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# SOME STRUCTURAL CHARACTERISTICS OF AZMAR ANTICLINE - NE IRAQ

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ABSTRACT.- The purpose of this study is to elucidate the structural style of Azmar structure, a major anticlinorium within the imbricate partition of Zagros fold-thrust belt in northeastern Iraq. Structural analysis of this anticlinorium demonstrated that it consists of four main NNW-SSE trending anticlines. They are imbricated SW ward through NE dipping reverse faults merge to a deep seated detachment. Furthermore, analysis of minor folds on hinge and limbs of the main Azmar anticline revealed the versatile style of such minor folds and their opposing vergencies. These features emphasize the role of faulting in development of the major fold and the minor folds. This interpretation has been supported by hinge angularity, as well as by association of hinge and limb disrupting reverse slip mesofaults with those minor folds. Therefore a progressive fault related folding is proposed for Azmar structure in this work.

Key words: Azmar Anticline, tectonic, thrus belt, Iraq

## INTRODUCTION

Tectonically, the study area belongs to the Zagros orogenic belt. The Zagros belt developed along the oblique collisional suture zone between the NE Arabian margin and Eurasia. It is linked toward the northwest to the Bitlis suture zone, which separates the Arabian and Anatolian plates. To the southeast, the convergence movement is still accommodated by the northward oceanic subduction beneath the Makran accretionary prism (Alavi, 2004) (Figure 1).

Azmar anticlinorium is situated within the Zagros Imbricate Zone. To the northeast this zone is sutured with Sanandaj-Sirjan Zone along the Main Zagros Reverse Fault. To the southwest inside Iraq, the imbricate zone is bounded by Zagros Foreland High Folds Zone through High Zagros Reverse Fault. Further to the southwest, the Zagros Mountain Front Fault represents the boundary between the later mentioned zone and the Zagros Foreland Low Folds Zone (Ibrahim, 2009) (Figure 2).

Azmar anticlinorium consists of a number of anticlines on either sides of its main hinge (Figures 3 and 4). Their hinges follow the trend of the main hinge (i.e NNW-SSE). All are asymmetrical to the SW, the SW limb of the main Azmar fold is overturned. Furthermore, their flanks are dissected by longitudinal reverse slip and transversal strike slip faults. The reverse slip faults verged towards both SW and NE directions. The strike slip faults are dextral and senistral, oblique and transverse to the trend of the anticlinorium respectively (Al-Hakary, in press) (Figure 3).

The older rocks exposed in the core of the main Azmar anticline belong to Balambo Formation of Valanginian-Turonian age. It consists of alternating layers of yellowish grey marl, shale and marly limestone. This formation is overlain by well bedded fine grained limestone with chert bands of Kometan Formation of Late Turonian-Early Campanian age. Shiranish Formation of Campanian-Maastrichtian age overlies Kometan Formation and consists of alternating layers of bluish marl and marly limestone. Tangero Forma-

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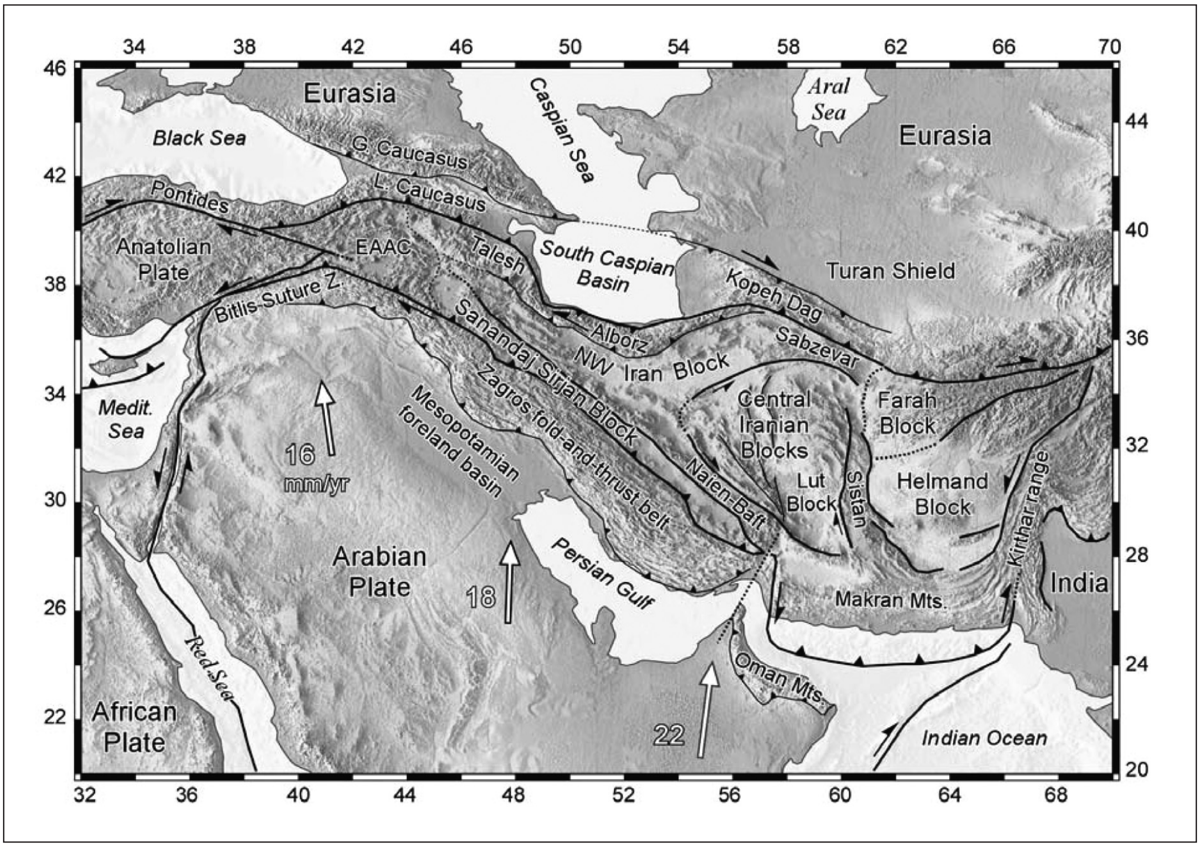



Figure 1- Plate tectonic context of the Arabian-Eurasian collision zone. Velocities of movement of Arabia with respect to Eurasia, in mm/yr, are from Sella et al., 2002. EAAC = East Anatolian Accretionary Complex (Alavi, 2004 ).

tion of Late Campanian-Maastrichtian age consists of clastic layers (sandstone, shale, marl, and sandy limestone) overlies the Shiranish Formation (Figures 3 and 4).

The main goal of the present work is to clarify the fold style of Azmar structure together with its minor constituents. In order to know whether this structure has been formed by passive folding or through fault propagation folding. Further more, to decipher the fold style of this structure in view of plate tectonic configuration of northern Iraq.

## METHOD OF STUDY

Field data for present investigation were gathered throughout a traverse along road cuts across Azmar Mountain (Figure 3). They include attitude measurements of bedding planes, field descriptions and interpretations aided by sketches and field photographs. The collected data were analyzed later in the office with the aid of stereographic projection manually and computationally as well. Georient software (GEORIENT 9.2) was used to prepare pi- diagrams of folds.

Any structural analysis of folds whatever their size scale, accomplished by designating the following characteristic elements of fold style: (1) shape of the fold in a profile plane which classified as parallel, similar … etc., (2) the interlimb angle in profile plane, (3) cylindericity of the fold in three dimensions, and (4) the presence and

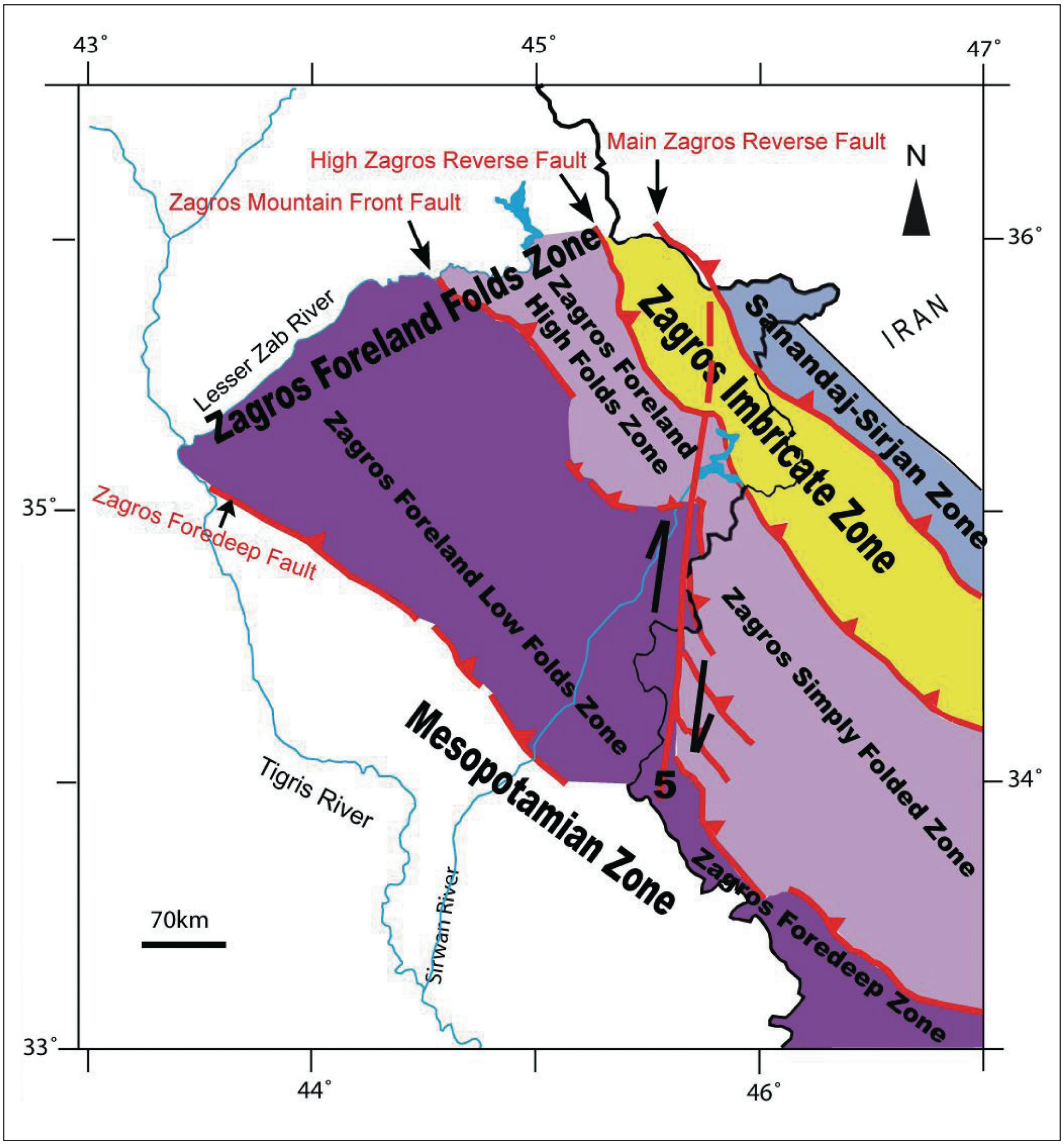



Figure 2- Main morphotectonic zones in the study area (NW segment of the Zagros Fold-Thrust Belt) and their continuations in Iran. The deep major basement faults which separate the main morphotectonic zones are drawn in red lines. The Khanaqin Fault (5) which is a dextral strike-slip has been considered as a boundary between the northwestern segment (Iraq Zagros part) and the southeastern segment (Iranian Zagros part) (Ibrahim, 2009).

type of associated axial plane foliation and/or lineation which is generally a characteristic feature in metamorphic domains (Van der Pluijm and Marshak, 1997).

The fourth parameter discarded in the present investigation because the study area consists exclusively of sedimentary successions and lacks any kind of foliations. The fold profile shape

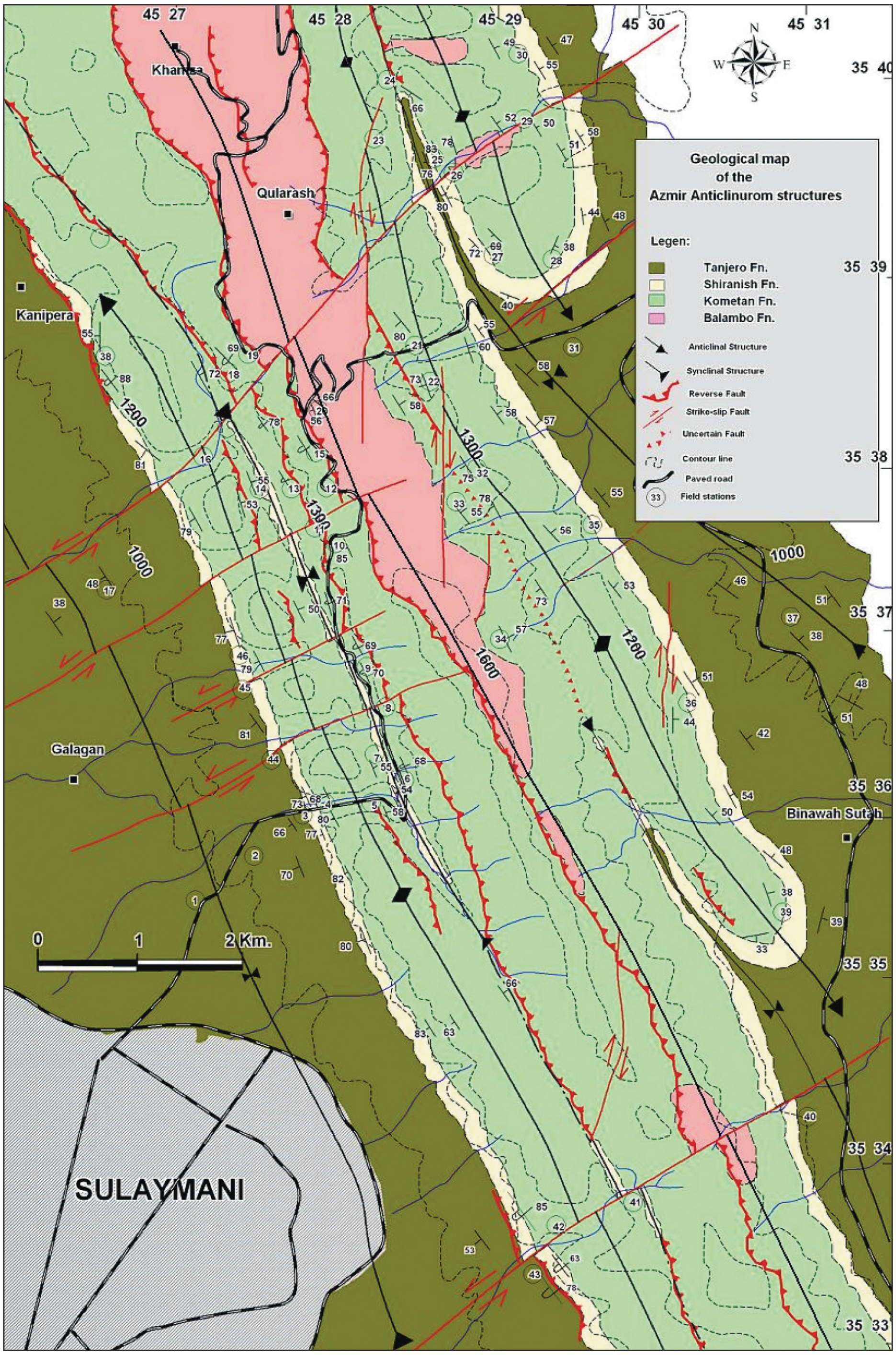



Figure 3- Geological map of Azmar anticlinorium (Al-Hakary, in press).

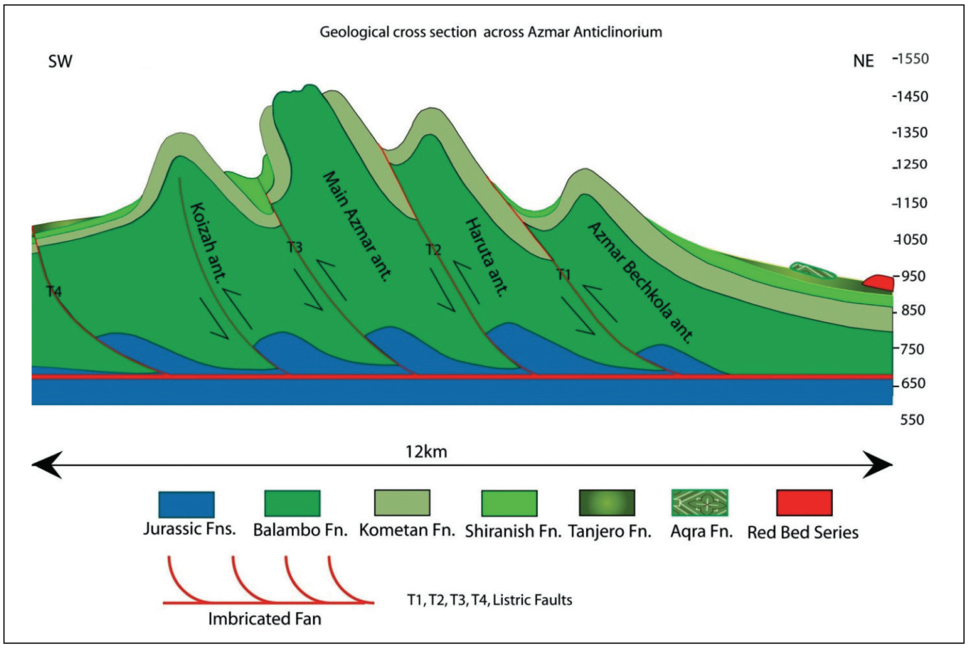



Figure 4- Geological cross section of the studied traverse in Azmar anticlinorium (Al-Hakary, in press).

examined by field photographs which clearly demonstrate the nature of curvature and bending of strata around hinge zones of folds.

Stereographic representations as pi-diagrams of bedding poles both synoptically and individually aided to detect attitudes and geometry of various fold elements. The output of this step was used to classify the main fold as well as its minor constituents. The pi-diagrams were critical also for checking the cylindericity of these folds.

## FOLD ANALYSIS

Azmar anticlinorium consists of four imbricated anticlines (Figures 3 and 4). The main folds as well as their minor ones developed in a multibeds system of alternating competent (limestone, marly limestone, dolomitic limestone) and incompetent (marl, shale) beds of Balambo, Kometan and Shiranish formations. The shapes of folds are well manifested in the competent beds, and they all appear as parallel folds class 1B of Ramsay. Whereas their shapes in the intervening incompetent beds approach classes such as 1C and 2 (similar fold) of Ramsay (Ramsay and Huber, 1987).

The main anticlines of this anticlinorium structure are named from NE toward SW: Azmar Bechkola, Haruta, Main Azmar and Koizah. All are doubly plunging, trending in NNW-SSE direction and imbricating towards SW through NE dipping imbricated fan faults (T1,T2,T3 and T4) which submerge into a deep seated detachment (Figures 3 and 4). They characterized with somewhat narrow and subangular hinge zones. Their SW limbs are steeply dipping and occasionally overturned towards NE as in Azmar main anticline, whereas the NE limbs are less steep. Accordingly their axial planes are NE dipping and verging towards SW (i.e foreland verging) (Figure 5). The range of interlimb angles 58-65º for these main anticlines refers to their closed class (Table 1; Fleuty, 1964). Furthermore the scattering of S-poles moderately around the Pi-

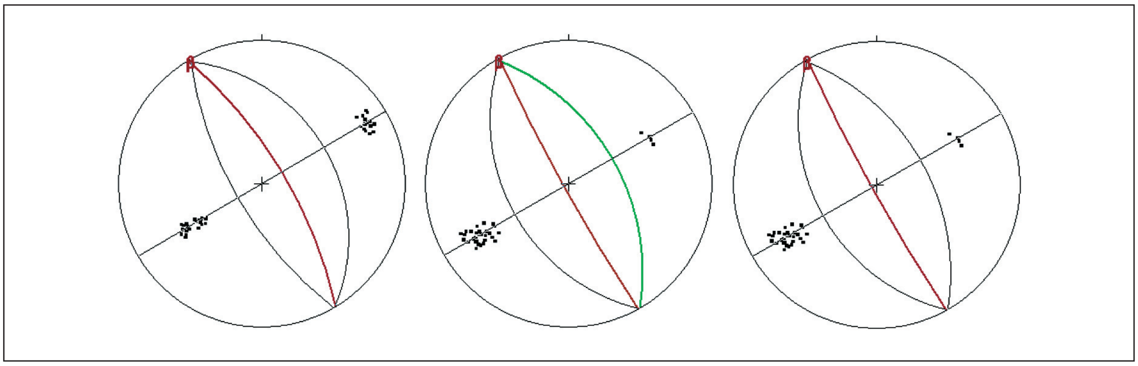


Figure 5- PI diagrams of Azmar anticlinorium (a: Azmar Bechkola, b: Main Azmar, c: Koizah anticlines). Red great circles refer to axial planes of these folds. Green great circle refers to normal NE limb and overturned SW limb of the same fold which represents at the same time the axial plane between these specific limbs.

**Table 1- The geometrical parameters of Azmar anticlinorium.**

| Folds | | Folds axis | Axial plane | Interlimb angle | Vergency | Fluety classification (1964) | |
|---|---|---|---|---|---|---|---|
| | | | | | | Based on interlimb angle | Based on dip of axial plane and plunge angle |
| Main Folds (A) | Azmar Bechkola | 330/01 | 149/ 77 | 58 | SW | Closed | Steeply dipping-subhorizontal |
| | Main Azmar | 330/01 | 331/87 | 65 | NE | Closed | Upright-subhorizontal |
| | Koizah | 329/03 | 150/83 | 60 | SW | Closed | Upright- subhorizontal |

planes refers to semicylindrical character of these folds (Ramsay and Huber, 1987).

## MINOR FOLDS

They are of outcrop scale and may have been developed on limbs and hinge zones of larger (major) folds. The major folds containing minor ones are termed anticlinoria or synclinoria, and their presence implies to genetic relationship with the enclosing major folds, even though they vary in shape and position in the larger structure. However, the orientations of these small folds resemble approximately with each other, and at the same time approximate their enclosing major folds orientations. Therefore, the small folds are sometimes called parasitic folds, because they are closely related to a larger structure (Van der Pluijm and Marshak, 1997; Ragan, 1986).

The geometric relationship between parasitic folds and the regional structure gives a powerful concept in structural analysis, known as Pumpelly's rule (Twiss and Moores, 2007). This concept states that the orientation of small (high order) structures is representative of the orientation of regional (low-order) structures. Thus the orientations of hinge line and axial surface of a small (minor) fold predict these elements for a regional fold. But field testing of this concept has proven to be remarkably robust in regional analysis.

There is a train of minor (high-order) folds in the hinge zone (Figure 6) and NE limb (Figure 7), and in the SW limb (Figure 8), of the main Azmar anticline (Figure 3). They have been developed through a stack of Balambo Formation made up

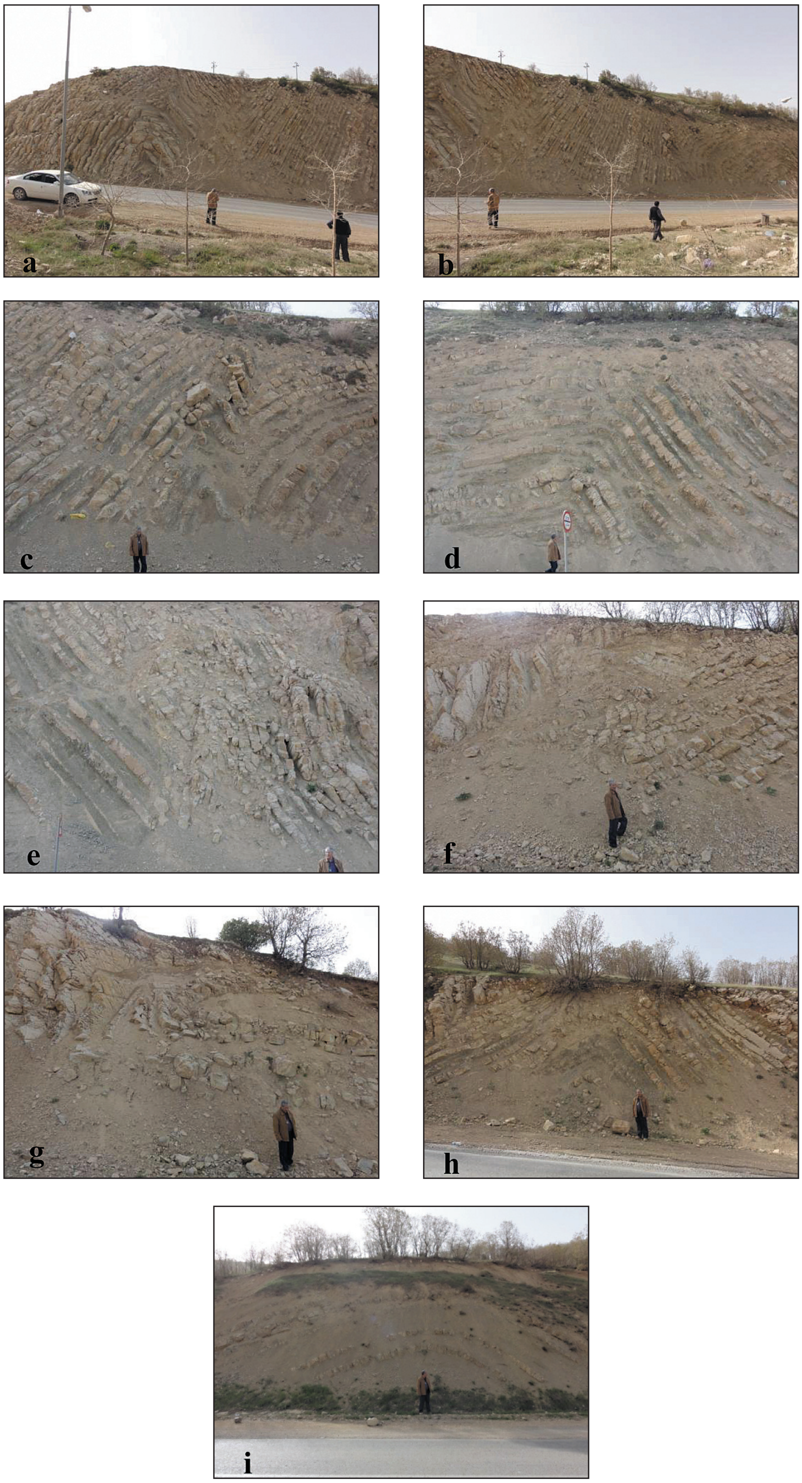



Figure 6- Train of varied style congruent minor folds in Balambo Formation at the hinge of main Azmar anticline. (a,b,c,d,e,f) are tight with angular hinges; g is recumbent; h and i are open with rounded hinges; e is disrupted with a reverse fault.


Figure 7- Varied style congruent minor folds at NE limb of main Azmar anticline. (a, b, c, d) in Balambo Formation; (e, f, g) in Kometan Formation. a is isoclinal; b , d and e are with angular hinges, the synclinal hinge of b is disrupted with a reverse fault; c is with rounded hinge; f and g are chert band minor folds; g is fan shaped.


Figure 8- Train of varied style congruent minor folds at SW limb of main Azmar anticline. (a and b) in Balambo Formation; a is a recumbent; b is a monoclonal minor fold separated from the recumbent one by a probable reverse fault dipping SW ward. (c and d) in Kometan Formation; c is recumbent; d is a recumbent minor fold sandwiched between an upper and a lower reverse faults dipping NE ward.

of alternating dolomite, limestone and marl, and the Kometan Formation thin limestone beds. The common characteristic feature of most of these minor folds is the angularity of their hinge zones and the general conformity of their axial trends (NW-SE) with the axial trend of their enclosing main Azmar anticline. The association of reverse faults with angular hinges and limbs of these minor folds (Figures 6e, 7b, 8b,8d) is powerful indication for the fault related type of these minor folds. This is a characteristic phenomenon of folding in the imbricated zone. The competency contrast between thin stiffer chert bands and the fine grained relatively thicker limestone beds of the Kometan Formation is distinctly obvious within the parallel fold style of limestone beds. Thus, the stack of limestone beds with chert bands gives up a disharmonic character for minor folds in this formation on both limbs of the main Azmar anticline (Figure 7f). Occasionally some chert bands give rise fan-shaped folds particularly in the NE limb of the main fold (Figure 7g). However the style of minor folds within the main fold varies through concurved (Figures 6h,i; 7c), chevron (Figures 6a,b,c,d,f,e; 7b,d,e), isoclinal (Figure 7a), recumbent (Figures 6g; 8a,c,d), disharmonic (Figure 7f), fan shaped (Figure 7g) and monoclinal (Figure 8b).

However, as evident from the representative Pi-diagrams of (27) minor folds (Figures 9,10 and 11) and (Table 2), there exist remarkable dis-

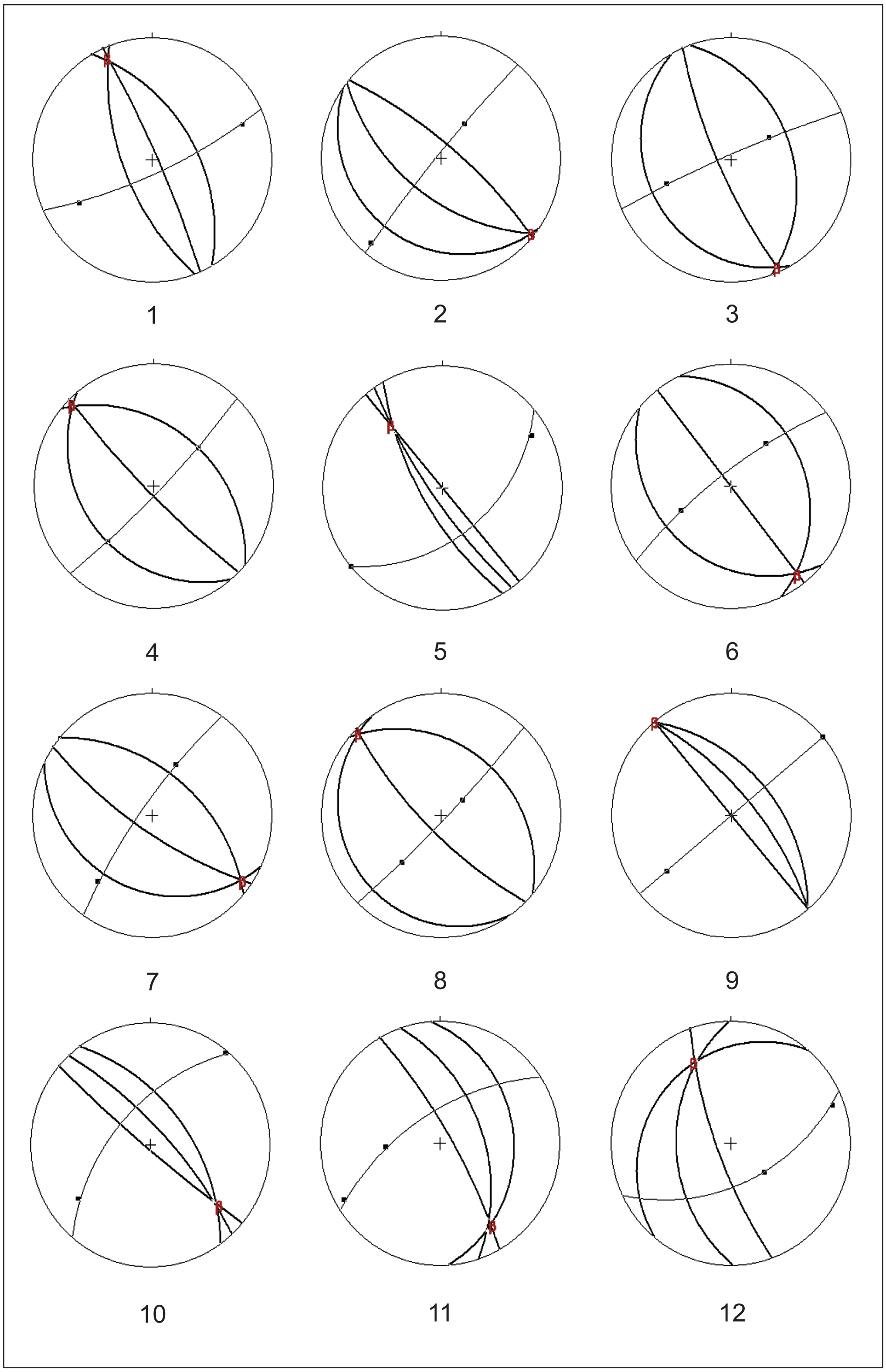



Figure 9- Stereographic representations (Pi-diagrams) of minor folds in main Azmar anticline. β: fold axis, ▪: poles to bedding.

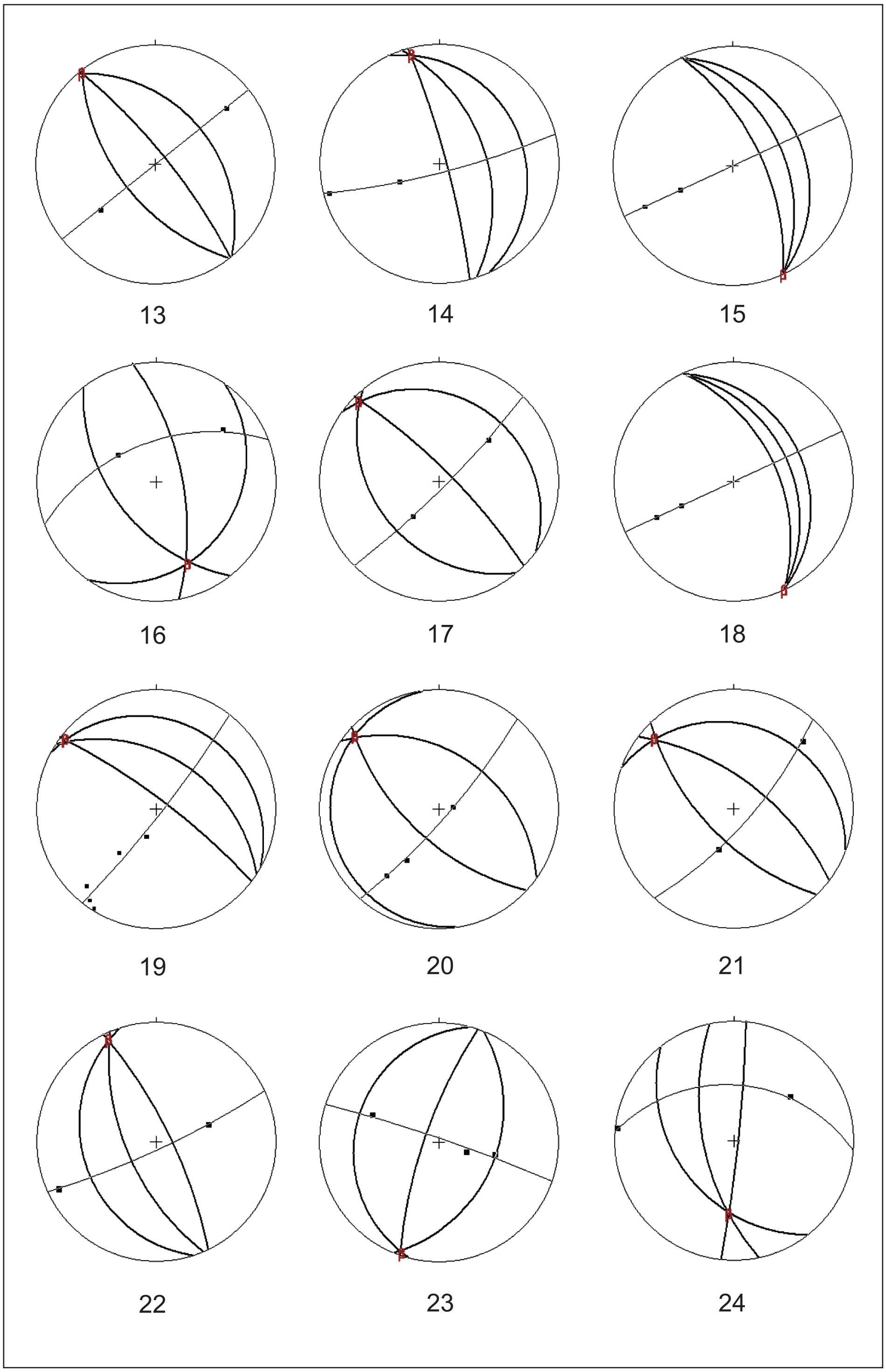
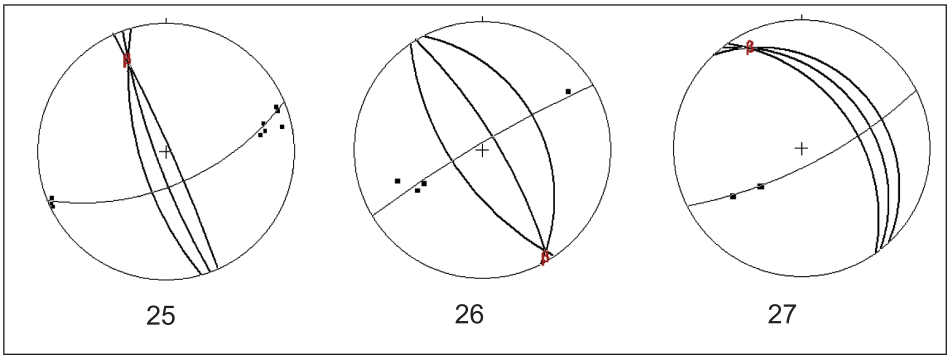



Figure 9- Continued

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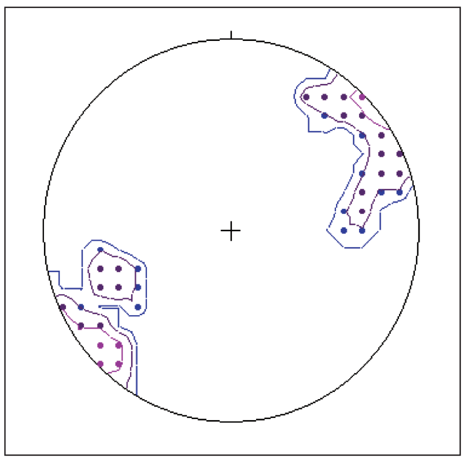

Figure 10- Gridded contour diagram of axial planes poles of 27 minor folds at Azmar main anticline.

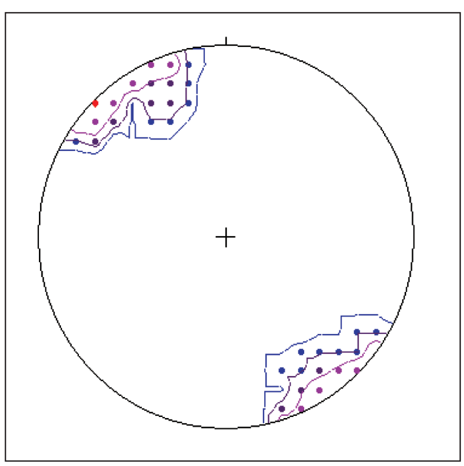

Figure 11- Gridded contour diagram of fold axes of 27 minor folds at Azmar main anticline.

**Table 2- The geometrical parameters of minor folds in the main Azmar anticline.**

| Minor fold no. | Location in main Azmar anticline | Fold axis attitudes Plunge / Trend | Axial plane attitudes Dip / Dip direction | Interlimb angle | Fluety classification (1964) | |
|---|---|---|---|---|---|---|
| | | | | | Based on interlimb angle | Based on axial plane dip |
| 1 | NE | 10/336 | 86/066 | 50 | Close | Upright - subhorizontal |
| 2 | NE | 02/130 | 64/218 | 72 | Open | Steeply dipping - subhorizontal |
| 3 | NE | 04/157 | 81/246 | 102 | Open | Upright - subhorizontal |
| 4 | SW | 05/314 | 85/225 | 90 | Open | Upright - subhorizontal |
| 5 | SW | 33/320 | 82/235 | 17 | Tight | Upright - moderately plunge |
| 6 | SW | 10/143 | 90/052 | 106 | Open | Upright - subhorizontal |
| 7 | hinge | 08/125 | 79/214 | 84 | Open | Steeply dipping - subhorizontal |
| 8 | hinge | 04/314 | 79/225 | 120 | Gentle | Steeply dipping - subhorizontal |
| 9 | NE | 00/320 | 75/050 | 31 | Close | Steeply dipping - subhorizontal |
| 10 | SW | 25/131 | 79/047 | 32 | Close | Steeply dipping - gently plunge |
| 11 | SW | 21/147 | 60/071 | 49 | Close | Moderately dipping-gently plunge |
| 12 | NE | 28/335 | 52/269 | 67 | Close | Moderately dipping-gently plunge |
| 13 | NE | 02/321 | 82/051 | 65 | Close | Upright - subhorizontal |
| 14 | NE | 06/346 | 58/072 | 56 | Close | Moderately dipping-subhorizontal |
| 15 | SW | 00/335 | 55/065 | 30 | Close | Moderately dipping-subhorizontal |
| 16 | NE | 27/159 | 72/079 | 106 | Open | Steeply dipping - gently plunge |
| 17 | NE | 05/315 | 82/045 | 105 | Open | Upright - subhorizontal |
| 18 | SW | 00/335 | 50/065 | 20 | Tight | Moderately dipping-subhorizontal |
| 19 | NE | 04/308 | 54/035 | 57 | Close | Moderately dipping-subhorizontal |
| 20 | NE | 07/311 | 69/223 | 122 | Gentle | Steeply dipping - subhorizontal |
| 21 | NE | 12/312 | 70/037 | 83 | Open | Steeply dipping - gently plunge |
| 22 | NE | 05/335 | 69/247 | 62 | Close | Steeply dipping - subhorizontal |
| 23 | NE | 02/199 | 80/289 | 100 | Open | Upright - subhorizontal |
| 24 | NE | 39/184 | 69/258 | 58 | Close | Steeply dipping-moderate plunge |
| 25 | NE | 22/337 | 83/250 | 22 | Tight | Upright - gently plunge |
| 26 | SW | 04/149 | 80/059 | 59 | Close | Upright - subhorizontal |
| 27 | SW | 11/333 | 45/052 | 20 | Tight | Moderately dipping-gently plunge |

crepancies in many respects among these minor folds and between them and the main Azmar anticline as well. The range of axial attitudes of these minor folds falls into three groups. A group (2,4-11,13,17,19-21) with axes trending generally in NW-SE direction. Another group with axes trending generally NNW-SSE in accordance with the trend of the main Azmar anticline, these are namely (1,3,12,14-16,18,22, 25,27). Yet there is a third group of two minor folds with somewhat discordant fold axes with regard to the first two groups, these are (23 and 24) trending in NNE-SSW direction, both of them are lying in the NE limb of the main Azmar anticline. Furthermore, these three groups are also differentiated somewhat in trends of their axial surfaces (Table 2). Accordingly, they are sorted in ENE, NE hinterland and SW foreland vergencies. Thus they are diversely verging with respect to hinge of the main Azmar anticline. This phenomenon contradicts with a normal vergency of minor folds on both flanks of a main fold, that is the minor folds on both limbs verge toward each other and towards the hinge zone of the main fold (Van der Pluijm and Marshak, 1997; Ramsay and Huber, 1987; Hobbs et al., 1976; Suppe, 1985).

Furthermore the interlimb angles of these minor folds vary largely, thus, they fall into tight (5,18,25,27), open (2,3,4,6,7,16,17,21,23), closed (1,9-15,19,22,24,26) and gentle (8,20) according to Fleuty (1964), (Table, 2).

## BOUDINAGE STRUCTURES

They are sausage-shaped lenses of relatively rigid (competent) beds embedded in a more ductile matrix in a rock that has undergone bed parallel stretching. In three dimension, they are long tabular bodies separated by boudin necks, that can be regarded as linear objects (Van der Pluijm and Marshak, 1997 ; Suppe, 1985).

It is observed in the present investigation that the thin chert bands embedded in relatively thicker limestone beds of the Kometan Formation were segmented into boudin like fragments (Figure 12). Thus it is obvious that the process by which this chert boudinage has been formed resembles to the mechanism just cited above. That is by bed parallel stretching on the NE limb of the main Azmar anticline. Such stretching in NE-SW direction might have been dominated during the relaxation episode that succeeded folding (i.e. during the uplifting stage of the major fold). This extension (stretching) direction accords with the step like minor normal faults in the same limb of the main fold (Figure 13), and with the bedding parallel stylolite seams with their peaks pointing vertically upward (Figure 14). Another form of chert boudine is also noted on the same NE limb of Azmar anticline. But the chert band in this case has not been segmented into pieces, rather it has a necked fashion (Figure 15). However, it is also the product of bed-parallel stretching in NE-SW direction.

In the subvertical part of SW limb of the main Azmar anticline, there are also boudinage structures, that have been developed within competent limestone beds of the Kometan Formation (Figure 16). Boudinage formation here is attributed to the tightening compressive direction which become sub perpendicular to the bedding at this limb. Thus secondary bed-parallel stretching of limestone beds occurred leading to the development of such boudinage structures.

## TECTONIC INTERPRETATION

The structural architecture of Azmar anticlinorium indicates that it has been developed through progressive folding with contribution of hinterland dipping reverse faults. Such these faults might merge with a deep seated detachment related to the collision of Arabian-Iranian plates led to Zagros Orogeny. Thus, it is postulated that the main regional compressive stress responsible for development of such structures was directed NE-SW. (Talebian and Jackson, 2002; Alavi, 2004; Agard et al. 2005).

The progressive folding is also manifested by versatile styles of minor folds disposition on main Azmar anticline. The differentiation of three groups of minor folds according to their orientations (Table 2, Figure 9), and their diverse vergency relative to hinge zone of the main Azmar anticline, besides their variance in interlimb angles, all indicate that these minor folds were developed progressively in accordance with the major fold development. They might have been developed during the tightening stage of the major fold and their modification continued contemporaneously with it. Moreover, the form of the major Azmar anticlinorium as well as the angular hinges of its various minor folds (chevron folds) refer to fault related folding scheme for this major structure.

However, the progressive folding was finally terminated by bed-parallel stretching oriented normally to the trend of Azmar anticlinorium. This stretching might be attributed to final uplift of the

Figure 12- Segmented boudin structures through limestone bed of the Kometan formation at NE limb of the main Azmar anticline.

Figure 13- A series of step-like minor normal faults in the limestone beds of the Kometan formation at NE limb of the main Azmar anticline.

Figure 14- Bedding parallel stylolite seam in the Kometan formation at NE limb of the main Azmar anticline.

Figure 15- Necked boudin of a chert band in the Kometan formation at NE limb of the main Azmar anticline.

Figure 16- Boudin limestone beds in Kometan formation at the subvertical part of SW limb of the main Azmar anticline.

whole structure and manifested by normal faulting (in NE limb), bedding parallel stylolite seams and boudin formation in chert bands and limestone beds in both limbs of the main fold.

## CONCLUSIONS

Fold characterization study of Azmar anticlinorium NE Iraq has revealed the followings.

1. Azmar anticline is a major NNW-SSE trending anticlinorium involving four main SW verged anticlines (Azmar Bechkola, Haruta, Main Azmar and Koizah), and imbricated to each other through NE dipping imbricate fan faults which submerge into a deep seated detachment.

2. The both limbs and hinge zone of the main Azmar anticline bear minor folds of various size (wavelength and amplitude), and style (curved hinge, angular hinge, chevron, isoclinal, recumbent) and associated with reverse faults disrupting their hinges or limbs. Minor folds on the either limbs verge differently relative to the hinge zone of the main fold, and they fall into three categories according to strike of their respective axial surfaces.

3. The shape of Azmar anticlinorium together with the angular hinges of most minor folds refer to fault related folding of the anticlinorium.

4. Disharmonic folds were displayed in thin chret bands embedded in relatively thicker limestone beds of the Kometan Formation at the NE limb of the main Azmar fold. Some of them display distinct forms such as fan folds.

5. Chert bands in the NE limb of the main Azmar anticline have been segmented into boudined pieces due to the bed parallel stretching that accompanied final stage of folding (uplifting). Whereas boudined thin limestone beds within marl matrix in the vertical part of the SW limb of the main fold reflect compression subnormal to the subvertical beds during the tightening stage of earlier formed fold.

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