ISSN: 2350-0328
International Journal of Advanced Research in Science, Engineering and Technology
Vol. 8, Issue 8 , August 2021

A Comparative Study of Paleostress Directions at Bekhme and Shiranish Formations in Bekhair and Chia Gara Anticlines. Duhok, Iraq

Nazar M. Rashid, Ramadhan Haji Sulaiman Zaidky

Dept. of Petroleum Engineering, College of Engineering, University of Zakho,Iraq.
Dept. of Petroleum Engineering, College of Engineering, University of Zakho Iraq.

ABSTRACT: Bekhair and Chia Gara anticlines are located within the high folded zone of the foreland basin of the Taurus-Zagros orogeny of northern Iraq. The Bekhme and Shiranish formations exposed in both anticlines with Campanian and Maastrichtian age respectively. The Bekhme formation consists of dolomitic limestone, however, the Shiranish formation consists of marly limestone in the lower part and marls in the upper part. These formations are highly jointed and the structural attitudes of the joints such as strike and dip angle are measured to find the direction of stresses responsible for creating these joints in these formations. The joints are classified into joint sets and joint systems. The joint sets are tensional joints their planes are parallel to the maximum stress (δ1) and the movement of these planes are parallel to the minimum stress (δ3). The joint systems are shear joints their acute angles are bisected in order to detecting the direction of the maximum stress axes (δ1), nonetheless, the obtuse angles of shear joints to detecting the minimum stress axes (δ3). The average of Paleostress direction responsible for folding in traverse 1 in Bekhair anticline was (S195°W - N356°W), however, in traverses 2 and 3 of Chia Gara anticline were (S168°E - N330°W) and (S163°E - N353°W) respectively.

Keywords: Paleostress, Bekhair, Chia Gara, joint sets, joint systems, stereonet projection, traverse.

I. INTRODUCTION

The paleostress analysis is the aspect of structural geology that deals with the interpretation of the tectonic stresses which once were responsible for creating the anticlines in the study area. It is believed that the fractures are associated with the process of folding. The generation of joints was a subject of controversy since the last century when (De Sitter, 1964) and some other scientists concluded that joints were generated during folding. (Numan et al., 1998) suggested that the attitude of joints in the limbs and crestal areas were different, and about their genesis they may have been developed since the synsedimentary tectonic, and added that when the joint attitudes of Pila Spi limestone formation in Bashiqa, Ain Safra and Jebel Maqlub anticlines (northwestern Mosul city) were reoriented to their original horizontal beds they looked similar.

The dynamic analysis of the fractures (joints, faults & micro fractures) in the rocks depends on comparison between the arrangement of the fractures developed in the field and the arrangement of same fractures developed in the laboratories during mechanical tests (Van der Pluim and Marshak, 2004). The mechanical tests of the clay models in the rock mechanical laboratories revealed good results about the tectonic implications of stresses from fractures. Experimentally, either individual sets or conjugate systems developed in a clay cake during Riedel's experiments (Bles and Fuega, 1986) (Fig. 1 and 2).

ISSN: 2350-0328
International Journal of Advanced Research in Science, Engineering and Technology
Vol. 8, Issue 8 , August 2021

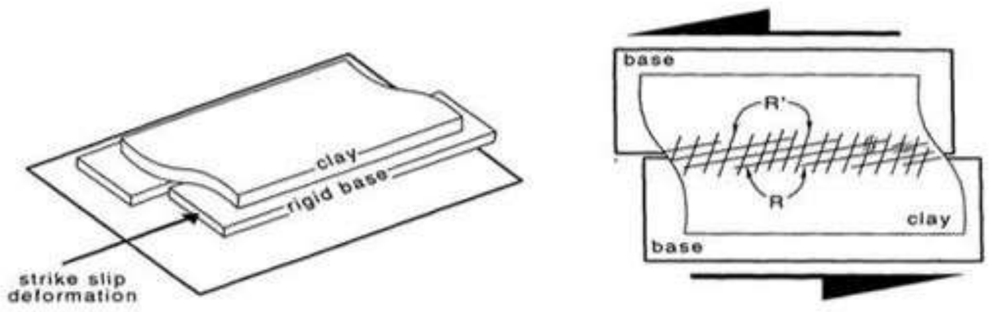

Fig. 1 The Riedel's experiment and the associated fractures R1 and R2 developed in overlaying clay bed. (Bles and Feuga, 1986)

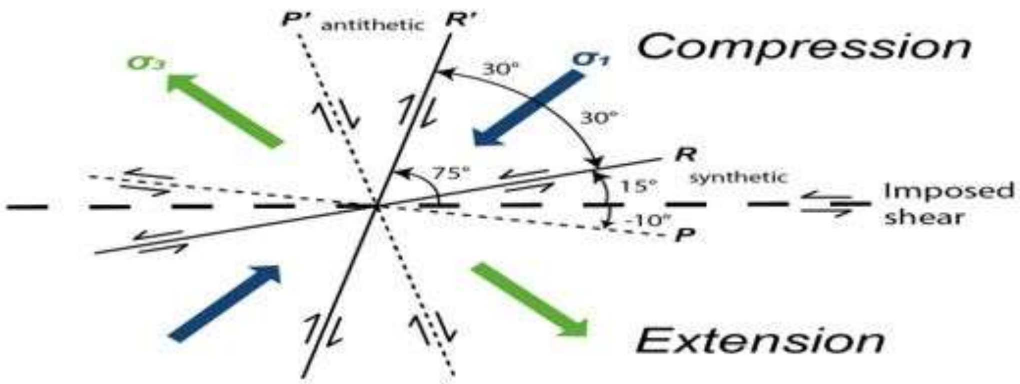

Fig. 2 The dynamic analysis of the fractures developed during Riedel's experiments (Hillacre et al., 2017).

The maximum stress axes usually bisect the acute angle of conjugate shear joints, nevertheless, the minimum stress axes bisect the obtuse angle of conjugate shear joints. (Wilcox et al., 1973) in (Bles and Feuga, 1986) concluded from a field study that some en-echelon arrays of miner folds occur at an angle of about 45° to the principal shear direction and 90° to the T- Fractures. (Ramsay, 1962) in (Ramsay and Huber, 1987) mentioned that the principal stress axes (δ1, δ2, and δ3) are normal to each other and they have a relationship with the sense of folds, suggesting that the (δ1) is horizontally perpendicular to fold axis and it is the maximum stress axis responsible for fold shortening, (δ2) is the intermediate stress axis and it is vertically perpendicular to fold axis, whereas (δ3) is horizontally parallel to fold axis and it is the minimum stress responsible for fold lengthening. The direction of stresses has been a vital subject in the aspect of structural geology. (Numan et al.,1998) concluded that the orientation of tectonic joints during folding was approximately (N-S) and (NW – SW) or (NE – SW) in Bashiqa, Ain Safra and Jebel Maqlub anticlines northwestern Mosul city. Moreover, (Al-Jumaily et al., 2012) and during their research about Perat anticline northeastern Sulaymaniyah city, referred that the direction of maximum compression stresses deduced from faults, stylolites, veins and tension joints during the folding episode was (NNE – SSW) and sometimes (NNW-SSE), whereas the direction of compression stresses during relaxation after folding was (ENE – WSW) and sometimes (E-W) (parallel to fold axis). The aim of this study is to make a paleostress comparison between Bekhair and Chia Gara anticlines by analyzing the directions of tectonic joints developed in Cretaceous competent exposures represented by Bekhme and Shiranish formations selected from 6 locations distributed within three traverses.

ISSN: 2350-0328
International Journal of Advanced Research in Science, Engineering and Technology
Vol. 8, Issue 8 , August 2021

II. TECTONIC AND GEOLOGICAL SETTING OF THE STUDY AREA

The study area is bounded between two latitudes 37° 03' 58.11" and 36° 51' 46.64" and two longitudes 43° 22' 54.79" and 43° 01' 17.12" covering an area of about 301 Km^2. Tectonically, the study area is located within the high folded zone of the foreland basin of the Taurus- Zagros orogeny of northern Iraq (Numan, 1997) (Fig. 3). This orogenic belt is a part of Alpine orogeny when the Arabian plate subducted underneath Eurasian plate in the Late Cretaceous. The main tectonic feature is the ophiolite obduction leading to a mild compression environment along the Neo-Tethys margin. The continuous subduction led to the oblique continental collision between Arabian plate and Eurasian plate at the time between Middle – Late Miocene. This collision was a reason for developing the (N-S), (NNW-SSE) and (NNE-SSW) tectonic stresses which in turn led to the development of the anticlines along the Zagros – Taurus orogeny. The geological time of TMS (Tectonostratigraphic Megasequence) of Bekhme and Shiranish formations belongs to AP9 (Arabian Plate 9). This TMS has lasted some 29 Ma (Sharland et al., 2001). The stratigraphy of the study area at Chia Gara anticline consists of rocks range in age from Late Jurassic to Late Miocene. However, the Bekhair anticline exposes rocks range in age from Late Cretaceous to Late Miocene. The Bekhme and Shiranish formations are well exposed in both anticlines and their locations were detected along the road cuts within three traverses at six locations. The first traverse cuts through Bekhair anticline and the second and third traverses cut through Chia Gara anticline (Fig. 4 and 5). The geological age of Bekhme formation is Campanian and consists of secondary dolomitic limestones which replaced the organic limestone and also consists of basal conglomerate in the lower boundary (Wetzel, 1950) in (Bellen et al., 1959). Nevertheless, the geological age of Shiranish formation is Maastrichtian and consists of marls in the upper part and overlying thin beds of marly limestone in the lower part (Hanson, 1940) in (Bellen et al., 1959).

ISSN: 2350-0328
International Journal of Advanced Research in Science, Engineering and Technology
Vol. 8, Issue 8 , August 2021

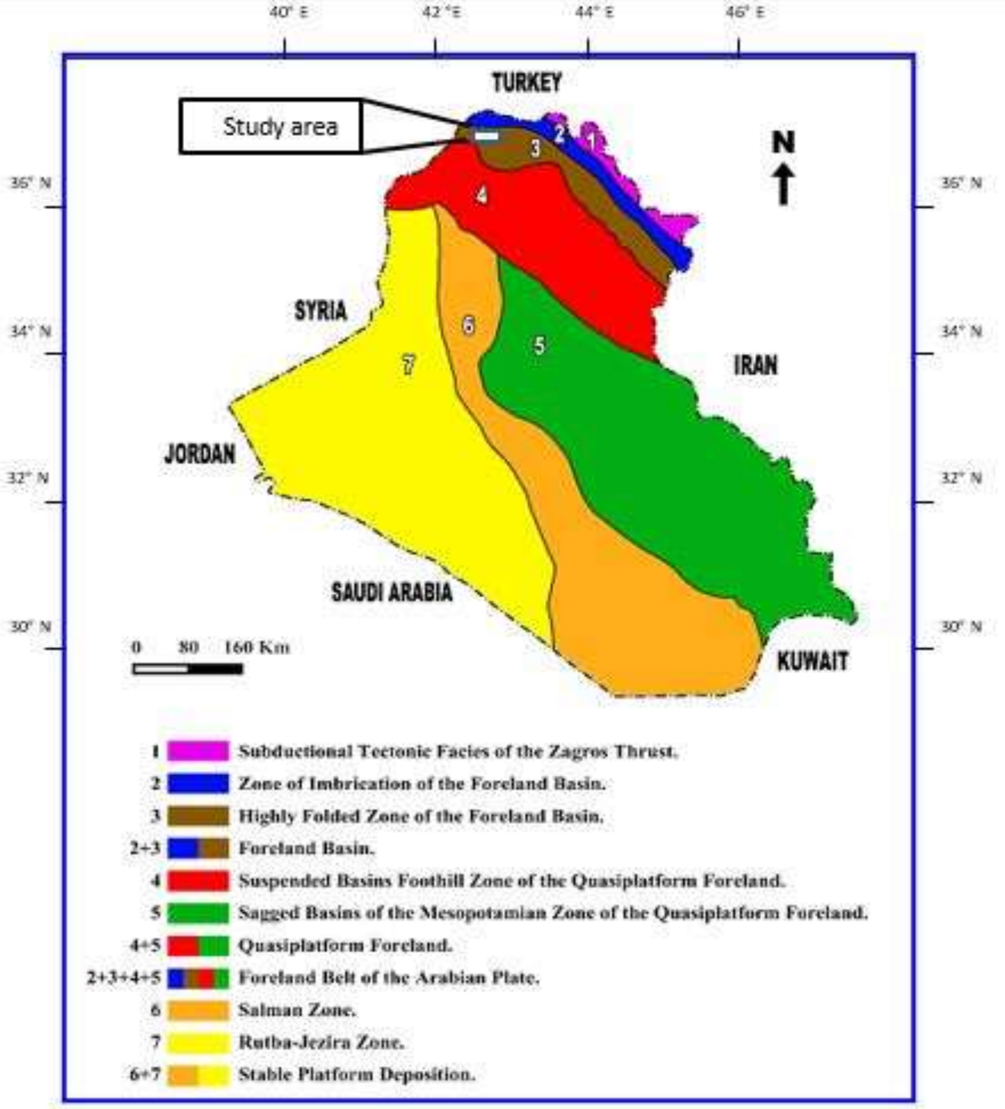

Fig. 3 The tectonic map of Iraq (Numan, 1997).

ISSN: 2350-0328
International Journal of Advanced Research in Science, Engineering and Technology
Vol. 8, Issue 8 , August 2021

Fig. 4 Google Image shows the traverses of study area.

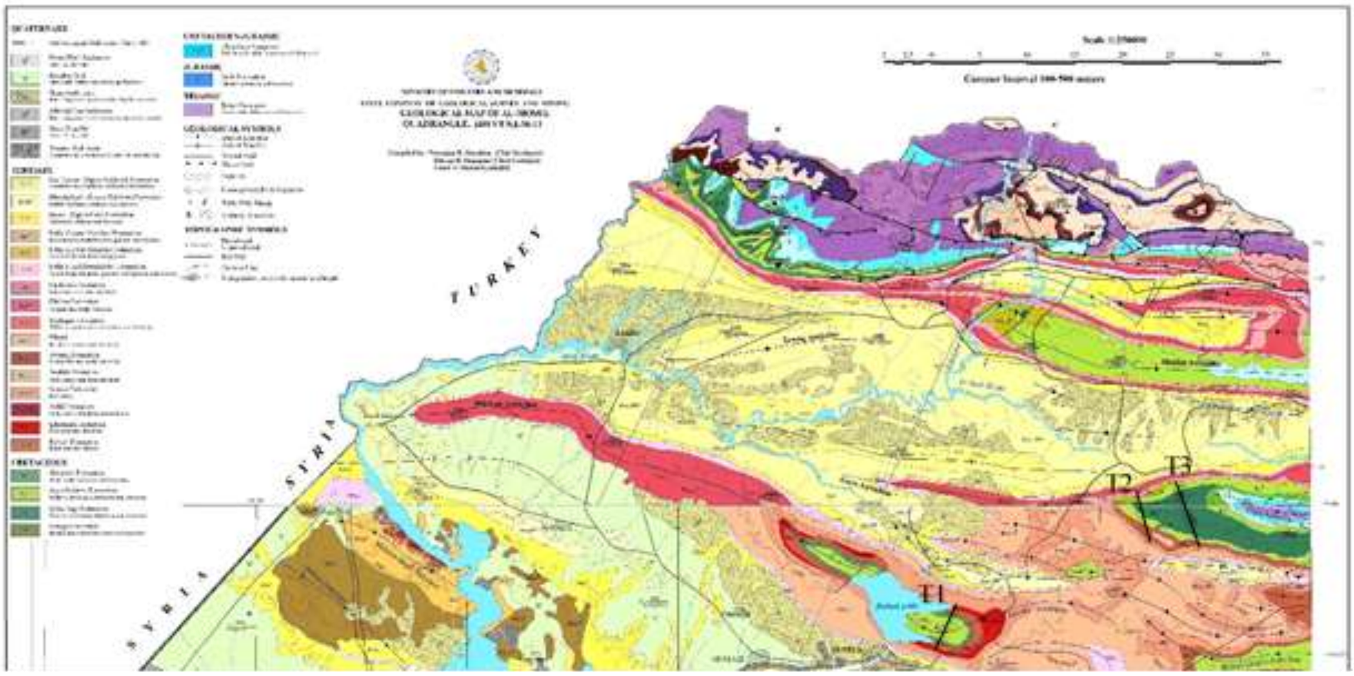

Fig. 5 The geological map of Al-Mosul quadrangle after (Sissakian et al., 2013) shows the study area traverses.

ISSN: 2350-0328
International Journal of Advanced Research in Science, Engineering and Technology
Vol. 8, Issue 8 , August 2021

III. METHODOLOGY

The research method was implemented firstly with the field work stage, this stage was proceeded with a field reconnaissance to Bekhme and Shiranish formations through six locations in Bekhair and Chia Gara anticlines. The locations were distributed on three traverses; Bajilor-Yak Mala traverse in Bekhair anticline, the other two traverses are Mazi- Ashawa and Spindar- Garagu in Chia Gara anticline. The GPS readings of these locations were registered then plotted on the google image (Fig. 4). The average of bedding planes (strike/ dip angle) was measured at each location by using Silva compass through depending the (LHR) (Left Hand Rule) during measurements. In addition, about 120 joint attitudes were measured too (20 readings for each location). A digital camera was used to take pictures for the joint sets and systems to identify their types, their relationships with bed axes, then to find out their paleostresses directions. The office work stage was done by plotting the joint and bedding planes readings (strike/ dip angle) on the stereonet program. The joint readings were classified and the paleostress directions were interpreted. A map with a scale of (1:250000) after (Sissakian et al., 2013) was used in this research to plot the locations of study area.

IV. CLASSIFICATION OF JOINTS AND THEIR KINEMATIC ANALYSIS

The classification of systematic joints follows three major axes of the bed. These axes were established by Bronu Sander between 1926 and 1930 in (Ramsay & Huber, 1987). The axis (a) is suggested to be parallel to the dip direction of the bed, the axis (b) parallel to the strike direction of the bed, and the axis (c) at right angle to the plane of the bed (pole of bed). These three axes are perpendicular to each other (Fig. 6). Afterward, many geologists such as (Turner & Weiss, 1963; Hanckok,1985) classified the joints into sets and systems. (Stearns, 1969) stated that the maximum stress axis is responsible for folding and it can be deduced from the acute angle of shear joints or parallel to plane of tension joints (Fig. 7). The classification of joints and the stresses interpretation is shown in (Table 1). In joint sets, the direction of the maximum stress axis (δ1) is parallel to the joint plane (compressive normal stress), whereas the minimum stress axis (δ3) is perpendicular to the joint plane (extensive normal stress). Nonetheless, in joint systems, the maximum stress axis (δ1) bisects the acute angle (compressive shear stress).

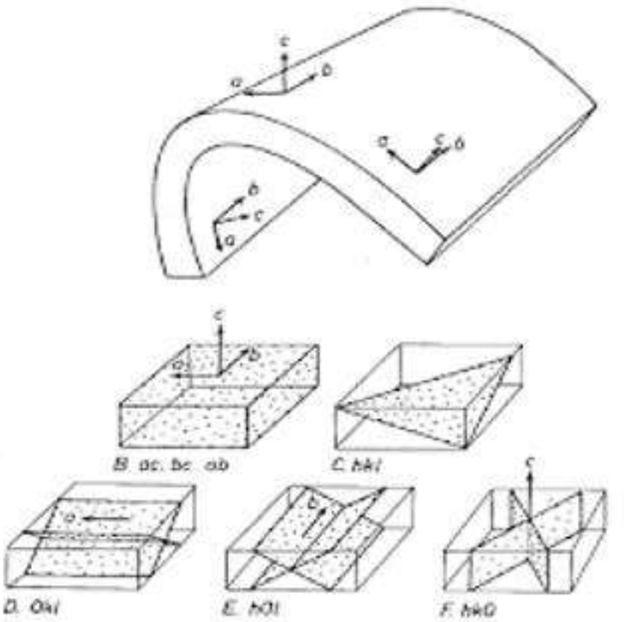

Fig. 6 Joints classification with respect to the fold axes (Bronu sander 1926, 1930) in (Ramsay & Huber, 1987)

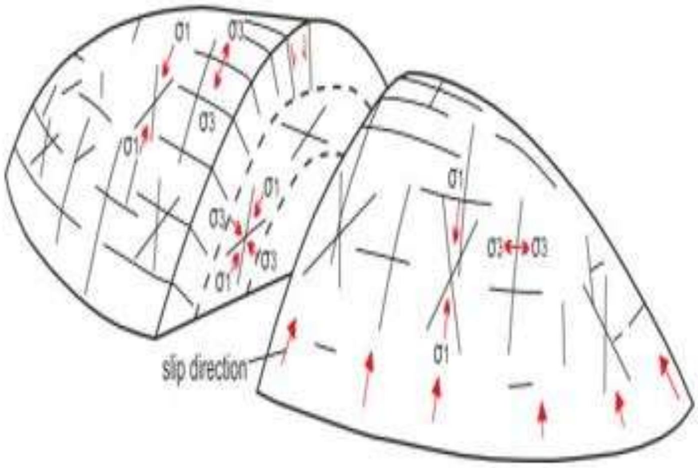

Fig. 7 Fold – related joint sets and systems (Stearns, 1969)

ISSN: 2350-0328
International Journal of Advanced Research in Science, Engineering and Technology
Vol. 8, Issue 8 , August 2021

Table 1. Classification of joint sets and systems and their kinematic analysis according to the fold axes.

Joint Sets	Description	Joint plane orientation	δ1 and δ3 Directions
Ab	Axis (a) is dip direction of bed and axis (b) is strike of bed, joint also called "bedding plane joint".	Joint plane is parallel to the bed axes (a) and (b).	δ1 parallel to (b) & (a) axes, δ3 orthogonal to Ab joint plane.
Bc	Axis (b) is strike of bed and axis (c) is pole of bed which is perpendicular to bed plane, joint also called "strike joint"	Joint plane is parallel to the bed axes (b) and (c).	δ1 parallel to (b) axis, δ3 orthogonal to Bc joint plane.
Ac	Axis (a) is dip of bed and axis (c) is pole of bed, joint also called "dip joint".	Joint plane is parallel to the bed axes (a) and (c).	δ1 parallel to (a) axis, δ3 orthogonal to Ac joint plane.
Joint Systems	**Description**	**Joint plane orientation**	**δ1 and δ3 Directions**
hk0	Axis (h) is the dip direction of bed and axis (k) is the strike of bed.	Joint plane cuts the axes (h) and (k) and parallel to (l) axis, then (l) = 0.	δ1 bisects the acute angle, and parallel to (a) or (b) axes, δ3 bisects the obtuse angle and parallel to (a) and (b) axes.
h0l	Axis (h) is the dip direction of bed and axis (l) is the pole of bed.	Joint plane cuts the axes (h) and (l) and parallel to (k) axis, then (k) = 0.	δ1 bisects the acute angle and parallel to (c) or (a) axes, δ3 bisects the obtuse angle and parallel to (c) or (a) axes.
0kl	Axis (k) is the strike of bed and axis (l) is the pole of bed.	Joint plane cuts the axes (k) and (l) and parallel to (h) axis, then (h) = 0.	δ1 bisects the acute angles parallel to (c) or (b) axes, δ3 bisects the obtuse angle and parallel to (c) or (b) axes.

ISSN: 2350-0328
International Journal of Advanced Research in Science, Engineering and Technology
Vol. 8, Issue 8 , August 2021

V. RESULTS AND DISCUSSION

The joints in the traverses were more abundant than faults and other micro – fractures. Most of these joints were considered as tectonic joints and they have an importance in paleostress implications and they are mostly tension and shear joints. The tension joints at first and second locations are more abondance than shear joints. Generally, the joints developed in Cretaceous beds were more frequent than those developed in Middle – Late Eocene beds. This may be attributed to the doubly tectonic pulses affected the Bekhme and Shiranish formations, first one in the Late Cretaceous when Arabian plate subducted underneath Eurasian plate, second one in the Late Eocene when collision happened between Arabian plate and Eurasian plate. The paleostress directions were analyzed through six locations distributed on three traverses, and as followings:

A. TRAVERSE 1 (BAJILOR – YAK MALA)

This traverse begins from Bajilor village to Yak Mala village and cut across Bekhair anticline from southwest to northeast with a length of about (3.5 km.). The study area of Bajilor village situated on the southern limb of Shiranish formation in Bekhair anticline on latitude 36° 52' 24.19" N and longitude 43° 02' 08.2" E. The joint sets are more abundance than joint systems on the bedding planes of this formation and this may belong to the alternation of weaker (incompetent) marl beds with the harder (competent) limestone beds (Ramsay and Huber, 1987) (Fig. 8).

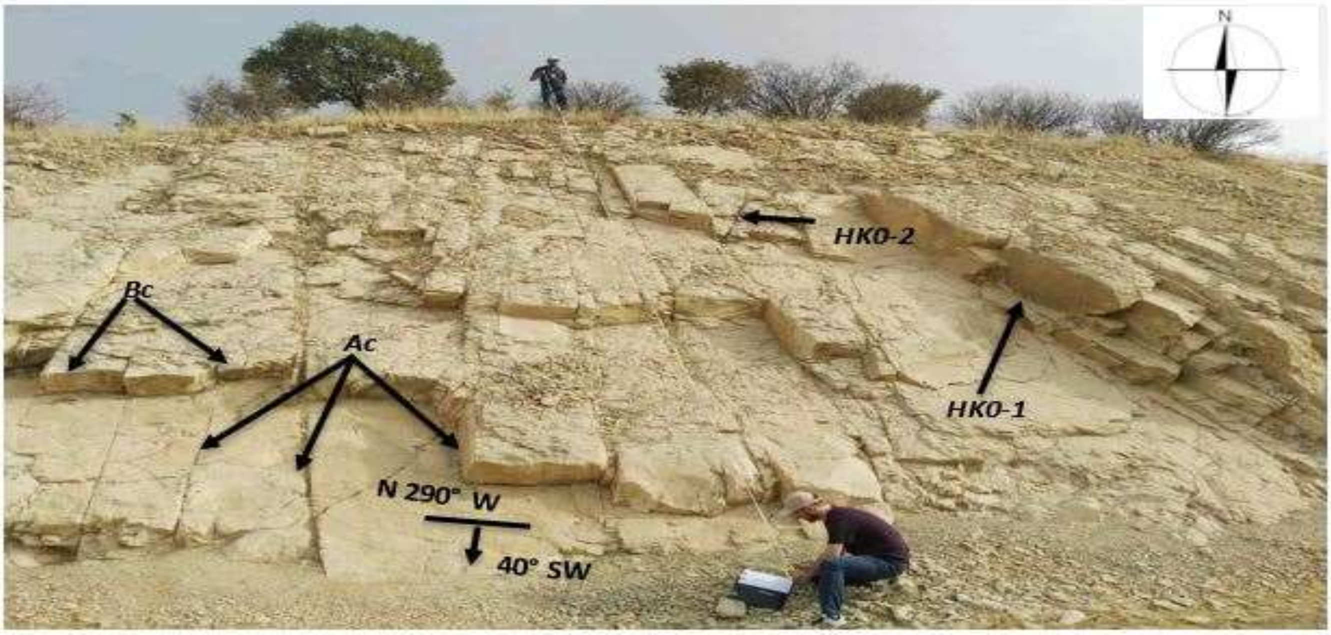

Fig. 8 AC and BC joint sets developed in southern limb of Shiranish formation – Bekhair anticline near Bajilor village.

ISSN: 2350-0328

International Journal of Advanced Research in Science, Engineering and Technology

Vol. 8, Issue 8 , August 2021

The average of bedding plane was (N290°W/40° SW) and the joint sets and their paleostress attitudes are seen in (Table.2 and 3). The second location is located on the northern limb of Bekhme formation near Yak Mala village on latitude 36° 54' 10.4 " N and longitude 43° 03' 34" E. The set joints were also higher than system joints and the average of bedding plane was (N093°E/25° NW).

Table. 2 The joint set measurements and the attitudes of (δ1 and δ3) in T-1 deduced from AC joint sets.

No.	JOINT TYPE	STRIKE°	DIP ANGLE°	(δ1) (TREND/PLUNGE)	(δ3) (TREND/PLUNGE)
1	AC	190	80	N354°W/57°NW	S100°E/10°SE
2	AC	192	85	S195°W/26°SW	S102°E/05°SE
3	AC	190	87	S190°W/00°SW	S100°E/03°SE
4	AC	195	85	S197°W/21°SW	S105°E/05°SE
5	AC	191	82	S199°W/44°SW	S101°E/08°SE
6	AC	194	80	S194°W/00°SW	S104°E/10°SE
7	AC	190	82	S193°W/22°SW	S100°E/08°SE
8	AC	196	84	S196°W/00°SW	S106°E/06°SE
9	AC	197	80	S210°W/51°SW	S107°E/10°SE
10	AC	193	81	S182°W/51°SW	S103°E/09°SE
11	AC	350	84	N350°W/00°NW	S260°W/03°SW
12	AC	360	80	N/00°N	E/10°E
13	AC	355	87	N355°W/00°NW	S265°W/03°SW
14	AC	354	80	N354°W/00°NW	S264°W/10°SW
15	AC	360	88	N/00°N	E/02°E
16	AC	005	80	N001°E/22°NE	N275°W/10°NW
17	AC	355	82	N003°E/44°NE	S265°W/08°SW
18	AC	350	85	N347°W/26°NW	S260°W/05°SW
19	AC	002	82	N002°E/00°NE	N272°W/08°NW
20	AC	350	83	N354°W/26°NW	S260°W/07°SW

Table. 3 The joint set measurements and the attitudes of (δ1 and δ3) in T-1 deduced from BC joint sets.

No.	JOINT TYPE	STRIKE°	DIP ANGLE°	(δ1) (TREND/PLUNGE)	(δ3) (TREND/PLUNGE)
1	BC	286	58	N286°W/00°NW	S196°W/32°SW
2	BC	305	74	N305°W/00°NW	S215°W/16°SW
3	BC	290	70	N286°W/12°NW	S200°W/20°SW
4	BC	295	65	N295°W/00°NW	S205°W/25°SW
5	BC	300	60	N308°W/13°NW	S210°W/30°SW
6	BC	280	75	N280°W/00°NW	S190°W/15°SW
7	BC	294	88	N292°W/44°NW	S204W/02°SW
8	BC	291	87	N291°W/00°NW	S201°W/03°SW
9	BC	298	80	N303°W/24°NW	S208°W/10°SW
10	BC	290	77	N290°W/00°NW	S200°W/13°SW
11	BC	115	73	S120°E/15°SE	N025°E/17°NE
12	BC	100	65	S142°E/55°SE	N010°E/15°NE
13	BC	111	74	S121°E/30°SE	N021°E/16°NE
14	BC	110	70	S122°E/39°SE	N020°E/20°NE
15	BC	105	77	S110°E/22°SE	N015°E/13°NE
16	BC	110	66	S110°E/00°SE	N020°E/24°NE
17	BC	100	75	S106°E/21°SE	N010°E/15°NE
18	BC	108	70	S099°E/24°SE	N018°E/20°NE
19	BC	110	74	S095°E/43°SE	N020°E/16°NE
20	BC	108	66	S108°E/00°SE	N018°E/24°NE

ISSN: 2350-0328
International Journal of Advanced Research in Science, Engineering and Technology
Vol. 8, Issue 8 , August 2021

The development of AC and BC joint sets in this traverse indicates that the area was affected by a compressional tectonic stress which was one time perpendicular to fold axis that developed folding and another time parallel to fold axis that reduced degree of folding. When compressional stress (δ1) was perpendicular to fold axis, the Ac joints were developed, and the extensional stress (δ3) was parallel to fold axis. However, when (δ1) hit the anticline parallel to fold axis, the (δ3) directed perpendicular to fold axis and as a result the BC joints were developed. The pulsating and relaxing episodes are still unclear; however, the relative chronology of joints (cross-cutting and termination relationship) revealed some facts that Shiranish and Bekhme formations undergone more than one tectonic pulse. The stereonet projections showed that the general attitudes of compressional stress responsible for folding at Bajilor and Yak Mala were (S195°W/12°SW) and (N356°W/07°NW) respectively, whereas the general attitudes of compressional stress responsible for fold relaxation were (N298°W/16°NW) and (S108°E/00°SE) respectively (Fig. 9, A, B, C, and D).

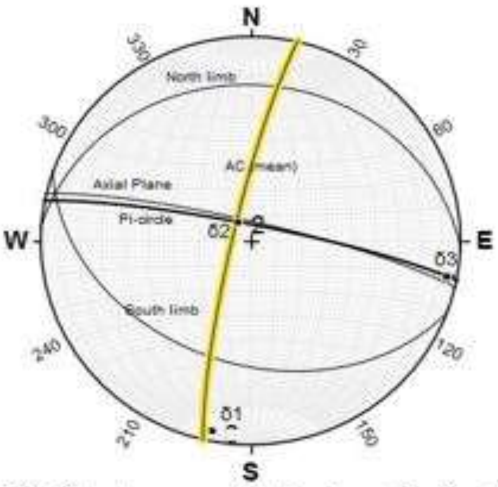

Fig. 9 A. The stereone projection shows the direction of (δ1=195/12) and (δ3=103/07) at the time of folding in S.L. of Shiranish formation, Bajilor, T1.

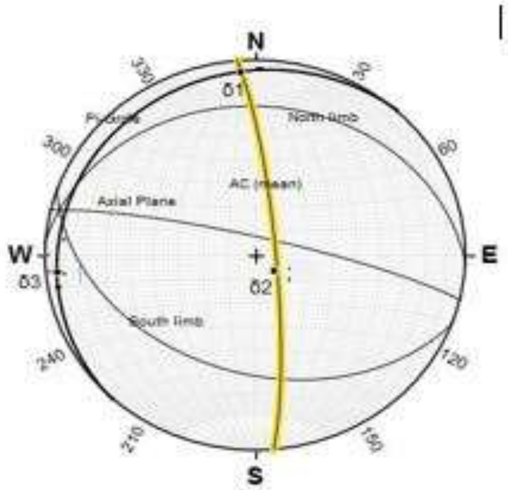

Fig. 9 B. The stereonet projection shows the direction of (δ1=356/07) and (δ3=265/06) at the time of folding in N.L. of Bekhme formation, Yak Mala, T1.

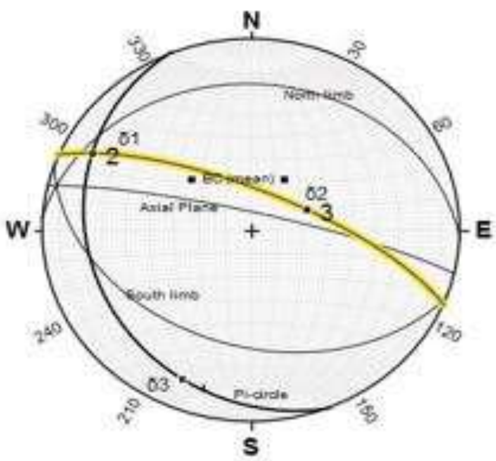

Fig. 9 C. The stereonet projection shows the direction of (δ1=298/16) and (δ3=203/17) at the time of fold relaxation in S.L. of Shiranish formation, Bajilor, T1.

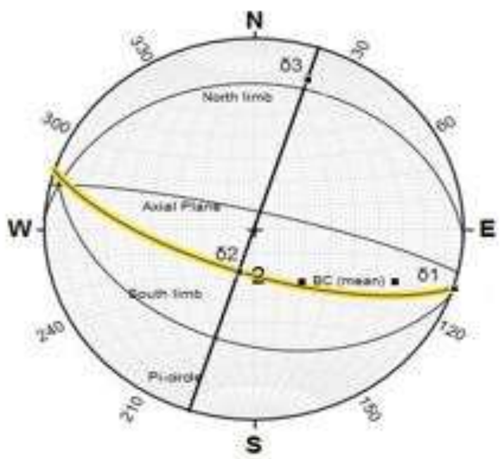

Fig. 9 D. The stereonet projection shows the direction of (δ1=108/00) and (δ3=018/19) at the time of fold relaxation in N.L.of Bekhme formation, Yak Mala, T1.

ISSN: 2350-0328
International Journal of Advanced Research in Science, Engineering and Technology
Vol. 8, Issue 8 , August 2021

B. TRAVERSE 2 (SPINDAR – ASHAWA)

The second traverse cuts perpendicularly the fold axis of Chia Gara anticline beginning from Spindar village to Ashawa village. The length of this travers is about (8 km) and extends from southeast to northwest. Spindar village is a third study location near the southern limb of Shiranish formation which locates on latitude 36° 57' 21.7" N and longitude 43° 20 ' 05.23" E. The bedding plane average was (S262°W/27°SE) and the attitudes of joints and stresses are listed in (Table 4 and 5). The fourth location situated on the northern limb of Bekhme formation near Ashawa village on latitude 37° 01' 10.41" N and longitude 43° 17' 31.7" E. The average bedding plane was (N066°E/53°NW). Many types of joints were seen in this traverse; however, the number of joint systems were higher (mostly hk0) than joint sets (Fig. 10).

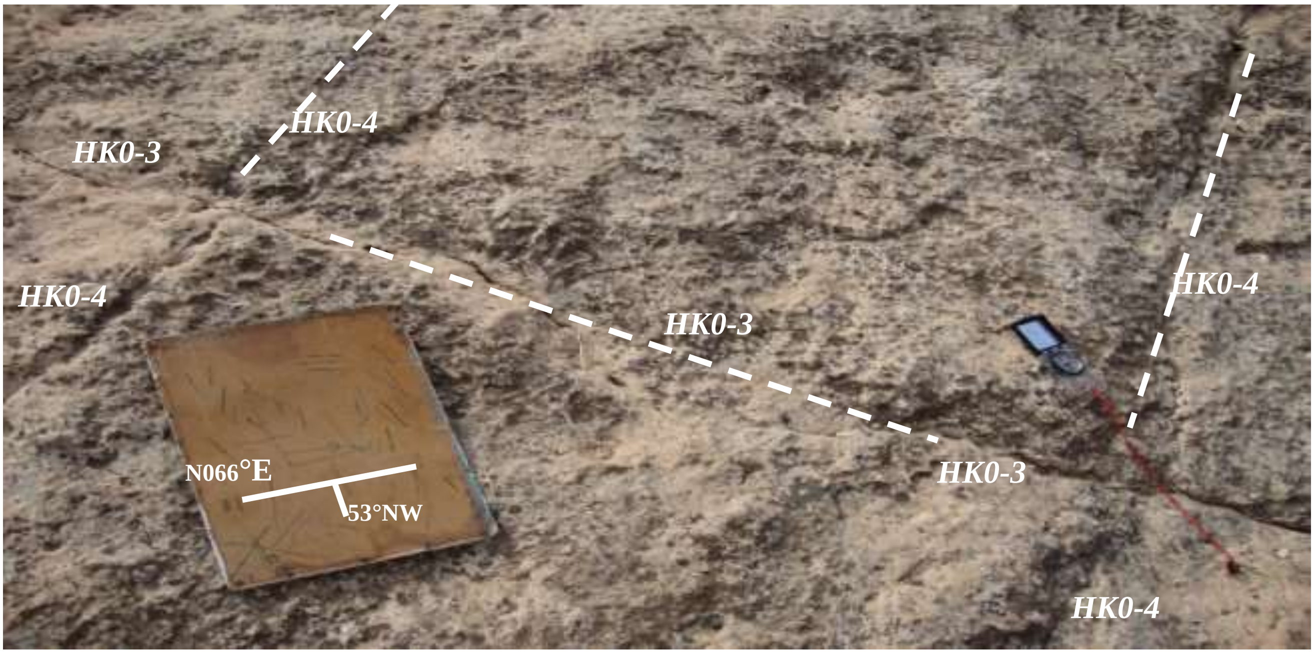

Fig. 10 HK0 – 3 and HK0 – 4 joint systems developed in northern limb of Bekhme formation – Chia Gara anticline near Ashawa village. The red rope of a compass refers to dip direction.

From the stereonet plot shown in (Fig. 11 A, B, C and D), it was found that the general attitudes of compressional stress responsible for folding at Spindar and Ashawa locations were (S168°E/01°SE) and (N330°W/04°NW) respectively, whereas the general attitudes of compressional stress responsible for relaxation were (S262°W/01°SW) and (N074°E/00°NE) respectively.

ISSN: 2350-0328
International Journal of Advanced Research in Science, Engineering and Technology
Vol. 8, Issue 8 , August 2021

Table. 4 The attitudes of (δ1 and δ3) in T-2 deduced from conjugate joint systems (HK0-1 and KH0-2).

No.	JOINT TYPE	STRIKE°	DIP ANGLE°	(δ1) (TREND/PLUNGE)	(δ3) (TREND/PLUNGE)
1	Hk0 – 2	190	20	S159°E /02°SE	N076°E /72°NE
2	Hk0 – 1	140	18		
3	Hk0 – 2	191	15	S177°E /04°SE	N074°E/725°NE
4	Hk0 – 1	141	18		
5	Hk0 – 2	190	16	S/06°S	N071°E/73°NE
6	Hk0 – 1	139	21		
7	Hk0 – 2	190	18	S155°E/04°SE	N078°E/75°NE
8	Hk0 – 1	141	15		
9	Hk0 – 2	191	13	S162°E/01°SE	N078°E/79° NE
10	Hk0 – 1	142	12		
11	Hk0 – 1	310	50	N328°W/04°NW	S235°W/42° SW
12	Hk0 – 2	340	48		
13	Hk0 – 1	315	55	N335°W/09°NW	S238°W/38°SW
14	Hk0 – 2	342	51		
15	Hk0 – 1	312	55	N329°W/04°NW	S236°W/37°SW
16	Hk0 – 2	340	53		
17	Hk0 – 1	314	50	N326°W/00°NW	S236°W/41°SW
18	Hk0 – 2	338	50		
19	Hk0 – 1	317	55	N334°W/07°NW	S239°W/37°SW
20	Hk0 – 2	341	52		

Table. 5 The attitudes of (δ1 and δ3) in T-2 deduced from conjugate joint systems (HK0-3 and KH0-4).

No.	JOINT TYPE	STRIKE°	DIP ANGLE°	(δ1) (TREND/PLUNGE)	(δ3) (TREND/PLUNGE)
1	Hk0 – 3	240	15	N283°W/06°NW	S165°E/77°SE
2	Hk0 – 4	275	11		
3	Hk0 – 3	242	13	S250°W/03°SW	S172°E/77°SE
4	Hk0 – 4	280	15		
5	Hk0 – 3	240	12	S267°W/02°SW	S169°E/79°SE
6	Hk0 – 4	280	11		
7	Hk0 – 3	245	10	S242°W/04°SW	S179°E/79°SE
8	Hk0 – 4	282	13		
9	Hk0 – 3	248	13	N273°W/02°NW	S175°E/78°SE
10	Hk0 – 4	283	12		
11	Hk0 – 3	040	10	N072°E/00°NE	N343W/82NW
12	Hk0 – 4	105	10		
13	Hk0 – 3	040	11	N076E/01NE	N340W/81NW
14	Hk0 – 4	104	10		
15	Hk0 – 3	040	12	N076E/01NE	N341W/80NW
16	Hk0 – 4	105	11		
17	Hk0 – 3	039	12	N072E/00NE	N342W/80NW
18	Hk0 – 4	105	12		
19	Hk0 – 3	039	11	N072E/00NE	N342W/81NW
20	Hk0 – 4	104	11		

ISSN: 2350-0328
International Journal of Advanced Research in Science, Engineering and Technology
Vol. 8, Issue 8 , August 2021

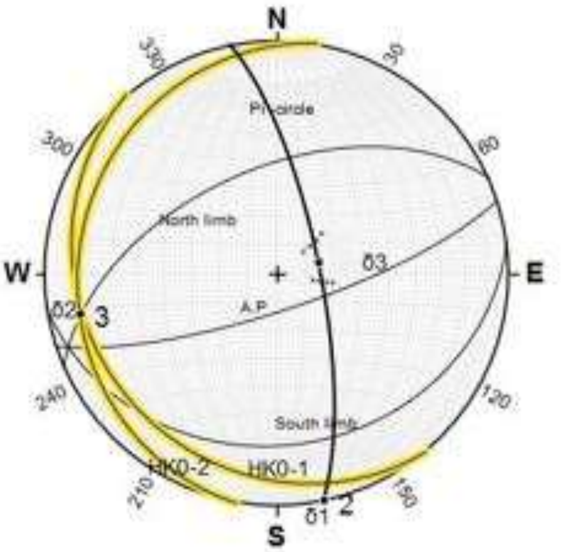

Fig. 11 A. The stereonet projection shows the attitudes of (δ1=168/01) and (δ3=075/75) at the time of folding in S.L. of Shiranish formation, Spindar, T2.

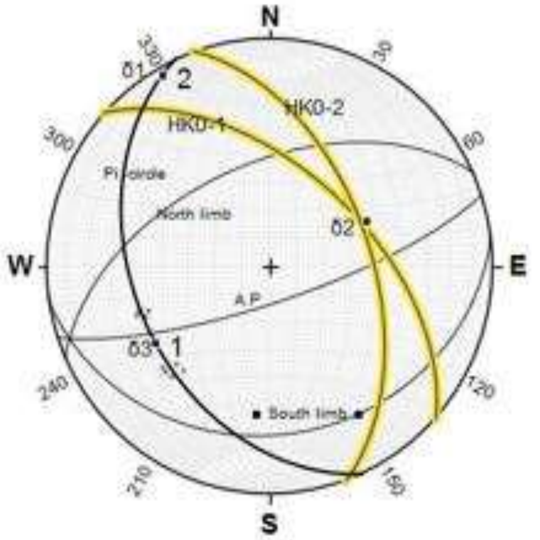

Fig. 11 B. The stereonet projection shows the attitudes of (δ1=330/04) and (δ3=237/39) at the time of folding in N.L. of Bekhme formation, Ashawa, T2.

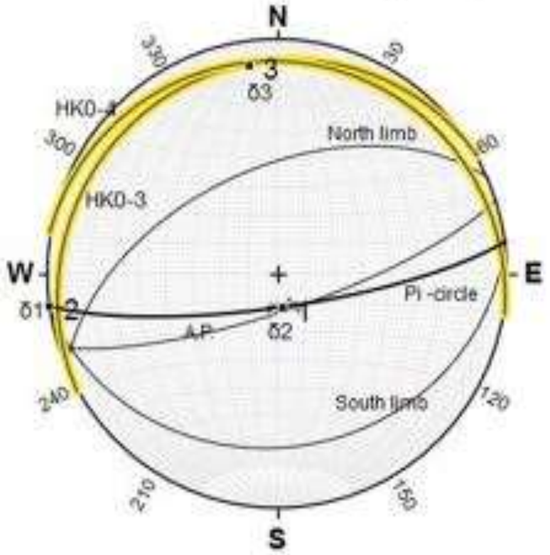

Fig. 11 C. The stereonet projection shows the attitudes of (δ1=262/01) and (δ3=172/78) at the time of fold relaxation in S.L. of Shiranish formation, Spindar, T2.

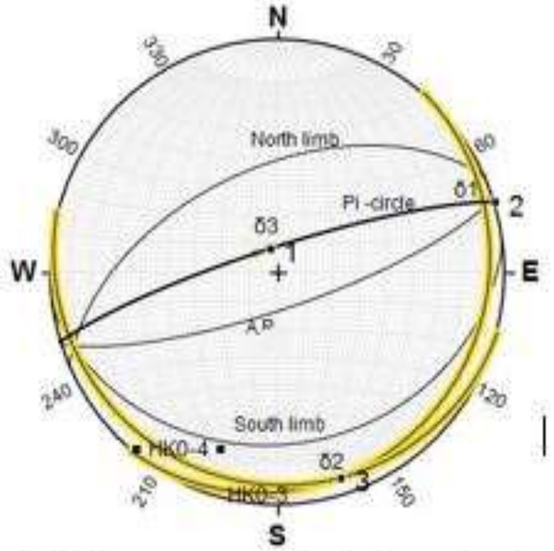

Fig. 11 D. The stereonet projection shows the attitudes of (δ1=074/00) and (δ3=341/81) at the time of fold relaxation in N.L. of Bekhme formation, Ashawa, T2.

ISSN: 2350-0328
International Journal of Advanced Research in Science, Engineering and Technology
Vol. 8, Issue 8 , August 2021

C. TRAVERSE 3 (MAZI – GARAGU)

This traverse starts from Mazi village on the southern limb of Bekhme formation and ends at Garagu village. The length of this travers is roughly (12 km) and extends from southeast to northwest in a parallel way to the second traverse. Mazi village is well known by its beautiful nature and springs which come from southern limb of Bekhme formation and flow towards south of village. The Mazi location is located on latitude 36° 56' 31.00" N and longitude 43° 23 ' 13.95." E. The bedding plane average was (N272°W/38°SW) and the attitudes of joints and their paleostresses are shown in (Table 6 and 7). The last location is near Garagu village which is about (12 km) north of Mazi village. This location is located on the northern limb of Bekhme formation on latitude 37° 01' 10.41" N and longitude 43° 17' 31.7" E. The average bedding plane of this formation is (N082°E/84°NW). The stereonet diagrams in (Fig. 12 A, B, C and D) showed that the general attitudes of compressional stress responsible for folding at Mazi and Garagu locations were (S163°E/01°SE) and (S173°E/02°SE) or (N353°W/02°NW) respectively, whereas the general attitudes of compressional stress responsible for relaxation were (N275°W/01°NW) and (S097°E/00°SE) respectively.

Table. 6 The attitudes of (δ1 and δ3) in T-3 deduced from conjugate joint systems (HK0-1 and KH0-2).

No.	JOINT TYPE	STRIKE°	DIP ANGLE°	(δ1) (TREND/PLUNGE)	(δ3) (TREND/PLUNGE)
1	Hk0 – 1	130	45	S165°E/05°SE	N068°E/52°NE
2	Hk0 – 2	190	40		
3	Hk0 – 1	135	45	S163°E/01°SE	N072°E/49°NE
4	Hk0 – 2	189	44		
5	Hk0 – 1	132	40	S160°E/03°SE	N074°E/53°NE
6	Hk0 – 2	194	43		
7	Hk0 – 1	136	43	S161°E/03°SE	N074°E/49°NE
8	Hk0 – 2	191	46		
9	Hk0 – 1	132	45	S165°E/04°SE	N070°E/51°NE
10	Hk0 – 2	190	41		
11	Hk0 – 1	330	85	N350°W/00°NW	S260°W/05°SW
12	Hk0 – 2	010	85		
13	Hk0 – 1	335	87	N355°W/02°NW	S265°W/04°SW
14	Hk0 – 2	014	86		
15	Hk0 – 1	340	82	N357°W/08°NW	S268°W/06°SW
16	Hk0 – 2	015	87		
17	Hk0 – 1	331	81	N352°W/01°NW	S262°W/10°SW
18	Hk0 – 2	012	80		
19	Hk0 – 1	333	84	N353°W/00°NW	S264°W/05°SW
20	Hk0 – 2	014	86		

ISSN: 2350-0328
International Journal of Advanced Research in Science, Engineering and Technology
Vol. 8, Issue 8 , August 2021

Table. 7 The attitudes of (δ1 and δ3) in T-3 deduced from conjugate joint systems (HK0-3 and KH0-4).

No.	JOINT TYPE	STRIKE°	DIP ANGLE°	DIRECTION OF (δ1)	DIRECTION OF (δ3)
1	Hk0 - 3	239	10	N310°W/01°NW	S213°W/80°SW
2	Hk0 – 4	280	11		
3	Hk0 – 3	241	10	S248° W/03°SW	S173°E/80°SE
4	Hk0 – 4	282	12		
5	Hk0 - 3	240	11	S254° W/01°SW	S171°E/79°SE
6	Hk0 – 4	281	12		
7	Hk0 – 3	240	09	S251° W/01°SW	S171°E/81°SE
8	Hk0 – 4	280	10		
9	Hk0 - 3	244	10	N281° W/03°NW	S172°E/82°SE
10	Hk0 – 4	285	08		
11	Hk0 – 3	72	02	S091°E/00°SE	N001°E/88°NE
12	Hk0 – 4	110	02		
13	Hk0 - 3	70	01	E/00°E	N/89°N
14	Hk0 – 4	110	01		
15	Hk0 – 3	71	02	S091°E/02°SE	N/88°N
16	Hk0 – 4	110	02		
17	Hk0 - 3	73	01	S094°E/00°SE	N004°E/89°NE
18	Hk0 – 4	114	01		
19	Hk0 - 3	70	01	S091°E/01°SE	N001°E/89°NE
20	Hk0 – 4	110	01		

ISSN: 2350-0328

International Journal of Advanced Research in Science, Engineering and Technology

Vol. 8, Issue 8 , August 2021

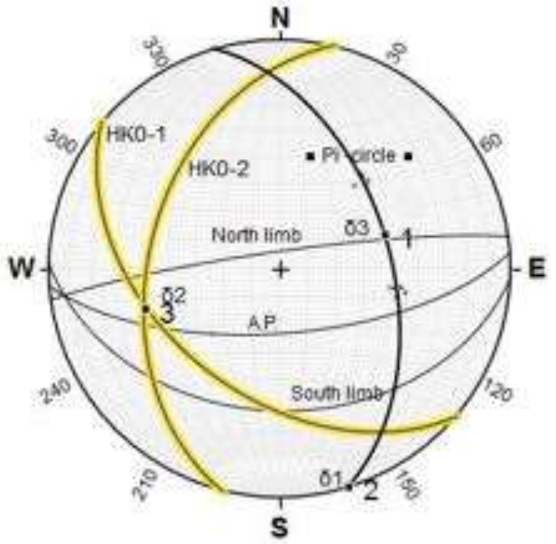

Fig. 12 A. The stereonet projection shows the attitudes of (δ1=163/01) and (δ3=072/50) at the time of folding in S.L. of Bekhme formations, Mazi T3.

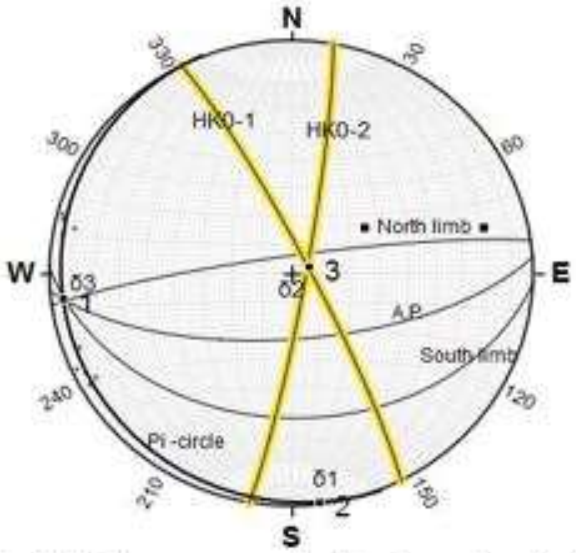

Fig. 12 B. The stereonet projection shows the attitudes of (δ1=353/02) and (δ3=264/06) at the time of folding in N.L. of Bekhme formation, Garagu T3.

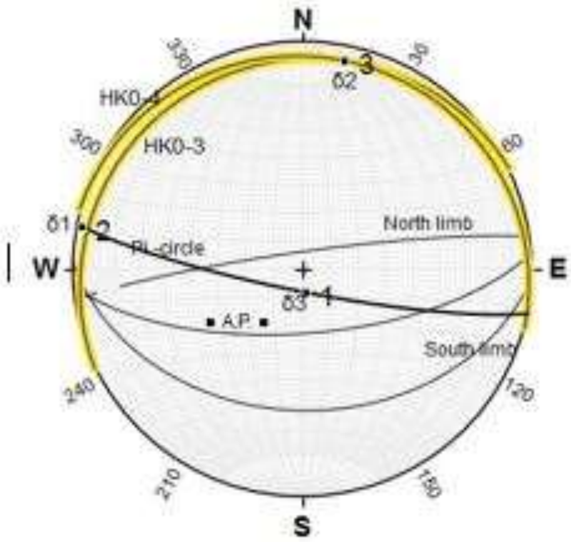

Fig. 12 C. The stereonet projection shows the average attitudes of (δ1=275/01) and (δ3=180/81) at the time of fold relaxation, S.L. of Bekhme formations,Mazi, T3.

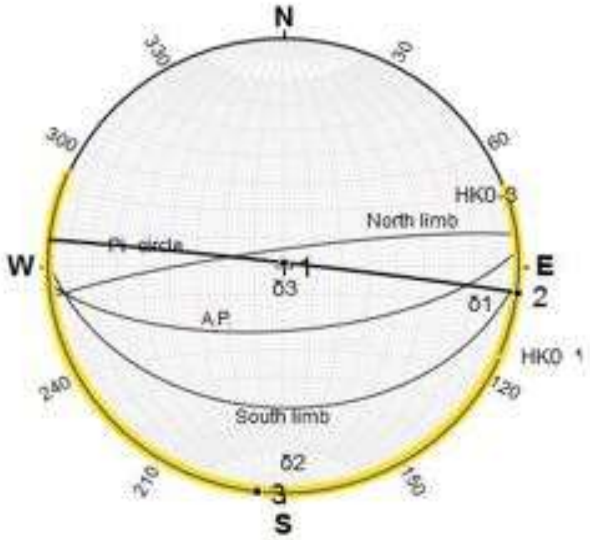

Fig. 12 D. The stereonet projection shows the average attitudes of (δ1=097/00) and (δ3=001/89) at the time of fold relaxation N.L of Bekhme formation, Garagu, T3.

ISSN: 2350-0328
International Journal of Advanced Research in Science, Engineering and Technology
Vol. 8, Issue 8 , August 2021

The kinematic interpretation of study area traverses is shown in the rose diagram in (Fig. 13). It can be noticed that there is a sharp rotation of the maximum and minimum paleostress directions at traverse 2 in relative to traverse 1 and 3. The degree of rotation (from north) between traverse 1 and 2 is about 26° anticlockwise and between traverse 2 and 3 is about 23° anticlockwise. The difference in degree of rotation is also seen from other directions. This may denote that there are two locally dextral strike-slip faults affected the area after folding, these strike - slip faults were possibly the reason behind the rotation between traverse 1 and 2 on the one hand, and between traverse 2 and 3 on the other hand. The general directions of maximum paleostress which were the reason for fold development in Bekhair anticline was (NNW-SSW). And in Chia Gara anticline they were similar in traverses 2 and 3 (NNW – SSE). In relaxation episode, however, the direction of maximum paleostress influenced Bekhair anticline in traverse 1 was (WNW – ESE), and the maximum directions influenced Chia Gara anticline in traverse 2 and 3 were (WSW – ENE) and (WNW – ESE) respectively.

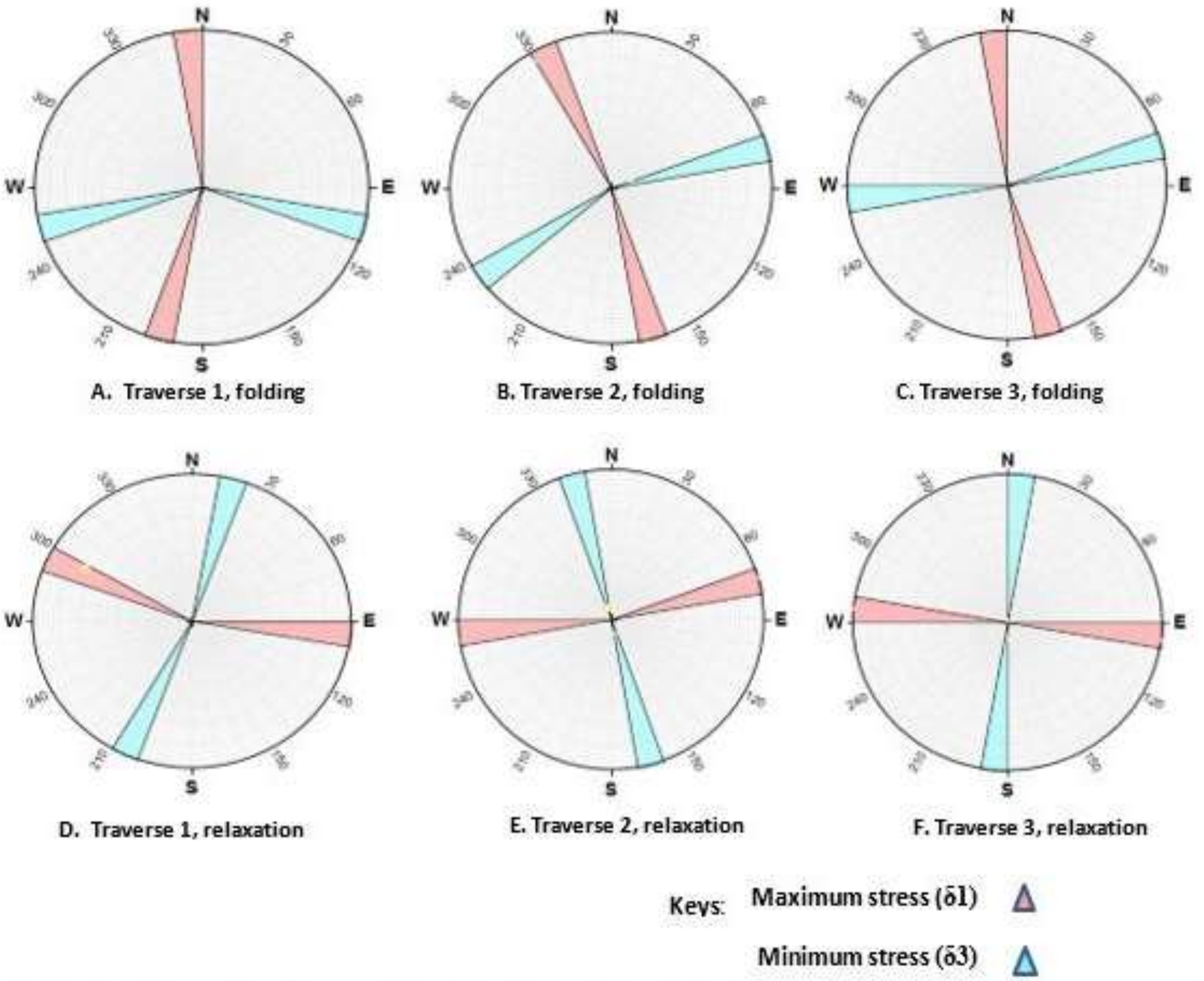

Fig. 13 Rose diagrams show the general directions of the maximum (δ1) and minimum (δ3) principal paleostress at traverses 1, 2 and 3. The diagrams (A, B and C) at the time of folding and the diagrams (D, E and F) at the time of fold relaxation.

VI. CONCLUSION

The Bekhair and Chia Gara anticlines and their associated joints were developed due to the tectonic activities between Arabian plate and Eurasian plate which began in the Late Cretaceous and continued till the Late Eocene. Most of joints developed in the Cretaceous rocks are classified as AC and BC joint sets and HK0 – 1, HK0 – 2, HK0 – 3, and HK0 – 4 joint systems. The AC and BC joint sets are more prevalence in traverse 1 than traverses 2 and 3. However the joint systems HK0 are more prevalence in traverses 2 and 3 than traverse 1. The joints AC, HK0 – 1 and HK0 – 2 indicated the compressional tectonic manner in the region and the joints BC and HK0 – 3 and HK0 – 4 indicated the extensional tectonic manner. During compressional stress, the (δ1) was perpendicular to fold axes and also was the reason behind the development of the anticlines in the region. The mean directions of compressional stress responsible for folding in Bekhair anticline deduced from Bajilor and Yak Mala were (S195°W) and (N356°W) respectively. However, the mean directions of compressional stress responsible for folding in Chia Gara anticline deduced from Spindar and Ashawa were (S168°E) and (N330°W) and Mazi and Garagu were (S163°E) and (N353°W) respectively. In addition, the general directions of compressional stress responsible for relaxation in Bekhair anticline deduced from Bajilor and Yak Mala were (N298°W) and (S108°E) respectively, and the general directions of same paleostress in Chia Gara anticline deduced from Spindar and Ashawa were (S262°W) and (N074°E) and those concluded from Mazi and Garagu were (N275°W) and (S097°E) respectively. The paleostress directions concluded from this study were approximately same to those concluded by other researchers during their studies on Bashiqa, Ain Safra, Jebel Maqlub anticlines northwestern Mosul city and Perat anticline northeastern Sulaymaniyah city. Finally, the existence of two locally right-hand strike – slip faults is strongly proposed in this study. The evidence of such an existence is the anticlockwise rotational movement of the mean direction of compressional paleostress responsible for folding in traverse 2 in relative to traverse 1 and traverse 3. The degree of rotation between traverse 1 and 2 is about 26° and between traverse 2 and 3 is about 23°.

REFERENCES

Al-Jumaily, I.S., H. Gh. M., Adeeb, R. Kh. Al-Hamdani, M. S. Dawlat. 2012. Structural Analysis and Tectonic Interpretation of Brittle Failure Structures at Perat Anticline – NE Iraq. Iraq national jounal of earth science, 12(2): 17-42.

Bellen, R., Dunnington , H. Wetzel, R., and Morton, D., (1959). Laxiquestatigraphique international, Vol. III, Iraq, Asia, 10a, 333 p.

Bles, J. L. and Feuga, B., (1986). The fracture of rocks. North Oxford Academic Publishers Ltd., 131p.

Buday, T. and Jassim, S.Z., (1987). The regional geology of Iraq, Tectonism, Magmatism and Metamorphism, V.2, D.G. of Geol. Surv. And Min Inves., Baghdad.

De Sitter, L. U., (1964). Structural Geology, 2nd ed., McGraw Hill, New York, 551p.

Hancock, P.L.,(1985). Joints and Faults; the Morphological of their Origins, proc. Geol, Ass. vol. 79, pp. 141-151.

Hillacre, K. Ansdell, B. McEwan, and M. Namara, “Structural analysis, paragenesis, and preliminary geochronology of the Arrow uranium deposit, Athabasca Basin, northern Saskatchewan, Canada: implications for controls on mineralization,” in SGA Proceedings, Vol. 2, p. 743, Quebec, 2017

Jassim, S. Z., and Goff J.C., (2006). Geology of Iraq. Published by Dolin, pargue and Musem, Brno Czech Republic, 2006.

Numan, N.M.S., (1997). A plate tectonic scenario for the Phanerozoic succession in Iraq. *Jour. Geol. Soc. Iraq*, 30 (2), pp.85-110

Numan, N.M.S., Hammoudi, R.A., and Chorowicz, J., (1998). Synsedimentary tectonics in the Eocene Pila Spi Limestone Formation in Iraq and its geodynamic implications. J. Africa Earth Sci., 27 (1), pp.141-148.

Price. N. J. (1966). Fault& Joint development in brittle and semi brittle rocks. Pergaman press Oxford.

ISSN: 2350-0328
International Journal of Advanced Research in Science, Engineering and Technology
Vol. 8, Issue 8 , August 2021

Ramsey, J.G. & Hubber, M.I., (1987). The techniques of modern structural geology.Vol.2. Folds & fractures Academic press. London, UK. 700P.

Sharland, P.R., R. Archer, D.M. Casey, R.B. Davies, S.H. Hall, A.P. Heward, A.D. Horbury and M.D. Simmons 2001. Arabian Plate Sequence Stratigraphy. GeoArabia Special Publication 2, 371 p

Sissakian , V.K., Hagopian, D.H., and Hassan, E.A. (2013) The Geology ofAl-Mosul Quadrangle. Sheet NJ–38–13, Scale 1:250,000. Iraq Geological Survey Library Report No. 2314, Baghdad, Iraq.

Stearns. D. W. (1969). Fracture as a mechanism of flow in naturally deformed layered rocks Proceedings, Conference on Research in Tectonics, Geological Survey of Canada Paper 68–52

Turner F.J. & Weiss L.E, (1963). Structural analysis of Metamorphic Tectonic, New York, 525p.

Van der pluijm, B. A., and Marshak, S., (2004). Earth structure: An introduction to structural geology and tectonics, 2nd ed., W. W. Northern and Company, Inc., USA, 656P.

Wilcox, R. E., Harding, T. P. & Seely, D. R. 1973. Basic wrench tectonics. AAPG, 57, 74–96