J. Basic. Appl. Sci. Res., **1(10)1490-1497, 2011**

ISSN 2090-424X
Journal of Basic and Applied Scientific Research
www.textroad.com

Analysis and Interpretation of Minor Folds Developed in the Cretaceous Formations within Azmir Anticlinorium, in a Part of Iraqi Zagros Fold and Thrust Belt, Suliyamania District, Northeastern Iraq

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ABSTRACT

The minor folds in Azmir area (Northeastern Iraq) were studied using various geometrical methods of analysis and interpreted as having been initiated by buckling process. The thickness variation with various inclination of the fold limbs and Isogon patterns of the folded layers show fold geometry similar to that of parallel type, having compound fold class 1B and 1C-2 with tendency toward Class 1C. All the geometric features are consistent to a process involving both buckling and homogeneous flattening mechanism. The process has undergone further fold development simultaneously with variation in compressive direction, resulted in superimposed folding.
KEY WORDS: Zagros, Minor folds, Anticlinorium, Axial planes, Fold axis, orthogonal thickness, progressive deformation.

INTRODUCTION

Analysis of structural geometry in a series of contiguous domains in the High Folded and Thrust Zones in the Iraqi part of Zagros Belt reveals several interesting features from regional tectonic point of views. One of the most attractive structure which outstanding within most major structure are minor folds, these structures demonstrate ductile deformation and play a role in the local architecture of rocks within any deformed area, they do not affect the shape and geometrical outlines of the major folds, but they can be used as a tool for analyzing tectonic regime of any area which they consist.

Different workers have used different nomenclature for describing minor folds. The term "*Drag folds*", which proposed by [1,2,3]; represents asymmetrical folds formed in the limbs of major folds, within incompetent layers sandwiched between competent layers. Other workers such as [4,5,6,7], have used the term "*Parasitic folds*" to describe other minor folds of tectonic origin. These folds are thought to have initially developed by early layer shortening which lead to the development of early symmetrical buckles of differing wavelengths as a result of thickness and competency variations between layers.

The purpose of this study is to describe and interpret minor fold structures, their geometry, mechanism and conditions during folding, and to see whether these different minor structures manifest the polyphase nature of deformation and secondly if they did, how could they possibly help in understanding further the intricate details associated with the small directional discrepancies between these deformations in the context of regional tectonism in the Iraqi Zagros fold and thrust belt.

In order to elucidate the importance of the minor folds in tectonic interpretation, Azmir Mountain which is a part of the Zagros Fold and Thrust Belt that trend northwest-southeast in the Northern Iraqi territories is selected for such study, the area located between geographical coordinates of longitude (45º 26′ 00″- 45 º 31′ 40″) and (35 º 33′ 00″ – 35 º 40′ 10″) Latitude (Fig.1). The study area located near about 15 km north Sulaiymania city.

GEOLOGY OF THE STUDY AREA

Stratigraphically, the studied area consist four major Formations belonging to Cretaceous successions (Fig.2), it embraces the following exposed formation in ascending order. The Balambo Formation (Valanginian-Turonion) is divided into the Lower Balambo Formation (Valanginian-Albian) and Upper Balabmbo Formation (Cenomaian-Turonian). In the studied area mostly the Upper Balambo Formation is widely exposed, consist of thin beds of shale, interbedded with medium to thick bedded limestone and marl. Depositional environment of this formation is deep basin, which tectonically represent the foredeep basin of Neo-Tethys during the convergent of Arabian and Iranian plates. The thickness of the formation is about 400m in the area (core of Azmir anticline).

Kometan Formation (Turonian-Early Campanian), usually overlaid Balambo Fn. the color of this formation is light gray while the weathering color is white to buff. The formation is composed of well bedded Limestone; this formation is highly deformed and contains well market striations and locally silicified and contain

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thin beds of chert, In southwest limb of Azmir anticline the attitude of the beds mostly overturned or vertical and show boudinage structure in large scale. The thickness of this formation in this area is about 110m., the lower contact of the formation with Balambo Formations is an unconformable and the upper contact with Shiransh Fn. is unconformable contain glauconitic bed in the base .

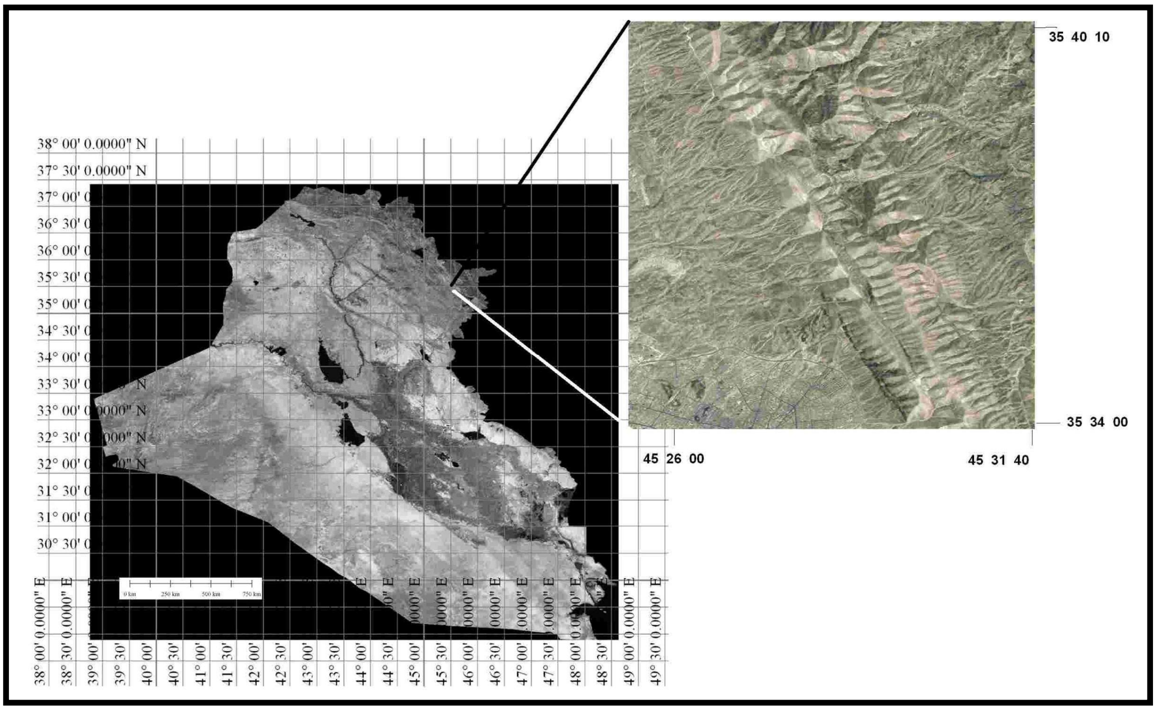


Fig.(1): Show the location of studied area

Shiranish Formation mostly surrounded the anticlines in the most area of highly folded zone. The age of the formation is Campanian- Maastrichtian. Lithologically the formation comprises from alternation of blue marl and marly limestone. Thickness of the formation varies from a place to another. It ranges from (50-100m). Contact of the formation with the underlying Kometan Formation is an unconformable and is conformable with overlaying Tanjero Formation. In studied area the formation in southwestern limbs is mostly covered because it is easily weathered and eroded. Well exposures of the formation are in the northeastern limb of Azmir structure. The environment of deposition is slope and basin plain. The tectonic condition of the formation is deposited in off - shore area of Cretaceous Foreland basin. Tanjero Formation (late Campanian – Maastrichtian) , is composed mainly of alternation of sandstones, claystones, shales, and beds of conglomerates that have dark yellowish green and olive green colors with common lateral and vertical variation. The lower contact is gradational and conformable with the underlying Shiranish Formation and the contact can be recognized in the field by the first appearance of interbedded sandstones and marls, as well as the change in color between Shiranish and Tanjero Formations is very clear in the field, and the upper contact is commonly unconformable with the overlying Kolosh Formation. This contact located outside our studied area. The thickness of the formation in studied area about 100m. The environment is Delta, shelf, slope and basin plain .The formation represent flysch deposits in Iraq.

Structurally, Azmir structure located within Imbricated zone of Iraqi Zagros Folds and Thrust belt, that composed of a series of overlapping anticlines and synclines that are from northeast towards southwest are as follow, Azmir bechkola anticline, at most upper northeastern side, then Haruta anticline and main Azmir anticline at middle part, while Mandol anticline located at lower most southwest side, and due to interlacement of all these anticline they form complex structure named Azmir Anticlinorium. This structures transected by many longitudinal thrust and back thrust faults, with a pronounced displacement along these faults, as well as many strike-slip faults of sinistral and dextral types, transect this structure gives a complex structural form (Fig.2). The length of Azmir anticlinorium is about 40Km in, it’s a double plunging anticlinal structure, SE plunge located near Arbat city while NW plunge interlocking with Surdash anticline giving a more complex inter-fingering area. The width of this structure varied from place to another; at SE area the width is about 1.5-2 km, while in the middle part become 2-3.5 km, but in most NW segment the width of this anticlinorium become 5-6 km. The detail structural study about each of these folds and faults as well as the role of them in tectonic regime is outside the aim of this study.

DATA AQUSATION AND ANALYSING:

A total of 38 minor folds were detected within cretaceous succession in the area under investigation, attitude of limbs were measured, from these data the fold axis, and their axial plane and interlimb angle were determined using stereographic projection.

Some of these minor folds were selected for analyzing geometrically using the methods of Ramsay [8], with the technique described by [9] together with the methods of [10] and [11]. The terminology used to describe folds and their attitudes follow that given by Ramsay [8]. These folds are intensely developed, as well as, the near profile sections of these folds are also well exposed due to the removal of overburden during the highway construction scheme.

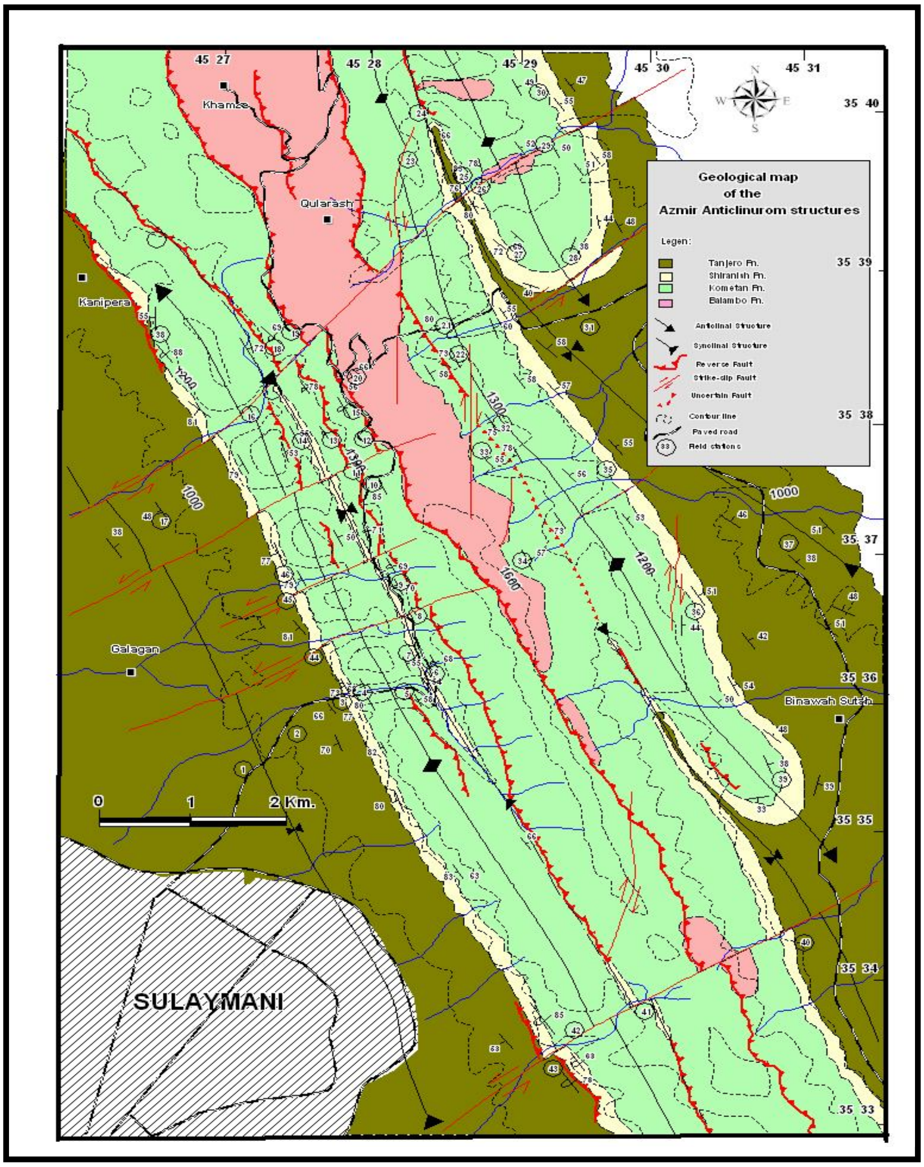


Fig.(2): Geological map of the Azmir Anticlinorium (*prepared by Author*) **.**

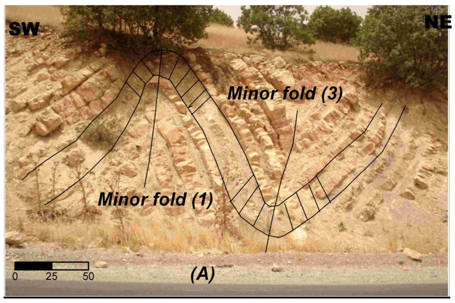
DESCRIPTIVE OF FOLD GEOMETRY

Folded structures presented are characterized by open to close interlimb angle with moderately inclined axial surface and gently to moderately plunging fold axis. Cleavages associated with the axial surface are poorly developed. In many cases, strain-slip cleavage can be locally observed. Lineation associated with the folded structures chiefly line intersection of the strain-slip cleavage and folded original bedding surface. The lineation characterized by small crenulations oblique to the fold hinge line are also present (Fig. 3).

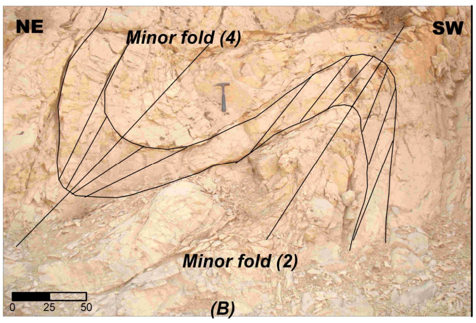
Fold geometry profile analysis:

The materials used in this method are eight field photographs taken on the outcrops, looking through the fold axes. Thus, they are the representatives fold profiles that normal to fold axis. The selected layer boundaries of the folded structures were traced onto sheet of clear and thin tracing paper. The tangent lines of various inclination (α) from the line normal to axial surface direction to both surfaces were constructed for selected folded layers. The dip isogons were also constructed for each profile, on the layers of each point of equal inclination angle. The shortest distance (orthogonal thickness) between two tangent ($t\alpha$) were measured, Layer thickness ratio, $t'\alpha$ were calculated using the relationship $t'\alpha = t\alpha / t_0$, where t_0 is the thickness of the layer at fold hinge, i.e.$T_0=t_0$. The values of these elements are shown in the table (1a-h). For each analyzed folded structure, $t'\alpha$ were plotted against the variation of inclination angle (α) as shown on the graphs of figure (5a-h) for each minor folds and figure (5, i) for all folds together. In this study only the values of $t'\alpha$ were taken into consideration because one of the elements, either t′α (orthogonal thickness) or Tα (axial trace thickness) are sufficient for determining type of the fold class [(8), (12)].

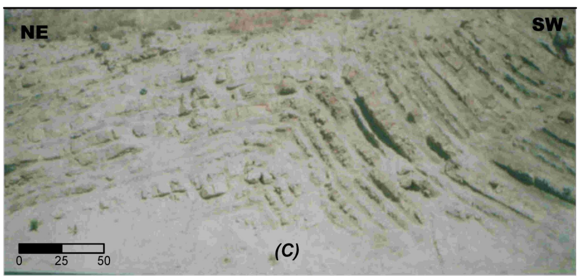
Fig (3): Minor fold photo profile show small granulation (black lines) obliquely inclined to fold hinge in one of the minor fold.



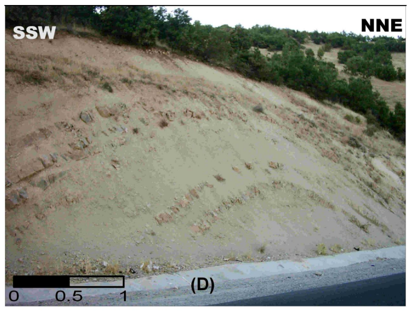
Minor Fold No. 1 and No. 3 in Kometan formation



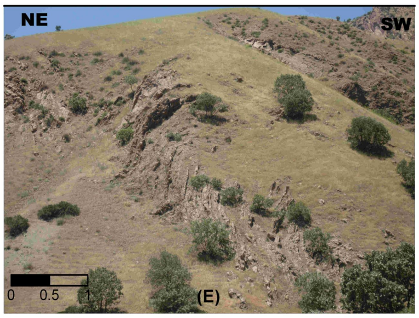
Minor folds 2 and 4 within Balambo Formation



Minor fold 5 within Balambo Formation



Minor fold No. (6) in Balambo Formation



Minor fold No. (7) in Kometan Formation

Minor fold No. (8) in Tanjero Formation

Fig(4, A-F): Show minor folds in different formation within studied area, numbers (1-8) are minor fold number for comparison with table (1) and figure (5).

Isogon patterns

The isogon lines of minor folded profiles shows two different pattern (Fig.4,A&B), one of the fold profiles is characterized by close spaced convergent to nearly parallel isogon lines and concentrated at the maximum curvature of the inner arc. While, the isogon lines of the other fold profile are strongly convergent with high angle to its axial trace. These isogon patterns are compatible with fundamental fold class1B and 1C-Class2 respectively. However, only the part close to the fold hinge has true characteristic of fold class 1B and 1C of those class model described by [8], [13].

Thickness/ dip variation

The dip isogon patterns described above are not conforming to the established simple fundamental fold class throughout the folded layers. This means that it is not possible to reach any reliable interpretation implied by these fold classes unless more detailed fold geometry has been investigated. Thus, the variation of the thickness ratio with respect to various inclination angle(α) have been constructed. The techniques described by Hudleston [9] have been used in the study of thickness variation with various inclination angle (α) for these fold profile. The thickness ratio have been calculated and plotted against the inclination angle as shown on the graph of figure(5a-h). The thickness ratio(t'), with various inclination (α) of the fold limbs of the fold profiles are restricted to the lower portion of the class 1C field to Class 2. In addition, the thickness has less variation for a considerable amount of inclination angle, approximately up to 30 degree. These may indicate that fold structures can be classified as being compound fold class of 1B and 1Cto Class2 with general tendency toward class 2.

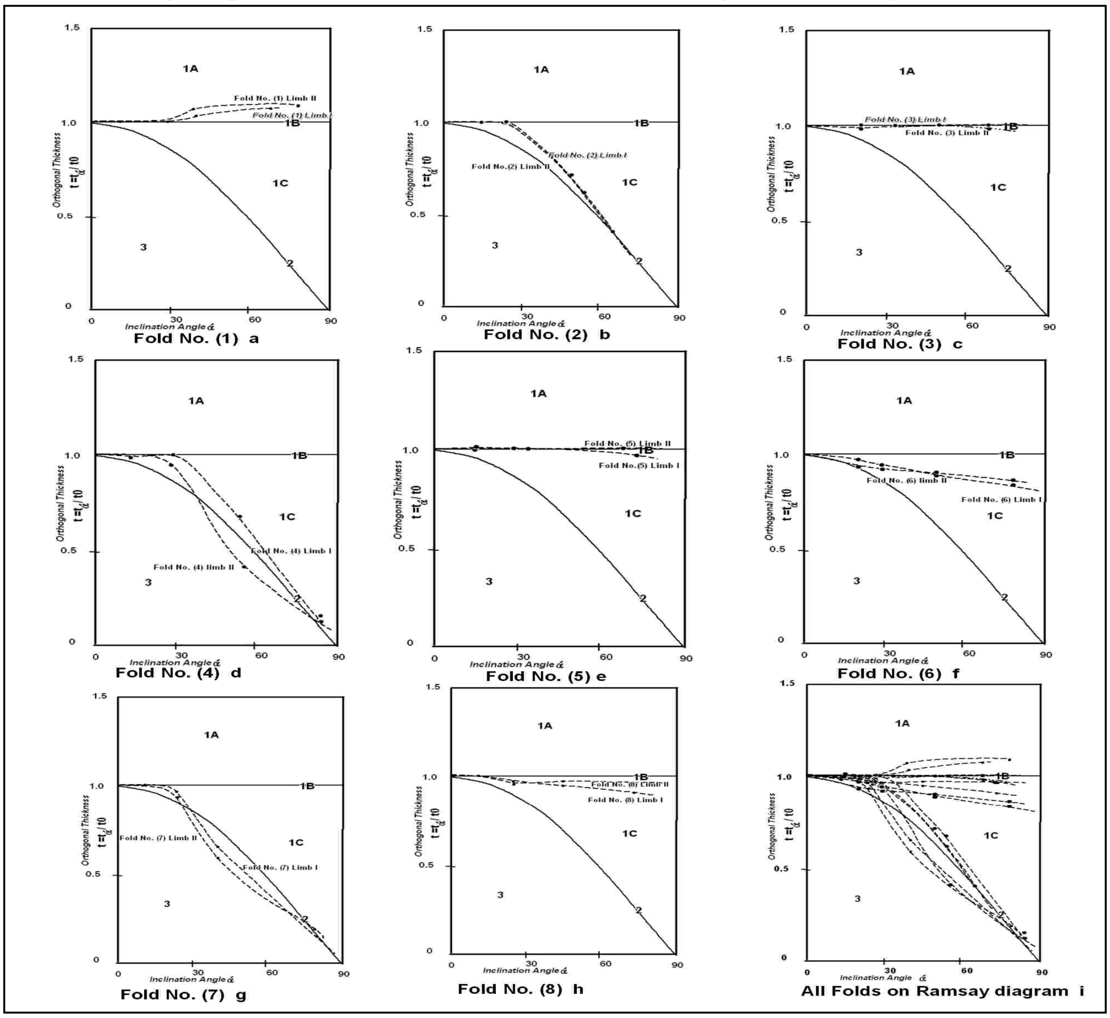


Fig.(5): Showing the projections of minor folds on Ramsay diagram.

INTERPRETATION

The geometrical analysis of the fold profiles described above show systematic variation in fold shape of parallel fold class. All the features brought out are compatible with folding process that involves buckling of the competent layers with considerable amount of homogeneous flattening [8,14,15]. The homogeneous flattening is a mechanism by which is impossible to crate a fold in a perfectly flat layer, but it can amplify an initial irregularity and change the geometry of fold from a specific fold class to another class.

Table (1): Numbered (1-8), represent the orthogonal thickness calculation within different inclination angle for eight minor folds (see Fig. 5a-h)

Fold No. (1)	**Limb (I)**				**Limb (II)**			
α	10	30	40	70	10	30	40	70
t_0	3.1	3.1	3.1	3.1	3.1	3.1	3.1	3.1
t_α	3.1	3.1	3.2	3.3	3.1	3.1	3.3	3.4
$t'_\alpha = t_\alpha/t_0$	1	1	1.03	1.06	1	1	1.06	1.09
Fold No. (2)	**Limb (I)**				**Limb (II)**			
α	15	25	50	65	15	25	50	65
t_0	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5
t_α	3.5	3.5	2.24	1.4	3.5	3.5	2.6	1.4
$t'_\alpha = t_\alpha/t_0$	1	1	0.64	0.4	1	1	0.74	0.4
Fold No.(3)	**Limb (I)**				**Limb (II)**			
α	20	35	50	70	20	35	50	70
t_0	2.8	2.8	2.8	2.8	2.8	2.8	2.8	2.8
t_α	2.75	2.8	2.8	2.8	2.8	2.8	2.8	2.7
$t'_\alpha = t_\alpha/t_0$	0.98	1	1	1	1	1	1	0.97
Fold No.(4)	**Limb (I)**				**Limb (II)**			
α	12	30	55	85	12	30	55	85
t_0	3.7	3.7	3.7	3.7	3.7	3.7	3.7	3.7
t_α	3.63	3.7	2.59	045	3.7	3.63	1.48	0.6
$t'_\alpha = t_\alpha/t_0$	0.98	1	0.71	0.12	1	0.98	0.4	0.16
Fold No.(5)	**Limb (I)**				**Limb (II)**			
α	15	35	55	75	15	30	70	80
t_0	2.8	2.8	2.8	2.8	2.8	2.8	2.8	2.8
t_α	2.8	2.8	2.8	2.7	2.8	2.8	2.8	2.8
$t'_\alpha = t_\alpha/t_0$	1	1	1	0.96	1	1	1	1
Fold No.(6)	**Limb (I)**				**Limb (II)**			
α	20	30	50	80	20	30	50	80
t_0	3	3	3	3	3	3	3	3
t_α	2.91	2.82	2.7	2.55	2.85	2.79	2.73	2.64
$t'_\alpha = t_\alpha/t_0$	0.97	0.94	0.9	0.85	0.95	0.95	0.91	0.88
Fold No.(7)	**Limb (I)**				**Limb (II)**			
α	10	25	40	80	10	25	40	80
t_0	3.3	3.3	3.3	3.3	3.3	3.3	3.3	3.3
t_α	3.3	3.2	2.2	0.5	3.3	3.1	2	0.7
$t'_\alpha = t_\alpha/t_0$	1	0.96	0.66	0.15	1	0.94	0.6	0.2
Fold No. (8)	**Limb (I)**				**Limb (II)**			
α	10	25	45	75	10	25	45	75
t_0	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5
t_α	2.5	2.45	2.38	2.33	2.5	2.4	2.45	2.45
$t'_\alpha = t_\alpha/t_0$	1	0.98	0.95	0.93	1	0.96	0.98	0.98

Analysis of the folding:

Attitude of the bedding surface and of structural features related to minor folds were measured. These structural features are considerably homogeneously distributed over the area. All these data were plotted on the lower hemisphere of the equal area net.

As shown on the figure (6) poles to the bedding surface are distributed along a girdle with plunging B-axis of 10º toward the direction of 332º. However, pole distribution and their distribution contour pattern indicate that the B-axis is variable along the axial surface (Fig. 6Bb). Pole to minor fold axial surfaces and minor fold axes were also plotted as shown in the stereogram of figure (7). The maximum concentration of the minor fold axes plunge 28º toward the direction of 316º and lie out away off the fold axial surface that contains the B-axis. The distribution contour pattern of the minor fold axes is more or less follows the fold axial surface. These variations can be clearly seen by superimposition of the figure (6B) and (7). This may lead to interpret that all the minor folds with their fold axes varied consistently with the variation of B-axis are presumably related to the folding phase with its fold axis represented by the B-axis. The B-axis is therefore a representative fold axis that is more likely an earlier phase of folding, assigned here as F1 fold. If so, the maximum concentration of minor fold axis is the representative F2 fold axis.

Poles to the minor fold axial surfaces are more or less dispersed along two distinctive girdles (Fig.7B). The most pronounced girdle is normal to both F1 and F2 axial surfaces. This means that most of the minor axial surfaces are coincided with either F1 or F2 axial surfaces. This characteristic may lead to an interpretation that the minor folds related to F1 folding phase were bodily rotated with general tendency toward F2 fold in the condition of superimposed folding with their axial surfaces slightly oblique to each other [16,17]. In this case it may be quite difficult to determine from the appearance of these minor folds which are the earlier phase. Meanwhile, the minor folds with pole to their axial surface dispersed along the other girdle (Fig.7B) are possibly related to the F1 phase of folding. All these characteristics are suggestive of superimposed folding with fold axial surface oblique to each other. This interpretation is consistent with the presence of the small crenulations oblique to larger minor fold hinge (Fig.3).

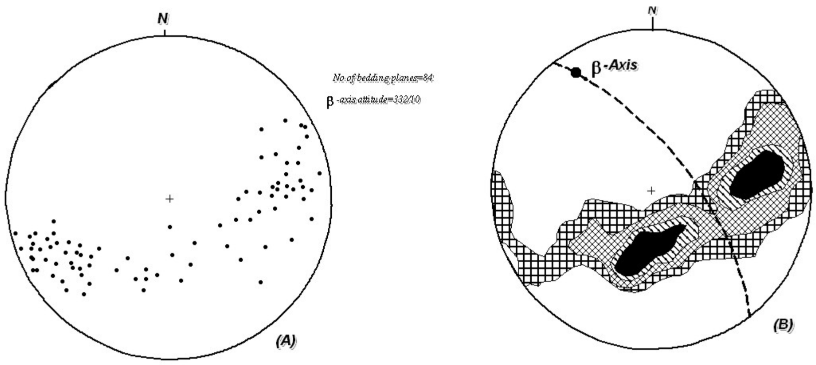


Fig. (6): Stereographic projection of poles of the bedding planes(A), with contour diagram (B)

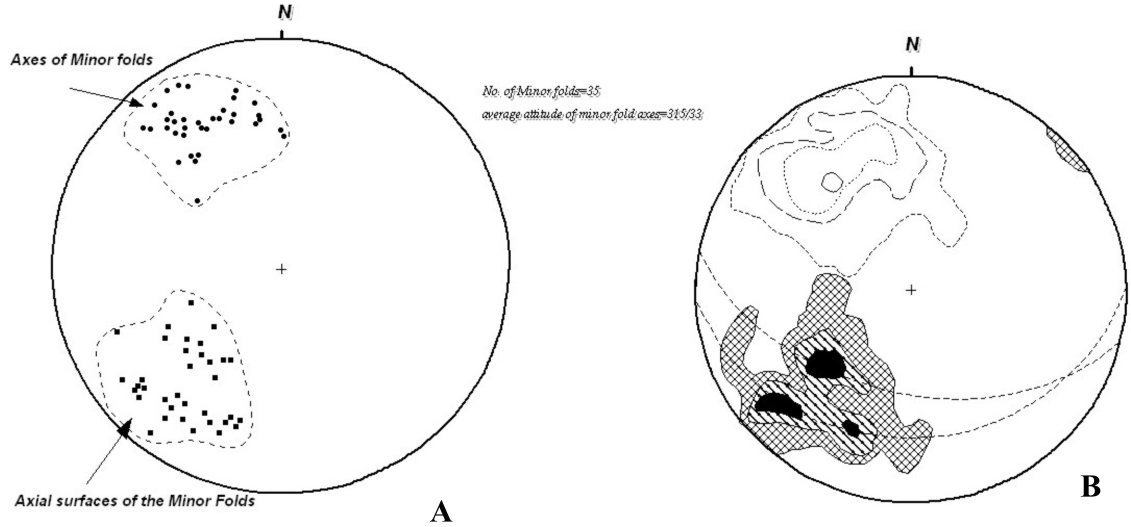


Fig.(7): Poles to the minor fold axes and axial planes (A), and Contours of them (B)

DISCUSSION

The geometrical analysis of the fold profile described above indicates that all the layers have initially been developed as parallel fold forms by buckling process. The process is progressively developed involving both buckling and flattening. The stress orientations responsible for folds development can be tentatively brought out, i.e. the maximum stress direction normal to fold axial surface with an intermediate stress component coincides with fold axis while the minimum stress direction normal to the plane containing the direction of both maximum and an intermediate stress components. As shown by figure (8), the second compression is at the angle of less than 20º to the first compressive direction. With this amount of angular relationship between the two compressive directions, Ghosh and Ramberg [(18)], Twiss and Moores,[(14)], found in their experimental study for superimposed folding by buckling process that superimposed folds did not occur at all. If so, the superimposed folds present in the area may be developed successively during a single phase of deformation with simultaneous varied compressive direction. In such case, the minor fold axis related to each folding phase tends to have their own plunge and trend lying in their axial surface. Thus, poles to minor fold axial surface related to the F2 fold tend to be concentrated into two maxima concentration in the stereoplot (Fig.7b). These two maxima represent measurements on either fold limbs and tend to diverse from the noses of the major fold such as these described by Prager [(18)] , Rowland, et.al, [(7)] and Groshong [(19)].

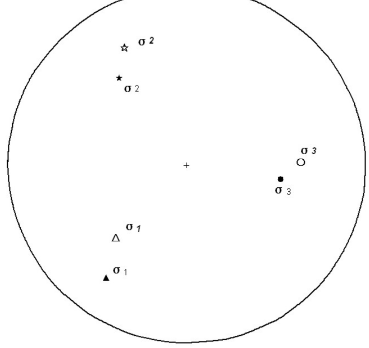


Fig. (8): Stress orientation related to F1 (Solid) and F2(circle) folding phase

CONCLUSION

The geometrical analysis of minor fold presented in the rocks of the Cretaceous succession represented by Balambo, Kometan, Shiranish and Tanjero Formations are adequately explained by a hypothesis of fold initiated by buckling. The earlier formed folds have undergone further fold development involving both buckling and homogeneous flattening processes. The process is a progressive deformation simultaneous with a little variation of compressive stress direction, resulting in superimposed folding. The general regional compression is approximately in the direction of northeast-southwest.

REFERENCES

1- Hills, E. S., **1962**, Outlines of structural geology, 4th ed., Methuen and Co. Ltd., London,p82P.

2- Billings, M.P., **1972**. Structural geology. 3rd ed. Prentice-Hall,USA.606p.

3- Spencer, E.W., **1977**, Introduction to the structure of the earth. 2nd ed.., McGraw-Hill book Co., NewYork, 640 p.

4- Suppe, J., **1985**. Principle of Structural geology. Prentice-Hall, Inc, New Jersey, 537p

5- Ramsay,J.G., and Huber,M.I., **1983**, The techniques of modern structural geology, Vol:1, Strian analysis, Academic press, London, 307P.

6- Marshak, S. and Mitra, G., **1988**. Basic methods of structural geology, Prentice- Hall, Inc., NewJersey, 446P

7- Rowland,S.m., Duebenderfer,E.M.,and Schiefelbein,I.M., **2007**, Structural analysis and synthesis, A Laboratory course in structural geology, 3rd edition, Bluckwell press, 304P.

8- Ramsay,J.G.,**1967**.Folding and fracturing of rocks. McGraw-Hill, New York, N.Y., 568 P

9- Husleston,P.J.,**1973**. Fold morphology and some geometrical implications of theories of fold development. Tectonophysics, 16.,pp:1-46

10- Turner ,F.J., and Weiss L.E., **1963**. Structural Analysis of metamorphic Tectonites, McGraw-Hill, New York,N.Y.

11- Hobbs, B. E., Means, W. D. and Williams, P.F., **1976**. An outline of structural geology. JohnWiley and sons, USA, 571p.

12- Ragan, D.M., **1983**, Structural Geology:An Introduction to geometrical Techniques, John Wiley& Sons, New York,393p.

13- Ramsay,J.G., and Huber,M.I., **1987**, The techniques of modern structural geology, Vol:2, Folds and fractures, Academic press, London, 700P.

14- Twiss, R. J. and Moores, E. M., **1992**. Structural geology. W.H. Freeman, USA, 532p.

15- Van der Pluijm, B. A., and Marshak, S., **2005**. Earth structure: An introduction to structural geology and tectonics, 2nd edition,Norton &Company, USA, 656P.

16- Skjernaa,L., **1975**. Experiments on superimposed buckling folding. Tectonophyscis, 27, pp:255-270.

17- Ghosh,S.K. and Ramberg,H.,**1968**. Buckling experiments on intersecting fold pattern. Tectonophysics, Vol: 5: pp:89-105.

18- Prager,G.D., **1975**. Stereographic Technique for determination of minor fold sense. Geol.Soc. American Bull.,V.86, pp:316-318.

19- Groshong, Jr.R.H., **2006**, 3-D Structural geology, Apractical guide to quantitative surface and subsurface map interpretation, 2nd edition, springer, 394P.