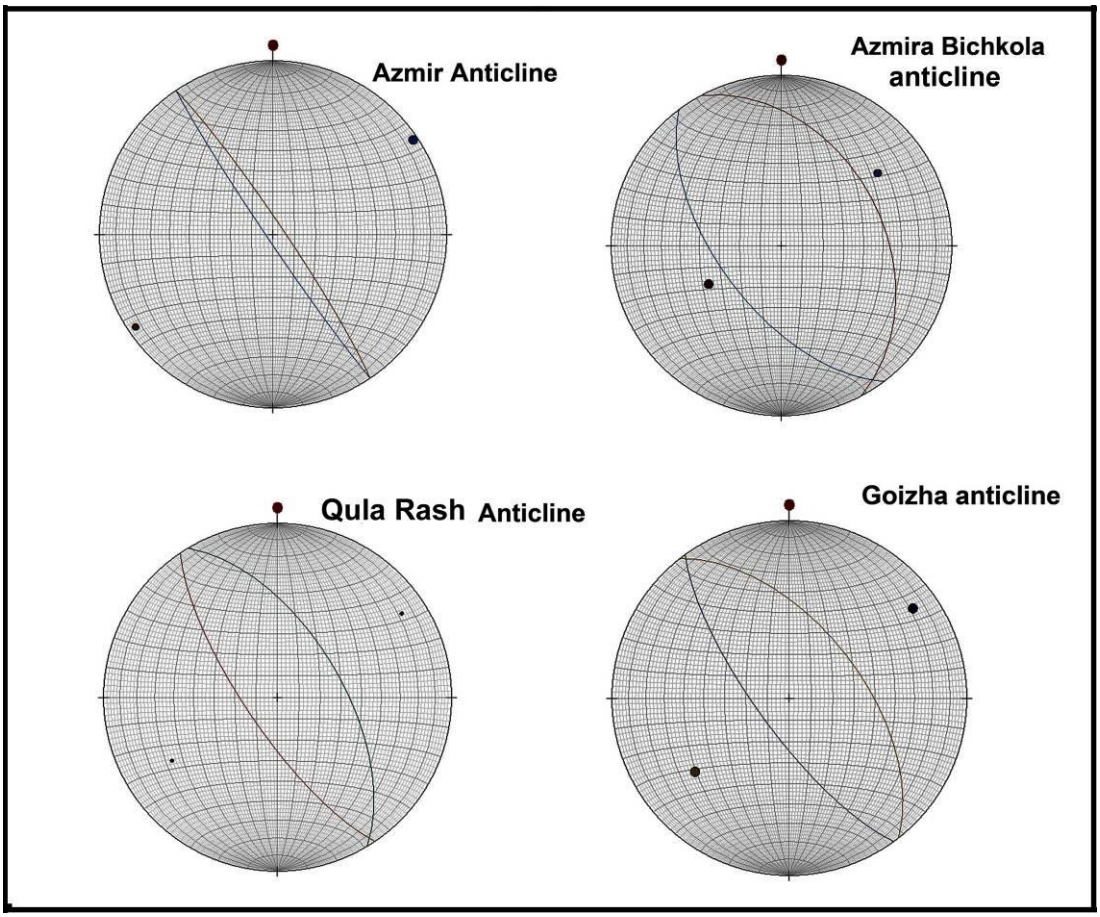

Fig. (11): Stereonet of the studied four anticlines**.**

Piggy-back Imbricate Thrust Fan versus Detachment Folds

The definition of the of the imbricate fan (as cited in web sites) is "a series of splay faults branching off and ramping sequentially out of the main, deeper floor décollement surface, which spreads the displacement over a large volume of rock. The junction line where the main thrust fault splits into two smaller thrust surfaces is a branch line. The branch points at the floor of an imbricate fan, where two thrusts separate toward the foreland, are called trailing branch points. The merging points of two thrusts joining into one as they are traced toward the foreland are called leading branch points. The youngest splay is the front thrust in a leading fan. In that case, the youngest splay carries the older one "on its back", which is called piggy-backing" (**https:// courses.eas.ualberta.ca/eas421/lecturepages /thrust.html.**

Goodarzi (2007) [14] gave the following description for the detachment fold "According to most authors, a prerequisite condition for the generation of detachment folds is the existence of a high competency contrast between the sedimentary units involved in the folding process. The simplest model therefore consists of a basal incompetent layer acting as a detachment zone, such as salt, overlain by a thick competent unit such as carbonates or sandstones. The basal unit responds in a ductile manner to fold growth, with migration of ductile material towards the core of the anticlines causing down warp of the adjacent synclines. The structure will develop more or

less symmetrically depending on the viscosity of the basal detachment: in areas such as Zagros characterized by ductile detachment horizons (Davis, 1985) [15] ".

Oveisi, et al. (2009) [16] mentioned that the detachment folds do not develop at the tip of a propagating ramp, but above the tip of a sub-horizontal detachment at depth. For detachment folds, limb rotation will produce progressive surface tilting, long and gently dipping panels and maximum uplift at the anticlinal crest. He added that the limited width (6 –7 km) of the Madar anticline, as compared to the Mand anticline (>16 km), suggests that the detachment is much shallower here than the depth of Hormuz Salt and possibly corresponds to the relatively ductile Gachsaran Formation (~2 km deep).

The detachment fold is defined by Epard and Groshong (1995) [13] as a fold that is formed above a stratigraphically fixed detachment horizon and without thinning in the syncline. They added that, in general, it requires layer-parallel shortening and a fold grows primarily by limb rotation, not by limb lengthening at constant dip. it needs homogeneous strain or second-order folding or Second-order conjugate faulting or Duplex for accommodating the shortening (Fig.6)

Ibrahim (2009) [9] in his detailed study of the Zagros Belt assigned the growth of Azmir Anticline to be during Paleocene and later ages, as thrust sheet, which was disconnected from below in the Lower Jurassic. He assigned Chemchamal and the Bawanoor anticlines (in the Low Folds Zone) as detachment fold. He added that both are broad, symmetrical anticlines, formed due to the movement of the Upper Fars, Lower Bakhtiari and Upper Bakhtiari formations on the Lower Fars detachment surface; during Pliocene.

Shaw *et al*. (2005) [17] stated that it is contractional anticlines which are formed above one or more basal detachments. They gave the following facts about detachment folds: **1)** Ductile thickening in the core of the fold (Fig.12), which may be governed by distributed brittle deformation or flow, causes amplification of the fold and with no visible thrust ramp. **2)** Detachment anticlines grow by limb rotation, often with some lesser component of kink band migration.

According to Fossen (2010) [18], in detachment folds, the slip is solely along the layering and form where the layers above a detachment are shorten more than their substrate and it is commonly found to be undeformed. Detachment folds tend to develop above very weak layers, such as over pressured shales or evaporates, typically concentric folds. He added that the folds formed by buckling and the weak layer flows (deforms) to accommodate the geometric difference between the flat decollement surface and the folded layers above. He further added that the detachment folds are generally upright and parallel (constant layer thickness), sometimes with box fold geometry and oppositely dipping axial surfaces. A strong viscosity contrast between the folded layer and its surroundings promotes the formation of a series of buckle folds (a fold train).

Ibrahim (2009, p.107) [9] included the Azmir – Goizha anticline in the Imbricate Zone and he assigned this zone as a piggy–back imbricate stack. Later on, Al-Hakari (2011) [4] interpreted Azmir anticlinorium (present Azmir– Goizha anticline) as piggy-back imbricate fan that consists of four emergent folds, which are superimposed over each other by adjacent listric faults and may be banded together at depth with the blind foreland vergen listric thrust faults (T1, T2, T3, and TB in Fig.13) as basal detachment fault. He added that the basal detachment fault is considered to be in the Lower Jurassic formations and Upper Triassic (Baluti Fn.).

He further added that a listric thrust fault, which emerges southwest of Goizha anticline; represents the High Zagros Reverse Fault (T4). Al-Jumaily and Adeeb (2011) [2] emphasized the role of faulting in development of the Azmir anticline (representing the four anticlines of Al-Hakari, 2011) [4] and other minor folds and concluded that they are imbricated fan (Fig.13 and 14).

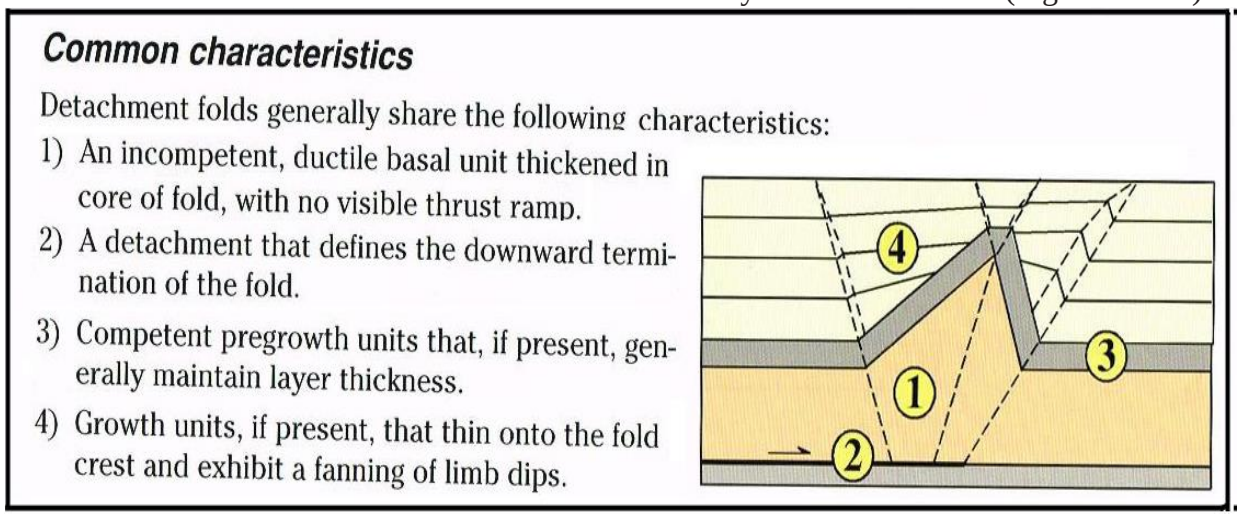

Fig.(12): Characteristic (A), and forms (B) of detachment folds (Shaw *et al*., 2005) [17] which can be applied, more or less, on the Azmir–Goizha anticline.

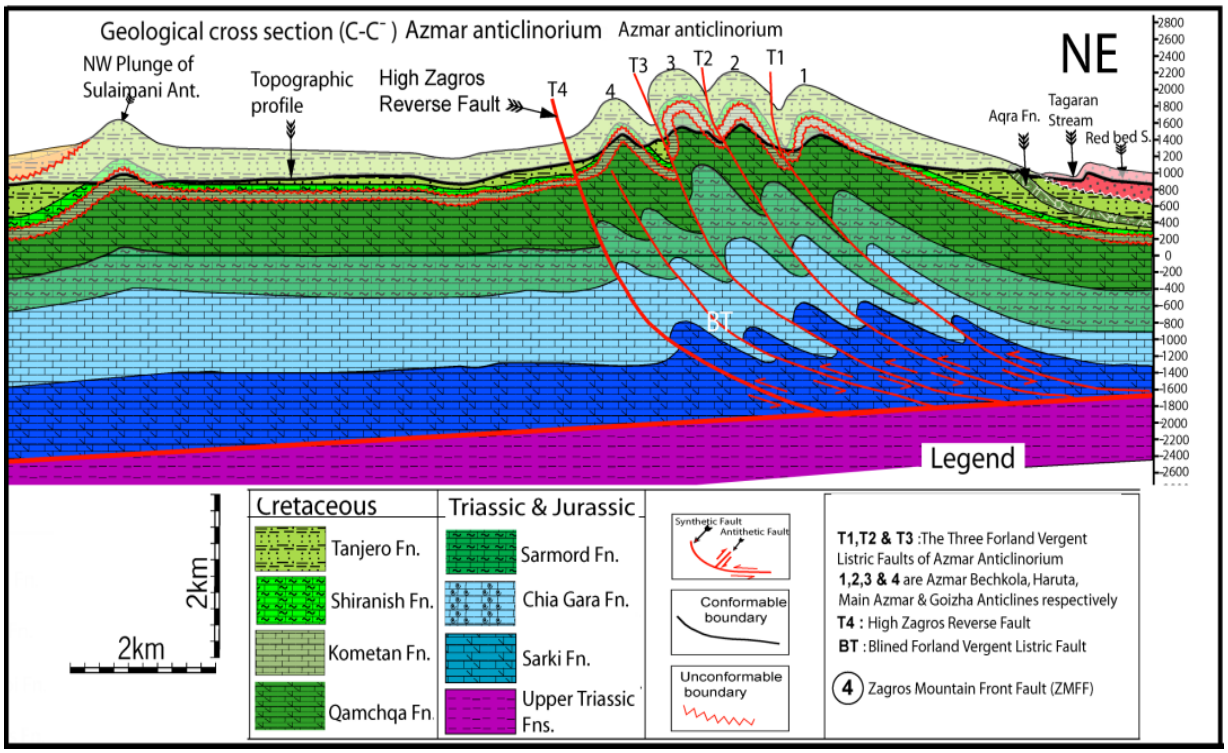

Fig.(13): Five reverse faults that are associated with piggy-back imbricate fan as the structure of Azmir – Goizha anticline (Al-Hakari, 2011) [4.], which are not found in the present study.

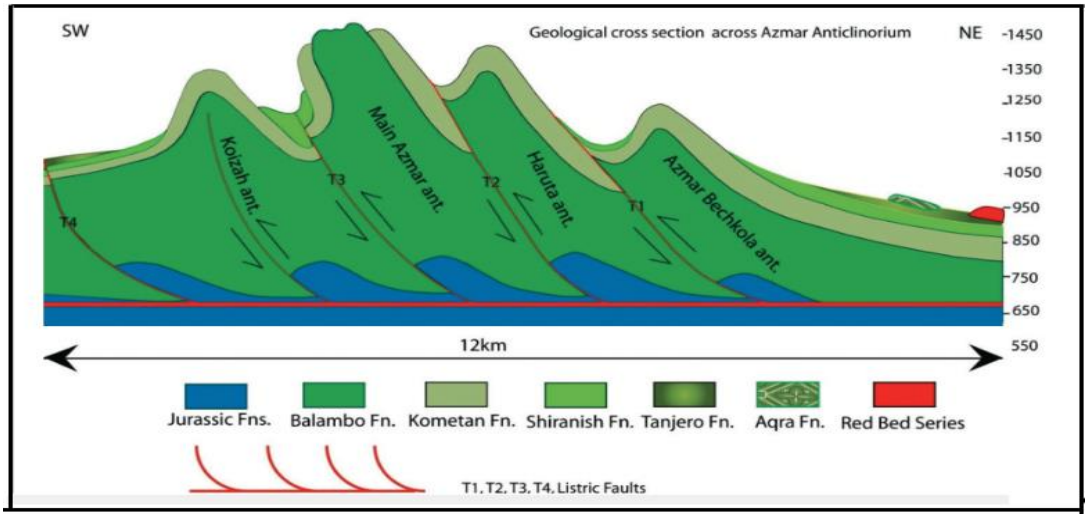

Fig.(14): Five reverse faults shaped Azmir – Goizha anticline as Imbricate fan (Al-Hakari, 2011 in Al-Jumaily and Adeeb, 2011) [2], which are not found in the present study.

Azmir – Goizha Anticline as Detachment Fold

When the above definitions and characteristics of the piggy-back imbricate fan and detachment fold are applied on the Azmir–Goizha anticline, it appears that it belongs to the latter type due to the following characteristics of the anticline.

1-The core of the anticline is occupied by intensely deformed incompetent rocks (marl and marly limestone of Sarmord Formation) and this core contains series of buckle fold, which is disharmonic with outer layers of the fold (Kometan and upper part of Balambo Formation) (Fig.2, 8, 9 and 10).

2-In the exposed core of the Azmir, Azmira Bichkola and Naugiran anticlines, there are no fault bend or fault propagation folds (Fig.13). In one case it shows Second-order conjugate faulting (Fig.14), which according to Epard and Groshong (1995) [13] is formed, due to accommodation of shortening of detachment fold (Fig. 6c).

3- According to Mitra (2003[19]), the detachment folds are generally more symmetric than other fold forms in fold belts, particularly in the early stages of evolution. Unlike fault-bend and fault propagation folds, they commonly display opposite vergen both across and along fold trends (Figs. 2, 3, 4 and 8). Faulting is usually secondary and occurs primarily to accommodate variations in strain with structural and stratigraphic position. The progression of the detachment fold evolution is generally considered to involve a thrusting through the forelimb with increasing shortening (Fig.16). Azmir–Goizha anticline has all these characteristics as shown in the aforementioned five figures

4- In detachment fold, the tightness of the fold increases downwards this coincides with all folds of the studied area (Figs.13, 16, 18 and 19).

5- In Zagros Fault – Thrust Belt, many authors (Verges *et al*., 2011[20], Yamato, *et al*., 2011[21], Oveisi, *et al*., 2009[16], Sherkati *et al.*, 2005 [22], Davis, 1985[15], and Goodarezi, 2007) [14] have described detachment folds. The last author mentioned that in Zagros Fault – Thrust Belt, depending on the level of erosion, very different fold geometries can be observed at surface. Close to the lower detachment, tight anticlines can be observed, with potential internal disharmonic folding, separated by broad

gentle synclines, while towards the upper detachment, tight synclines and broad anticlines can be seen.

6- Multi-detachment fold or multi-detachment faulted fold (Mitra, 2003, fig.17) [19] is the most suitable type of detachment fold for Azmir–Goizha anticline. This is attributed to the different performance of Balambo (its lower part), Sarmord, Chia Gara and Jurassic formations as multi-detachment for either faulted or unfaulted detachment folds (Figs.2, 3 and 4). Lift-off detachment fold (Shaw et al. 2005) [17] is generally fit some fold in the studied area.

The Triassic decollement as the only surface of detachment, as indicated by Al-Hakari (2011) [4] is not a proved in present study. This is because Karim and Sulaiman (2012) [23] found shallow lateral thrust faults in Aqra Formation, 20 km to the north of the studied area. This is true for the presence of shallow ophiolite thrust sheet (seer cross section of Al-Mehaidi, 1975) [24] at 15 km to the northeast of the anticline.

7-During the fieldwork, the piggyback structure was not found, because there are no thrust sheet in the studied area; as can be seen from the geologic map and related cross sections (Figs.1, 2, 3 and 4). Piggyback structure is defined as carrying of early thrust sheets in 'piggyback' fashion on younger thrusts. In the studied area, there are some small thrust faults with small extent and they exist in the scale of (5 to 20) m, and they directed towards both foreland and hinterland (see next section).

8-The indication of Chemchamal and Bawanoor anticlines (in the Low Folds Zone) as detachment fold by Ibrahim (2009) [9] proves that the Azmir – Goizha anticline is detachment fold. In this connection, Hessami *et al*. (2001) [25], had mentioned that the deformation front started as early as the end of Eocene in the northeast of the Simply Folded Zone, and propagated progressively to the southwest, where unconformable contacts can only observed between younger units.

Therefore, the progressive folding and deformation is true for the whole Zagros area by means of which simple detachment fold of AGA is complicated due to increase of compression and shortening during the time.

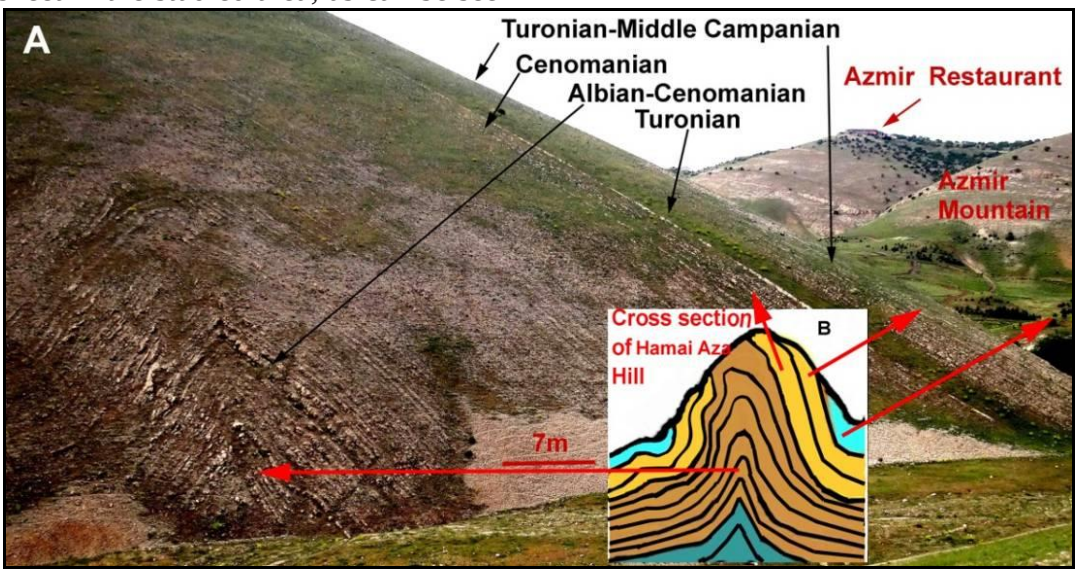

Fig.(15): A) Symmetrical fold in the core of the forth (Hamai Aza) hill of Naugirdan anticline (only northeastern part is shown) in which the tightness increases downwards, B) Complete cross section of the same hill show competent (orange) and incompetent (brown) rocks

Fig.(16): Second-order conjugate faulting formed due to accommodation of shortening of detachment fold in Balambo Formation in the core of the second hill of Azmira Bichkola anticline.

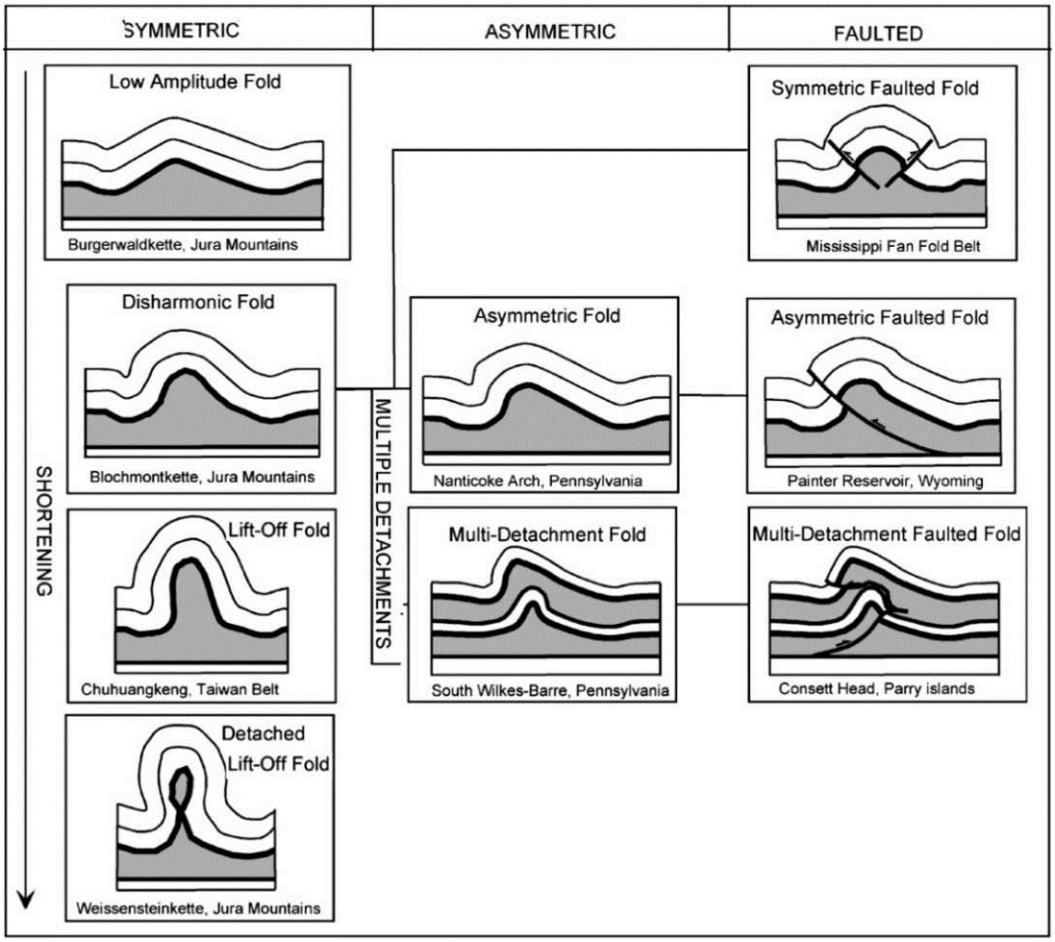

Fig.(17): Variations in structural styles of detachment folds related to magnitude of shortening, asymmetry, faulting, and the occurrence of multiple detachments with an example for each type of structure (Mitra,2003) [19].

Fig.(18): Detachment chevron asymmetrical folds in Balambo Formation inside the core of Azmir anticline, 1 km north of Khamza village and 15 km to the northeast of Sulaimani City. It can be observed that there are no faulting and the tightening of the folds increases downwards

Fig.(19): Small (at the left) and large anticlines, with northeast vergence inside Little Qayiwan Village, within the Sarmord Formation

Small Faults in the Studied Area

As aforementioned, the studied area includes some small thrust and normal faults, with small extent along the strike and the dip. They exist in the scale of (5 to 20) m and they are directed towards both foreland and hinterland (Figs.20 and 21).

Ali (2008, p.122) [26] has indicated two local thrust faults that cut the crest and southeastern limb of Goizha anticline (Fig.22). Al-Hakari (2011) [4] described Domino like blocks of the normal faults in the northeastern limb of Qula Rash anticline with strike of NW – SE (Fig.23). He added that such stretching in NE – SW direction might have been dominated during the uplifting stage of the major fold. The same faults are found by Al-Jumaily and Adeeb (2011) [2] at the northeastern limb of the main Azmir anticline and described them as a series of step-like minor normal faults in the limestone beds of the Kometan Formation.

In the present study, these faults are re-examined and the following are inferred:

1-The faults are neither located in the northeastern limb of Qula Rash anticline nor in the northeastern limb of the main Azmir anticline, but they are located in the southwestern limb of the Dry Dam (Wshka Bandaw) anticline, which is located between Azmir and Qula Rash anticlines (Fig. 2).

2- The domino like normal faults was not found, because there are not displacements along the adjacent blocks, they were found to be a set of joints**.**

3-The gaps at the base of the blocks are not rotational gaps, but they are wedges of scree or accumulated soil at the base of the slopes (Fig.23).

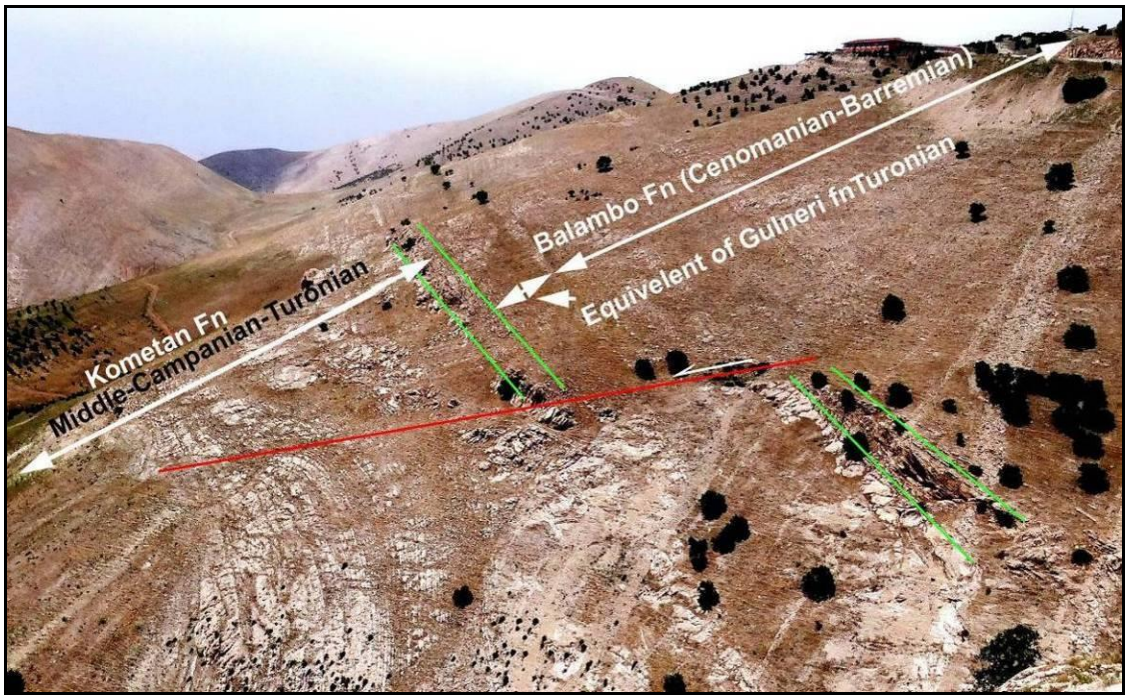

Fig. (20): Normal fault at 500 m downstream of Ali Agha Bridge, southeastern limb of Azmir Anticline

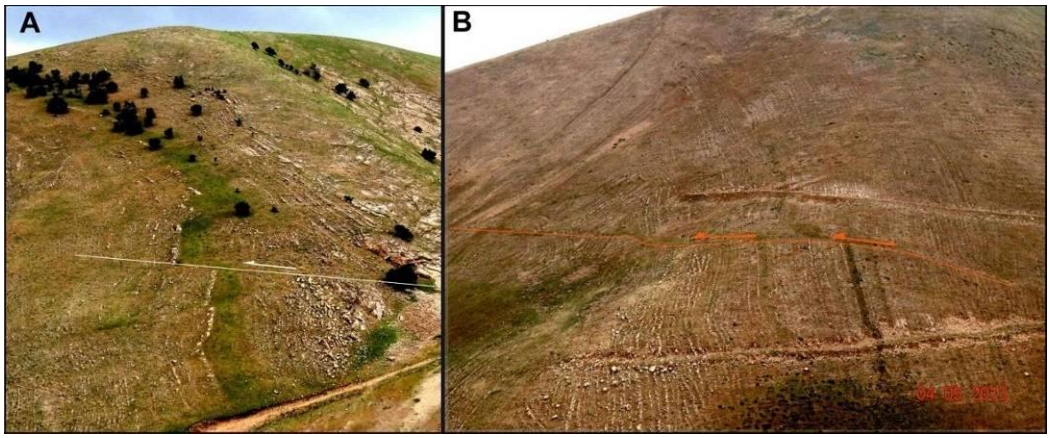

Fig.(21): The only faults that can be observed in the studied area are small thrust faults that have displacement not more than 25m, A) Hamai Aza hill, B) Kaziwa Valley.

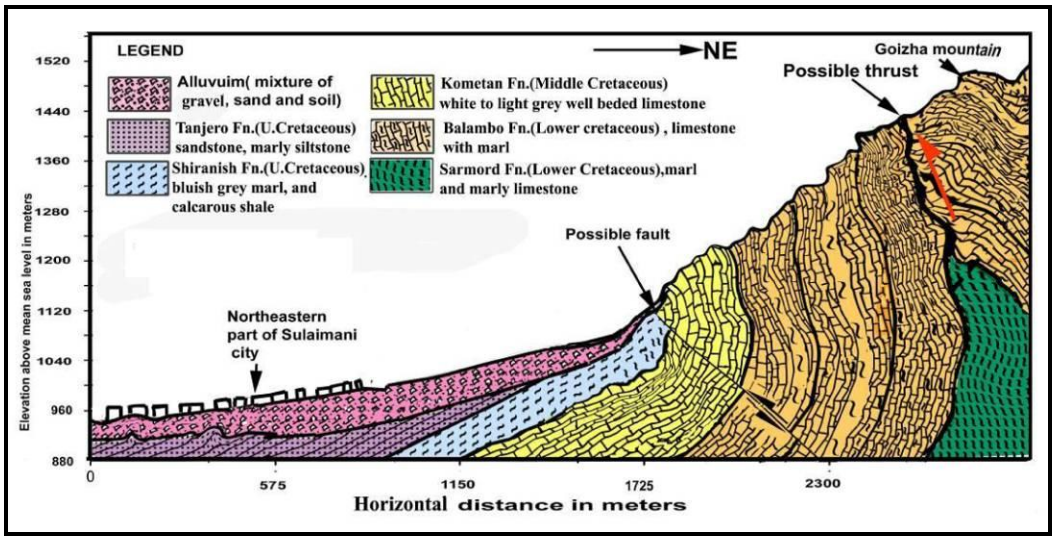

Fig.(22): Faults that were indicated by Ali (2008) [26] in the southwestern limb of Goizha anticline

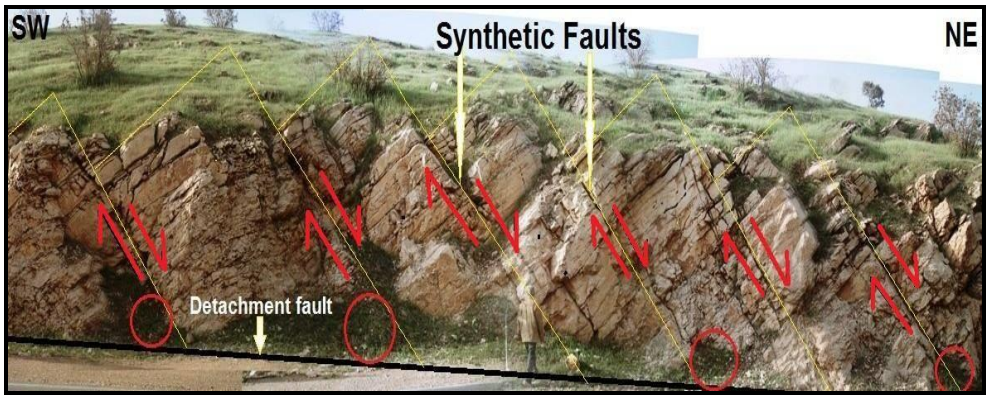

Fig. (23): A set of domino like blocks in the southwestern limb of Qula Rash anticline.

These faults have rotated the blocks, the small gaps (red circles) occur below the synthetic fault blocks (Al-Hakari, 2011) [4]. They are considered as joints in the present study.

Imbricated versus High Folded Zones

Many authors (Buday, 1980[27]; Karim, 2004a [6]; Jassim and Buday, 2006 in Jassim and Goff, 2006[12] and Al-Qayim *et al*., 2012) [28] indicated that the study area lies in the boundary between the High Folded and Imbricate Zones. Recent studies (Ibrahim, 2009; Al-Hakari, 2011[4]; Omer, 2011[3]; and Al- Jumaily and Adeeb, 2011[2]) had assigned the studied area as imbricate fan, which means that the studied area is part of the Imbricate Zone. Lawa *et al.* (2013, p.79) [29] have clearly indicated that Azmir – Goizha anticline is within the Imbricate Zone (or Zagros Imbricate Zone), as they put its southern boundary to the south of the anticline. In the present study, no sign of imbrication was found; as it appeared from Figs. (2, 3 and 4). Therefore, it is better to consider the Azmir – Goizha anticline within the High Folded Zone instead of the Imbricate Zone. This is agreeing with the geologic cross section of the studied area that is drawn by Karim, (2004b) [30] and shows no clear imbrications (Fig. 24).

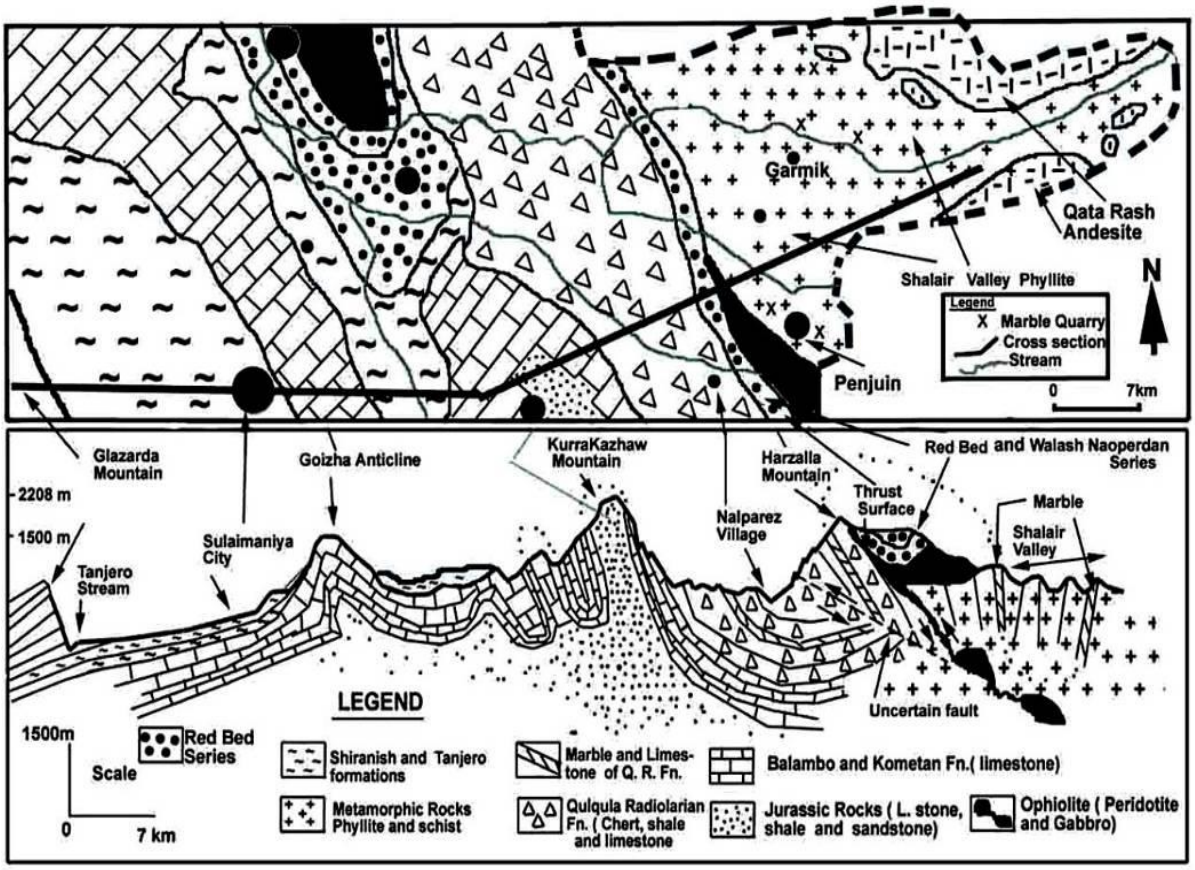

Fig. (24): A geologic cross section passing through studied area (Goizha anticline) that is drawn by Karim, (2004b) [30] and shows only overturned anticlines with no clear imbrications.

Large Faults in the Studied Area

Many sinistral strike-slip faults were detected within Azmir anticlinorium with trend of NE – SW and labeled as (ss1, ss2, ss3, ss4, and ss5) by Al-Hakari (2011) [4] and Omer (2011) [3], the displacement along these faults ranges between (50 – 70) m, as measured from the horizontal displacement in the lithology. All the five strike-slip faults that are drawn and found by the latter two authors were not found in the present study, as can be seen from the axis of the anticlines in the geological map of the area (Fig.1). On the map, it is clear that there is neither transversal shift in the elongation of the outcrops nor in the axes of the three anticlines (Fig.1). Moreover, the locations of these faults are checked in the outcrops, in the field and lateral shifts were not found too (Figs. 25 and 26).

The same thing is true for the five thrusts (or reverse) faults that are found and drawn in the Figures (5, 13 and 14) by the mentioned last two authors. The shortening by folding, which is calculated for the formation, previously must be checked again due to result of the present study, which modified the geological map of the study area and introduced new formations. The present study expects that most of the shortening of Kometan and Balambo formations had occurred due to softness of the underlying Sarmord Formation not Triassic formations. The Gulneri Formation, as soft rocks, acted as local detachment surface for the shortening of the Kometan Formation.

The High Zagros Reverse Fault that is drawn by Ibrahim (2009) [9] and Al-Hakari (2011) [4] is not found too in the studied area, which is supposed to be located in the northern and northeastern limits of Sulaimanyia city beneath the modern villages, such German, Kaziwa and Barzayiakani Azmir in addition to Kurdsat Satellite TV center. Al-Qayim *et al.* (2012, p.112) [29] have indicated the fault near the crest of the Azmir anticline. About this fault, the above three authors have cited, respectively the following three paragraphs:

1)"It is a NW – SE trending longitudinal listric fault (transformed into reversed displacement), which separates the Zagros Imbricate Zone from the High Folds Zone of the Zagros Foreland Folds Zone. It is considered as a deep basement fault in Iran because along it, in various places, the Hormuz Salt intrudes and reaches the surface (Mobasher, 2007) [31] and there is some seismic activity with strike slip focal mechanism solutions (Aziz Zadeh, 1997) [32]. The HZRF is an active fault since the Permian and to the Recent (Bahroudi and Talbot, 2003) [33]. It is a 65°NE dipping active major forethrust fault, which is expressed on the surface as a Balambo and Azmir anticlines. The more competent Balambo and Kometan formations were thrusted along the HZRF over the low elevated incompetent rocks (Shiranish and Tanjero formations). The HZRF has been displaced dextrally in the Halabja–Said Sadiq area due to the effect of the dextral strike slips N–S trending Khanaqin Fault".

2)"This is a NW – SE trending longitudinal listric fault, which separates the Zagros Imbricate Zone from the High Folded Zone of the Zagros Foreland Fold – Thrust Belt. It is considered as a deep basement active fault since the Permian to the Recent (Bahroudi and Talbot, 2003) [33]. The more competent Balambo and Kometan formations were thrusted along the fault over the low elevated incompetent rocks (Shiranish and Tanjero formations). The fault extended from southwest of Goizah anticline passing through the overlapping area between main Azmar and Surdash anticlines to the NNW".

3)"The NW-trending "High Zagros Reverse Fault" separates the Zagros Imbricate Zone

from the Zagros Folded Zone. It is interpreted as a deep basement fault in Iran because it is associated with outcrops of Hormuz salt intrusions (Mobasher and Babaie, 2007) [34], and there is some seismic activity with strike-slip focal mechanism solutions (Aziz Zadeh, 1997) [32]. The fault has been active since Permian time (Bahroudi and Talbot, 2003) [33]. In northeast Iraq, it dips 65°NE-and is clearly expressed on the surface as an axial fault along the Balambo and Azmur anticlines (Ibrahim, 2009). The more competent Balambo and Kometan formations were thrusted along the fault over the low-elevated incompetent rocks of the Shiranish and Tanjero formations. The fault has been displaced dextrally as in the Halabja–Said Sadiq area due to the effect of the dextral strike-slip NS trending longitudinal faults (Ibrahim, 2009) [9]".

Another large fault is the Khanaqin strike-slip fault (Ibrahim,2009, p.149) [9] or Khanaqin longitudinal fault (Al-Qayim *et al.*, 2012) [29], which, according to former auther, it trends towards south at 3 km and 12km to the east of Chwarta town and Sulaimani city, respecticly (Fig.27). If this trend is true, it must passes near the southeastern end of the studied area where the Lower (Sarmord and Balambo formations) and Upper (Kometan and Gulneri formations) Cretaceous rocks are croping out. Neither Upper nor Lower Cretaceous outcrps show the expression of this fault. Karim (2004b) [30] studied a normal fault that passes nearly 5 km to the east of Chwarta town, but it does not reach the studied area and terminates near the northwestern plunge of the Ashkawta Rash (Dokanian) anticline. This normal fault has the expresion in the outcrops of Early and Late Cretaceous rocks.

Fig.(25): The valley between 3rd and 4th Naugirdan hills, where previouslyis mentioned to be a site of sinistral strike-slip fault, but no fault is fond in the presnt study (The photo looks SW)

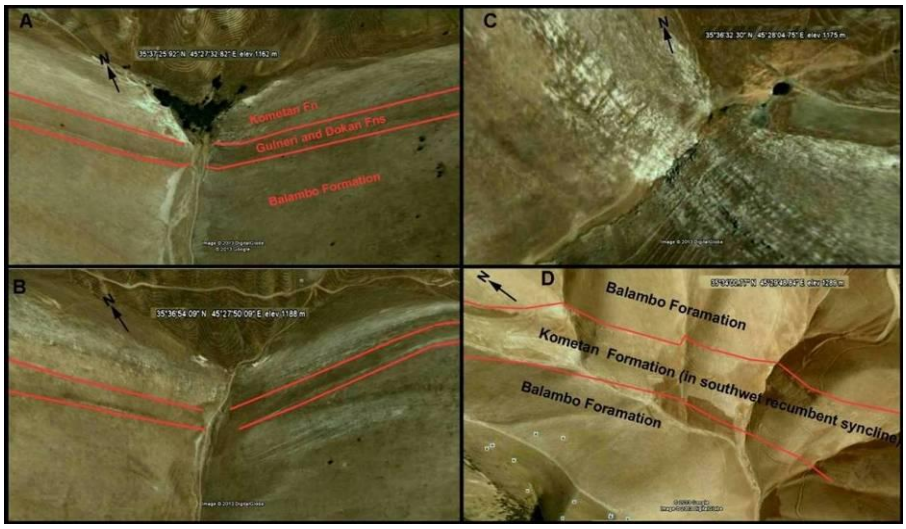

Fig.(26): The location of the ss4, ss2 ss3, and ss5 sinistral strike faults of Omer (2011) [3] and Al-Hakari, (2011) [4] (see Fig. 2 which shown on Google earth images. These faults are not found in the present study shown in the A, B, C and D images.

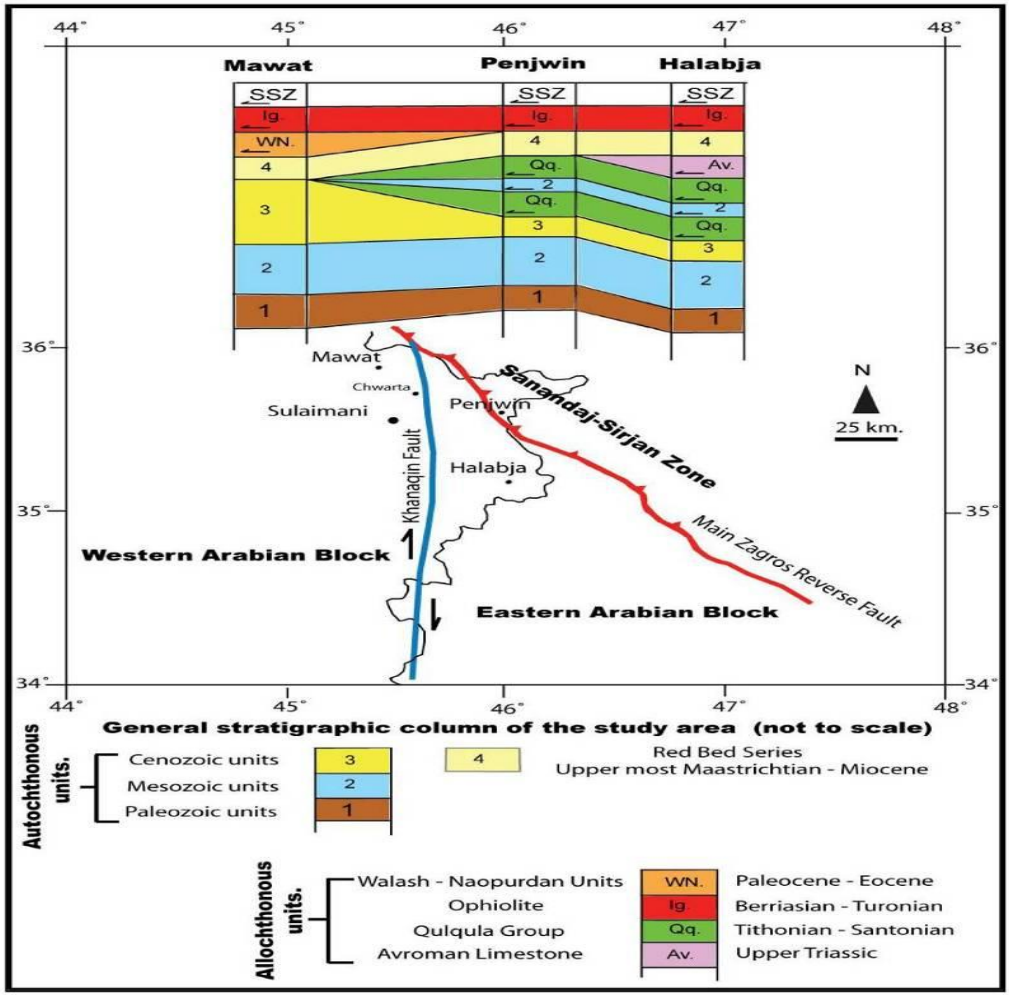

Fig. (27): Location of the Khanaqin fault (Ibrahim, 2009) [9]

Conclusions

This study has the following conclusions:

1-The core of the Azmir anticline is occupied by Sarmord formation not Balambo Formation, as mentioned in all previous works.

2-The previously indicated piggy-back imbricate fan of Azmir–Goizha anticline is found to be a multi-detachment fold.

3- The five strike-slip faults that are indicated in the previous works were proved in this study not to exist. This is true too for the five thrust (or reverse) faults that are indicated in the previous studies.

4- Domino like synthetic fault blocks, which were proved in the previous works were proved to be joints, not faults.

5- The main Azmir anticline is isoclinal fold, while the other three smaller ones are close folds.

6- Many small thrust and normal faults were found, but all are of small scale; not more than tens of meters in their extent and did not coincide with previous ones.

7-It is more relevant to consider the Azmir–Goizha anticline within the High Folded Zone rather than within the Imbricate Zone, as no imbrications were found in this study.

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