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Fracture Analysis for the Triple Junction of Bekhair- Brifca- Zawita, Anticline Northern Iraq

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Abstract

The aim of the research is to detect the relation between the fracture sets and systems with the stages of folding. The triple junction area of the research comprises the three faced plunges of three anticlines Bekhair, Brifca and Zawita anticline. GEOreint, ver 9.5.0 was used for analyzing and classifying the data collected from the field measurements on 11 stations in proportion to the orthogonal tectonic axes. The age of exposed rocks ranges from Paleocene up to Miocene. The fractures were represented as joints, veins in addition to different types of faults. The Kinematic analysis of the fractures revealed that the stress caused the (ac) and (hko> a) fractures is coincides with the regional compression stress that form the folds where the max. Principle stress ($\sigma 1$) is oriented NE-SW parallel to the tectonic axis (a) that lead to shorten the layers in perpendicular direction to the fold axis. While the extension stress was determined in the form of (hko> b) where the ($\sigma 1$) oriented horizontally in NW-SE direction parallel to the tectonic axis (b) and coincides with the regional extension stress. High distribution of (hkl) in different directions during fracturing and faulting indicates the local stresses associated with more than one phase of deformation.

Keywords: Triple junction, Bekhair, Brifca, Zawita, Fractures, GEOrient ver 9.5.0

تحليل الكسور في منطقة الارتباط الثلاثي لطية بيخير– بريفكا – زاويته المحدبه شمال العراق

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الخلاصة

يهدف البحث الى الكشف عن العلاقة بين انظمة ومجاميع الكسور مع مراحل الطي. ان منطقة البحث تتضمن الارتباط الثلاثي لمناطق الغطس المتقابلة لثلاث طيات محدبة هي طية بيخير وبريفكا وزاويته في شمال العراق. تم استعمال برنامج ال(GEOrient ver. 9.5.0)، لتحليل وتصنيف المعلومات الماخوذة من القياسات الحقلية لاحدى عشرة محطه نسبة الى المحاور التكتونية المتعامدة. يتراوح عمر الصخور المنكشفة بين الباليوسين والمايوسين. تمثلت الكسور بالفواصل والعروق وانواع مختلفة من الفوالق. التحليل الحركي للكسور كشف عن الجهد المسبب لانظمة الكسور(ac)ومجاميع(hko> a) بانه متطابق مع الجهد الانضغاطي الاقليمي المتسبب في عملية الطي حيث يكون محور الاجهاد الاعظم بالاتجاه شمال شرق–جنوب غرب موازي الى المحور التكتوني(a) ادى الى تقصير في الطبقات باتجاه عمودي على محور الطيات، بينما الجهد المتسبب في التمدد استدل عليه بواسطة مجاميع الكسور(hko> b) حيث ان محور الاجهاد الاعظم يكون افقيا بالاتجاه شمال غرب– جنوب شرق موازي الى المحور التكتوني (b) ويتطابق مع محور الاجهاد الاقليمي

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التمددي. انتشار نسبة عالية من مجموعة الكسور (hkl) باتجاهات مختلفة اثناء عملية الطي والتكسر الهش
تدل على الاجهادات والضغوط الموضعية المرافقة لاكثر من طور واحد للتشويه.

Introduction

The study area lies geographically on the northern part of Iraq within the area of Dohuk Governorate of about 30 km to the east of Dohuk city and tectonically the study area is located within the Unstable Shelf and High Folded Zone (Figure 1) and comprises three plunges of three important anticlines: they are Bakhier, Brifca and Zawita anticlines. The plunges of these three folds were arranged in very abnormal triple connections and this is reflecting the importance of studying this area. The area comprises some well-known villages like Besire, Barebahar, Zawita, Deralosh, Bablu, Afrikia, Itut, Benarenki and Banye.

The aim of this research tends to expose the tectonic agents that controlling this connection. A Systematic and Genetic analysis of fractures interplay with folds generation. The fractures were analyzed and classified by using Georientver 9.5.0

Fractures

Fractures are the structures developed by brittle failure, and are exteremly widespread in the upper 10 km of the crust where tempratures and confining pressures are relatively low (0-300ºC, 0-4 kb)[1-2]. Fracture also defiened as a planes where the rock loss its cohesive strength, and displacement along these planes may be occures. Discontineous may be happened either perpendicular or inclined to the bedding planes [3]. Fractures show an incredible range of sizes from megalineaments with lengthes of handreds or even thousand of kilometers, to Microcracks with length of frictions of millimeter such as may be seen in thin sections of rock under the microscope[1].

The general term fracture covers all discrete break in a rock mass where cohesive was lost. It covers fault, where two sides are displaced relative to each other, and joints where the two sides show no differentiated displacement (relative to the naked eye), and veins where cosiderable thickness (>1 mm) of filling material occupies the region of the fracture walls [1].The term fracture involved four types (Joints, faults, veins, cracks). Joints and faults are the most important fractures had taken in consideration in this study to deduce the orientation of the stresses to which the rocks have been subjected. Generally the fractures divided into systematic and non-systematic[4].

Joints

The most common geological structures that are created in the upper crust are joints [5]. Joint defined as a natural, unfilled planar or curviplanar fracture which formed by tensile loading that means the walls of joint move a part very slightly as the joint develops. Joint formation does not involve shear displacement [6].It was regarded as fractures of geological origin that has no obvious displacement [7] except the vertical displacement on the joint plane. The length of such fractures is measured in feet, tens of feet or even hundreds of feet and may have any attitude; the strike and dip of joints are measured in the same way as for bedding [4]. Some joints are vertical others are horizontal and many are inclined at various angles. The joint sets is a group of systematic joints, where the two or more geometrically related sets of joints in a region is joint system, and two sets of joints that are at right angles to one another is orthogonal system, but if the angle of intersection is 30º to 60º so the pair is called conjugate system. If the conjugate system was of the same age and same stress, it will be called Complementary joints system [7-8]. There are two types of classification for joints: Geometrical classification which described with respect to orthogonal reference tectonic axes and genetic classification based on the size of the shear component of displacement at the moment of origin [9-10-11].

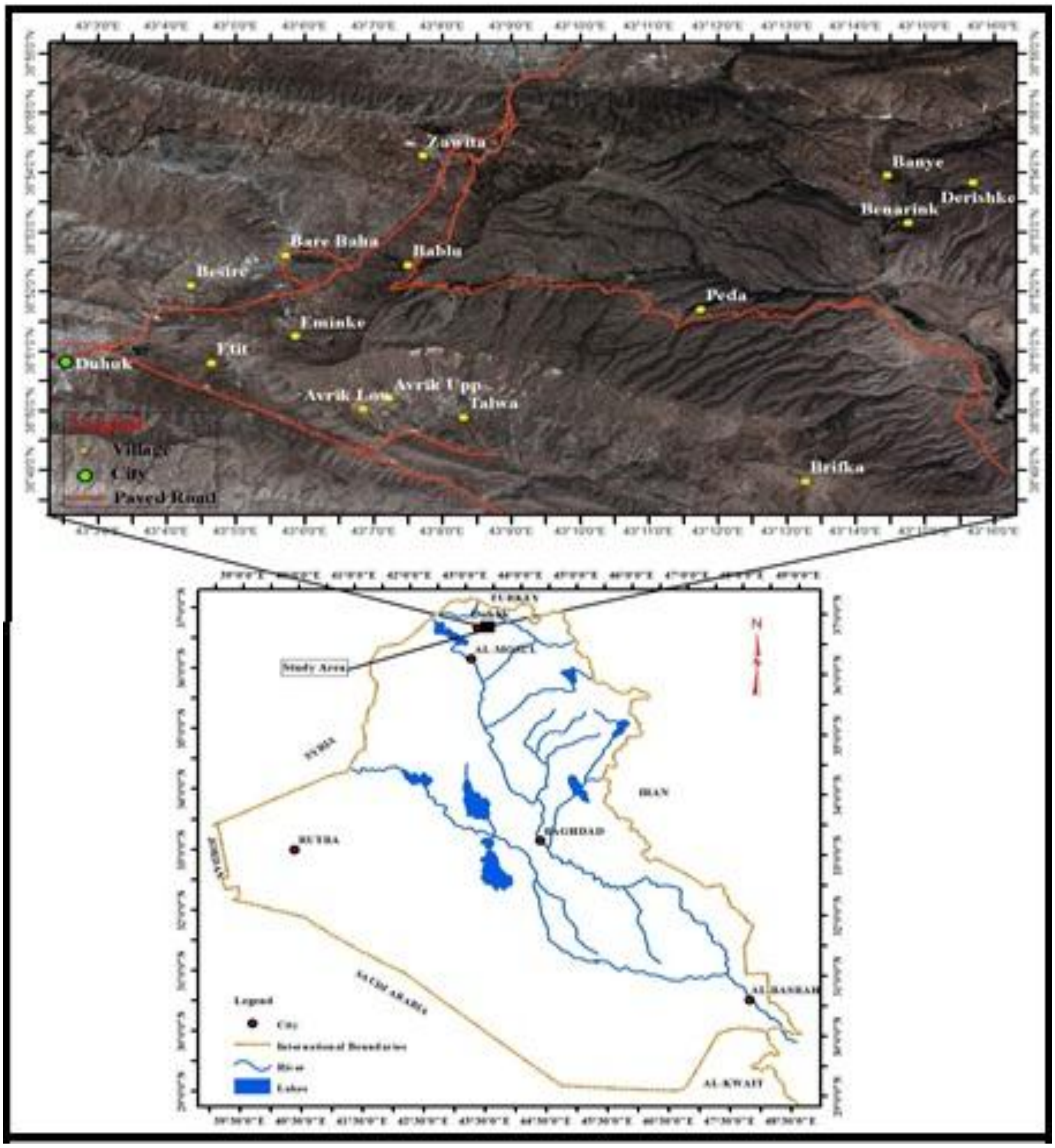

Figure 1- The Location of the Study Area

Joints in study area

About 300 readings of joint planes were collected during field works in the study area through distributed stations (11 stations) along the traverses. Each station was normally distributed in the areas where different sets of fractures together with the bedding appear clearly in three dimensions (i.e. in cross section and plane view) depending on the exposure of outcrops. Attitude of the joint plane was measured as well as the attitude of bedding plane which contain the joints. Software program (GEOrient, ver 9.5.0) was used for analyzing and classifying the joints. The data were collected from Pila Spi, Gercus, and Kolosh Formations everywhere exposed. The fractures are described and classified geometrically in each station in proportion to the orthogonal tectonic axes, into the following sets and systems:-

Joint sets: is a series of parallel joints, they are commonly observed to have relatively constant spacing.

1.ab set fractures

The planes of these fractures are perpendicular to **(c**) axis and include or parallel to both **(a)** and **(b)** axes. This set comprises all the planes parallel to the bedding planes. The (**ab)** set fracture may be caused by recent unloading or due to weathering activities [6]. Fractures of this set comprise joints and veins in the study area (plate 1-2)

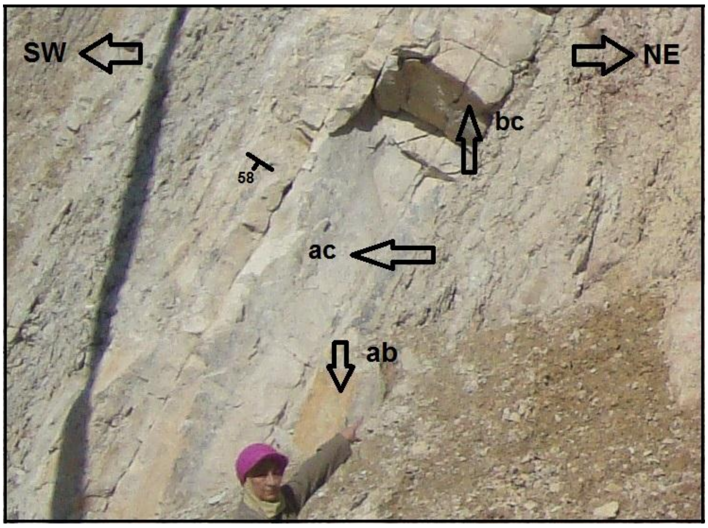

Plate 1- ab fracture set in Pila Spi Formation in the Southern Dome of SE Plunge of Bekhair anticline.

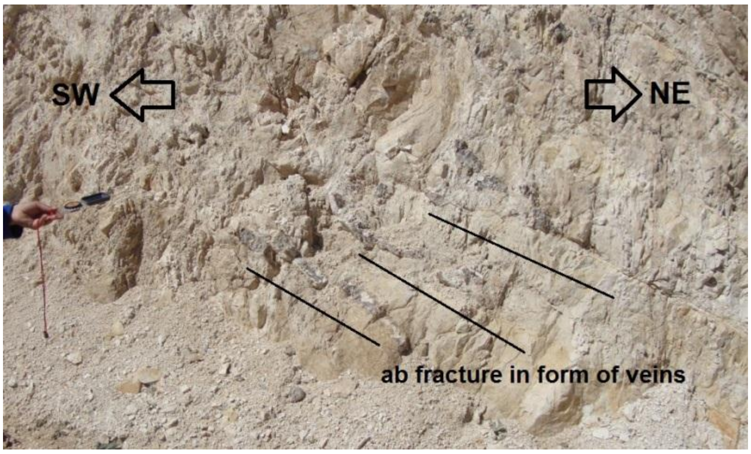

Plate 2- Veins in Pila Spi Formation in the southwestern limb of Brifca anticline.

2.ac set fracture

The planes of this fracture are parallel or include both **(a, c)** axes whereas the tectonic axis **(b)** is perpendicular to the plans containing them, in other word **(ac)** sets are perpendicular to the hinge line of the fold. It is extensional joints that are parallel to the greatest principle stress axis. The general trends of this set in the plunge of Bekhair anticline is NNE-SSW, whereas the trends are NE-SW in Brifca anticline plunge (Plate - 3, 4, 5).

Plate 3- ac fracture set in Pila Spi Formation in the Southern Dome of SE plunge of Bekhair anticline

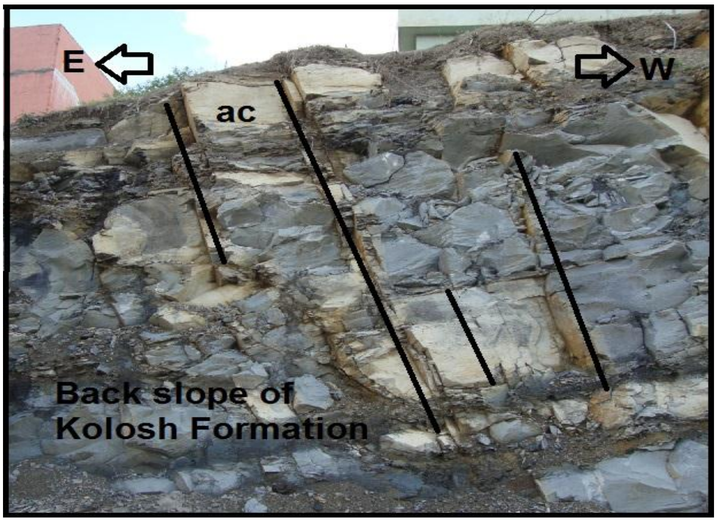

Plate 4- ac fracture set in back slope of Kolosh Formation in the Southern Dome of SE Plunge of Bekhair anticline

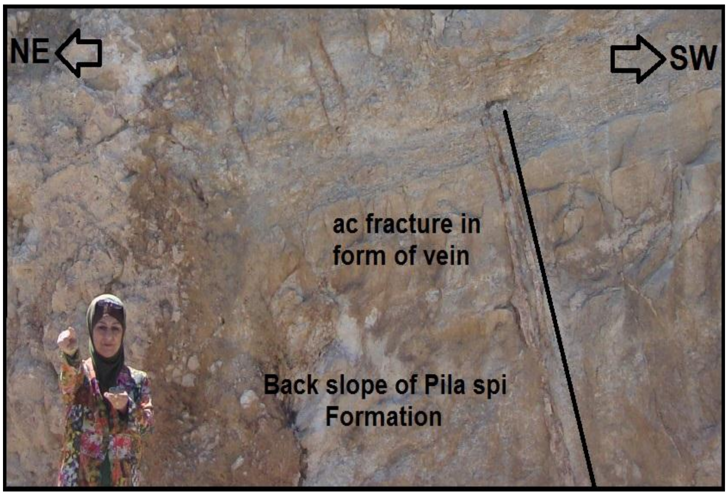

Plate 5-ac joint in form of vein filled with calcite in Pila Spi Formation in the northeastern limb of Brifca anticline

3.bc set fracture

The planes of this set of fractures are parallel to tectonic axes **(b)** and **(c)** and perpendicular on the **(a)** axis. They are normal to subnormal to the bedding planes. The majority of fractures of this set is joints and concentrated in the southeastern plunge of Bekhair anticline (Plate-6).

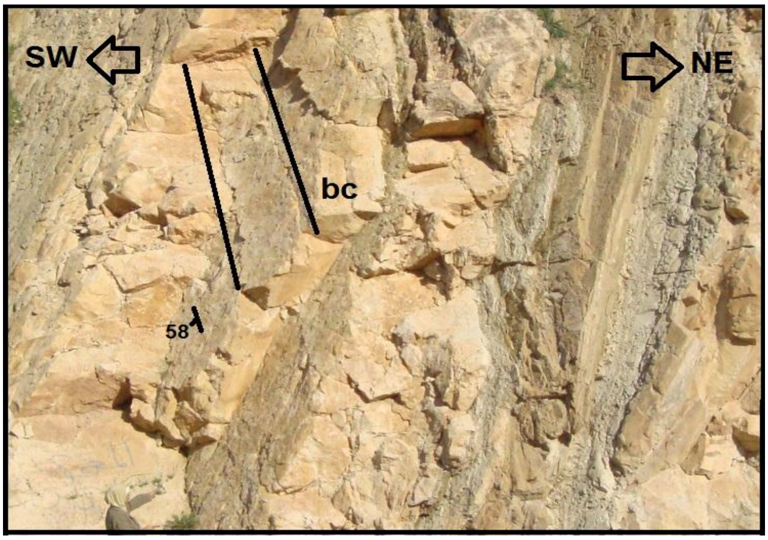

Plate 6- bc joint in Pilaspi formation in the middle of the plunge area of Bekhair Anticline (Bablu)

Joint systems

The system represents shear joints where the fracture planes are parallel to one of the three tectonic axes and intersect the other two axes. System expressed by symbols **(h, k, l)**, referring to intersecting the fracture plane with the tectonic axis **(a, b, c)** respectively, and the symbol **(o)** refers that the joint parallel to one of the axes, so the systems were classified as follows:

1. **hko system:** In which the fracture planes are parallel to the **(c)**axis and intersect **(a, b)** axes, the fractures are approximately perpendicular to the bedding planes .The system subdivided into two conjugate subsystems.

hko acute about (a) subsystem

This subsystem consists of intersecting two sets; the tectonic axis **(a)** bisects the acute angle between these two sets, whereas the tectonic axis (**b)** bisects the obtuse angle. These fractures were observed through the exposed geological formations as conjugate sets or single set form 40º-50º with tectonic axis **(a)**. It was observed as joints and veins. The principle stress axes **(σ1 and σ3)** are parallel to the tectonic axes **(a)** and**(b)** respectively.The fractures of this subsystem are highly distributed in the study area Plate-7**.**

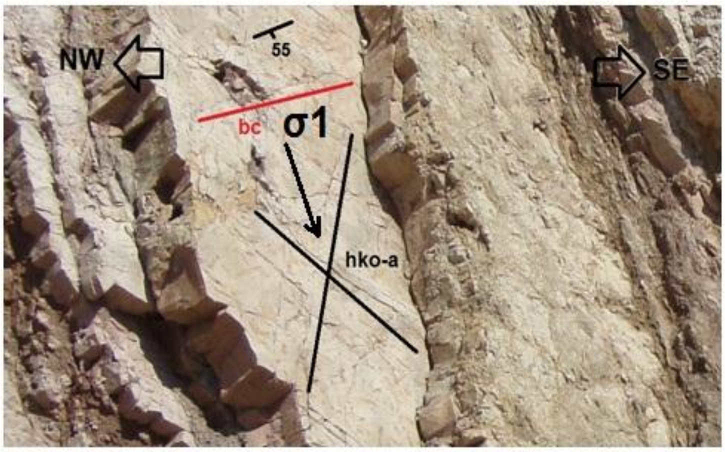

Plate 7- hko-**a** fracture subsystem in Gercus Formation in the Southern Dome of SE plunge of Bekhair anticline

hko acute about (b) subsystem

In this subsystem the two conjugate fractures are bisected by the two tectonic axis **(a)** and **(b)**. The axes **(a)** and **(b)** bisect the obtuse and acute angle respectively. It was mainly recorded as joint fractures with high percentage in most of the geologic formations. The principle stress axes (**σ1 and σ3**) are parallel to the tectonic axis **(b)** and **(a)** respectively Plate-8.

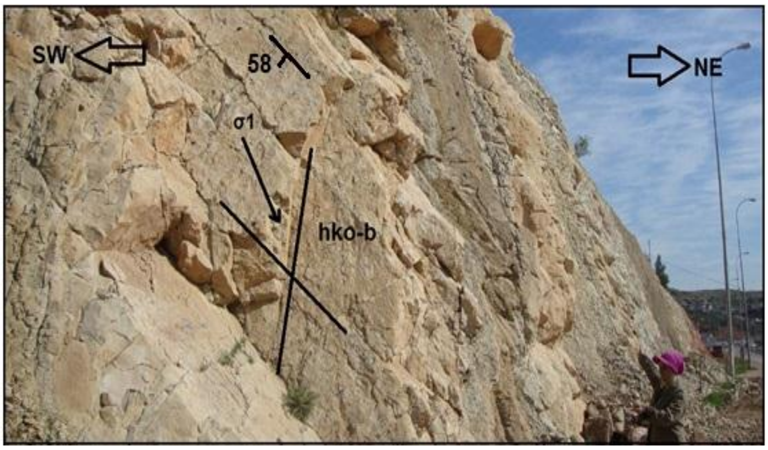

Plate 8- hko-b in Pila Spi Formation in the Southern Dome of SE Plunge of Bekhair anticline

2.hol system

In which the fracture planes are parallel to the **(b)** axis and intersect **(a, c)** axes. These planes form an acute angle with the bedding plane. This system subdivided into two conjugate subsystems.

hol acute about (a)subsystem

The two sets of this subsystem are bisected by the tectonic axes **(a)** and**(c)** and make an acute and obtuse angle around each of them respectively. This subsystem is exists in the inner arcs of the fold more than the outer arcs [12].The two principle stress axes **($\sigma 1 \& \sigma 3$)** are parallel to **(a, c)** axes respectively . it recorded as joints and veins in the study area Plate-9.

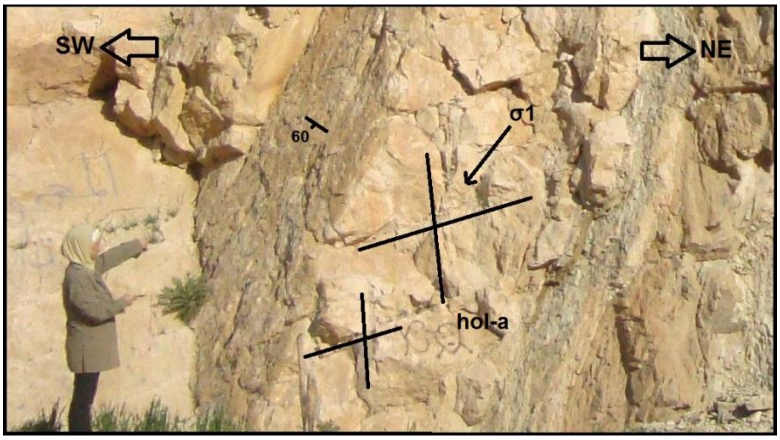

Plate 9- hol-a fracture subsystem in the Southern Dome of SE Plunge of Bekhair anticline

hol acute about(c) subsystem

This subsystem is also consisting of two conjugate shears trending parallel to the **(b)** axis. The tectonic axis **(c)** bisects the acute angle between the two sets of this subsystem, whereas the tectonic axis **(a)** bisects the obtuse angle. The fractures of this subsystem were determined in Pilaspi and Gercus formations. It was recorded mainly in form of joints and veins. These fractures were observed through the exposed geological formations as conjugate sets or single set form an angle less than 45º with tectonic axis **(c)** Plate-10.

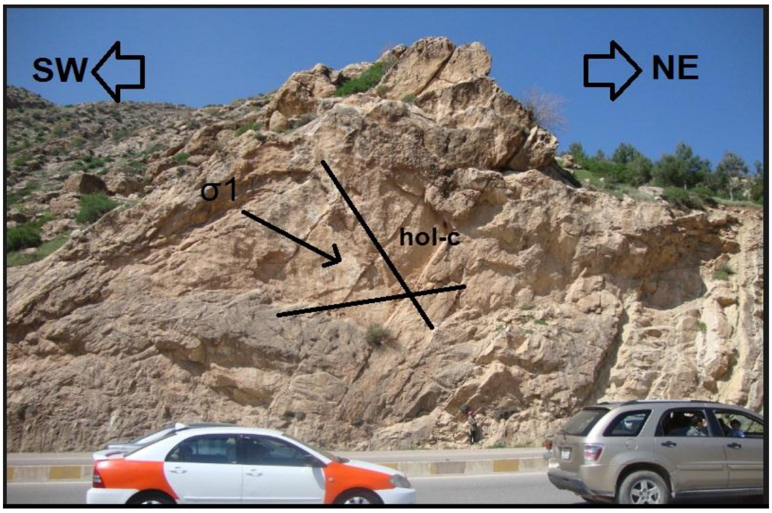

Plate 10- hol-c fracture subsystem in Pila Spi formation in the Southeastern Dome of SE plunge of Bekhair anticline

3.okl system

In which the planes of fracture system are parallel to **(a)** axis and intersect **(b, c)** axes. The system subdivided into two conjugate subsystems.

okl acute about(c) subsystem

The two planes of fracture intersect forming acute angle bisected by the tectonic axis**(c)** whereas the tectonic axis **(b)** axis bisect the obtuse angle and the fracture planes are parallel to the tectonic axis **(a)** axis. The planes of fracture make acute angle with the bedding planes and observed as conjugate sets and single set. It was recorded as joints, faults and veins, with highly distributed Plate11-12.

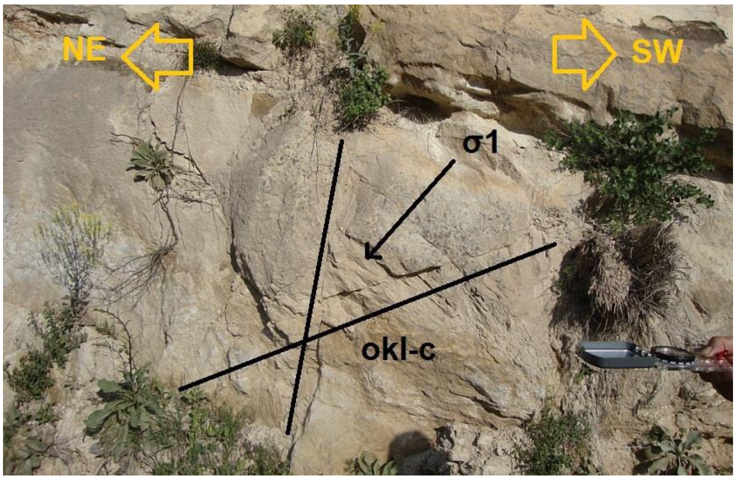

Plate 11- okl-c joint in Pila Spi formation in the southwestern limb of Benarinke anticline

Plate 12- okl-c fracture subsystem in back slope of Kolosh Formation in the Southern Dome of SE plunge of Bekhair anticline

okl acute about (b) subsystem

The fracture planes of this subsystem developed parallel to the orientation of the tectonic axis **(a)** and the two sets of conjugate subsystem intersect with the bedding planes in acute angle and obtuse angle. The tectonic axis **(b)** bisects the acute angle whereas the obtuse angle is bisected by the tectonic axis**(c)**. This subsystem has low distributed in the study area Plate-13.

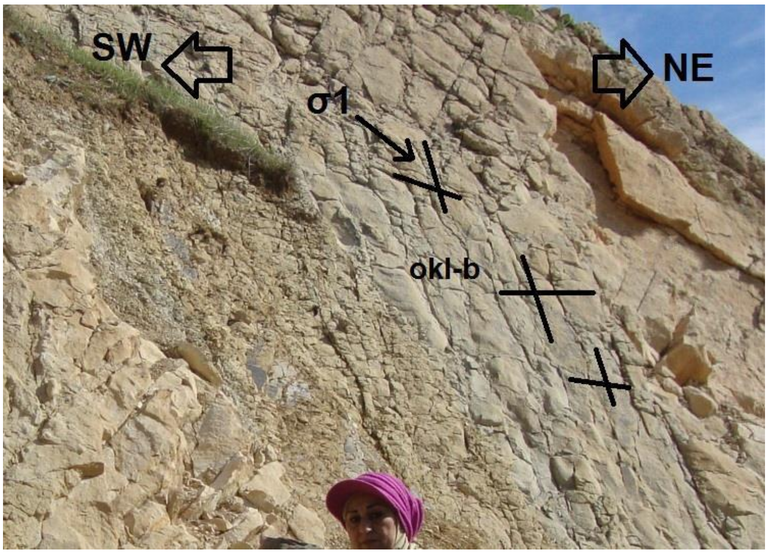

Plate 13- okl-b Fracture in Pila Spi Formation in the Southern Dome of SE Plunge of Bekhair anticline

4.hkl system

The **hkl** system contain fracture planes intersect the three tectonic axes; therefore there is no geometrical relationship between the system and the fold. It characterized by wide distribution in the areas of plunge and approximately in all formations as a single group and conjugate groups. It was caused by different local stresses Plate 14-15.

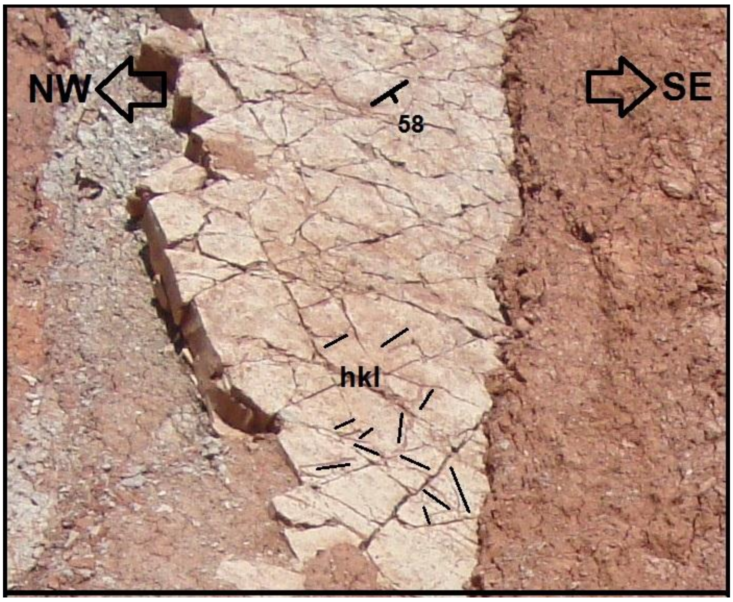

Plate 14-hkl Fracture in Gercus Formation in the Southern Dome of the southeastern plunge of Bekhair anticline

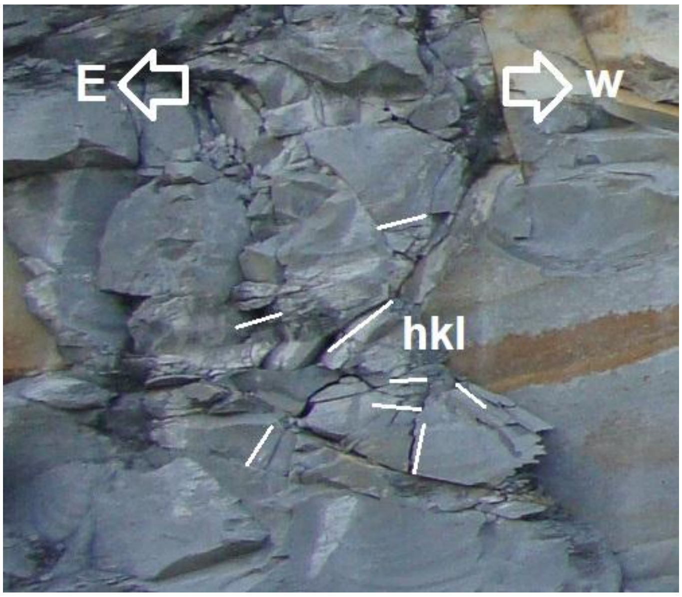

Plate 15- hkl Fracture in backslope of Kolosh Formation in the Southern Dome of SEplunge of Bekhair anticlin

Figure-2explaine the studied fractures in stations, the location of each station is defined on the geologic map associated with the analysis of fractures in each station

Data analysis

The orientation data on jointing holds valuable information about the orientation of the stress field at the time of failure. In the case of vertical joints the strike of the joint defines the direction of maximum horizontal stress. The maximum principle stress could be either parallel or perpendicular to the earth's surface, depending on the depth at which the joint formed [6]. The measured data for joints of the study area were analyzed by using stereographic techniques for each formation. The orthogonal fracture sets **(ac)** are determined in the study area at the rate of (13%) from the total distributed joint types, Figure-3. It might be resulted from the horizontal compressive stress which is responsible for folding at the structural phase of compression where the maximum principle stress **(σ1)** is horizontal and perpendicular to the fold axis.The orthogonal fracture set**(bc)** is parallel to the fold axis and caused by extensional stress creating on the outer arc during folding where the maximum principle stress **(σ1)** is horizantal parallel to fold axis

The shear fracture systems appear either as individual set or conjugate systems. The data showed that all types of the tension and shear fracture systems is exist in the formation with different ratio. The **hko-a** and **hkl** are distrbuted at the rate of 17.4% which refer that the main principle stress is perpendicular to the fold axis that caused the folding acssociated with differenet orientions of local stresses distrbuted randomly.**okl** acute about **(c)** and **hol** acute about **(c)** distrbuted at the ratio of 14.5% and 10% respectively indicating the vertical maximum stresses which caused the uplifting to the area of plunges. Figure- 3 explain the rate of each set and subsystem in the study area.The data are studied stereographically for each formation separatly and was displayed in Figures 4-14.

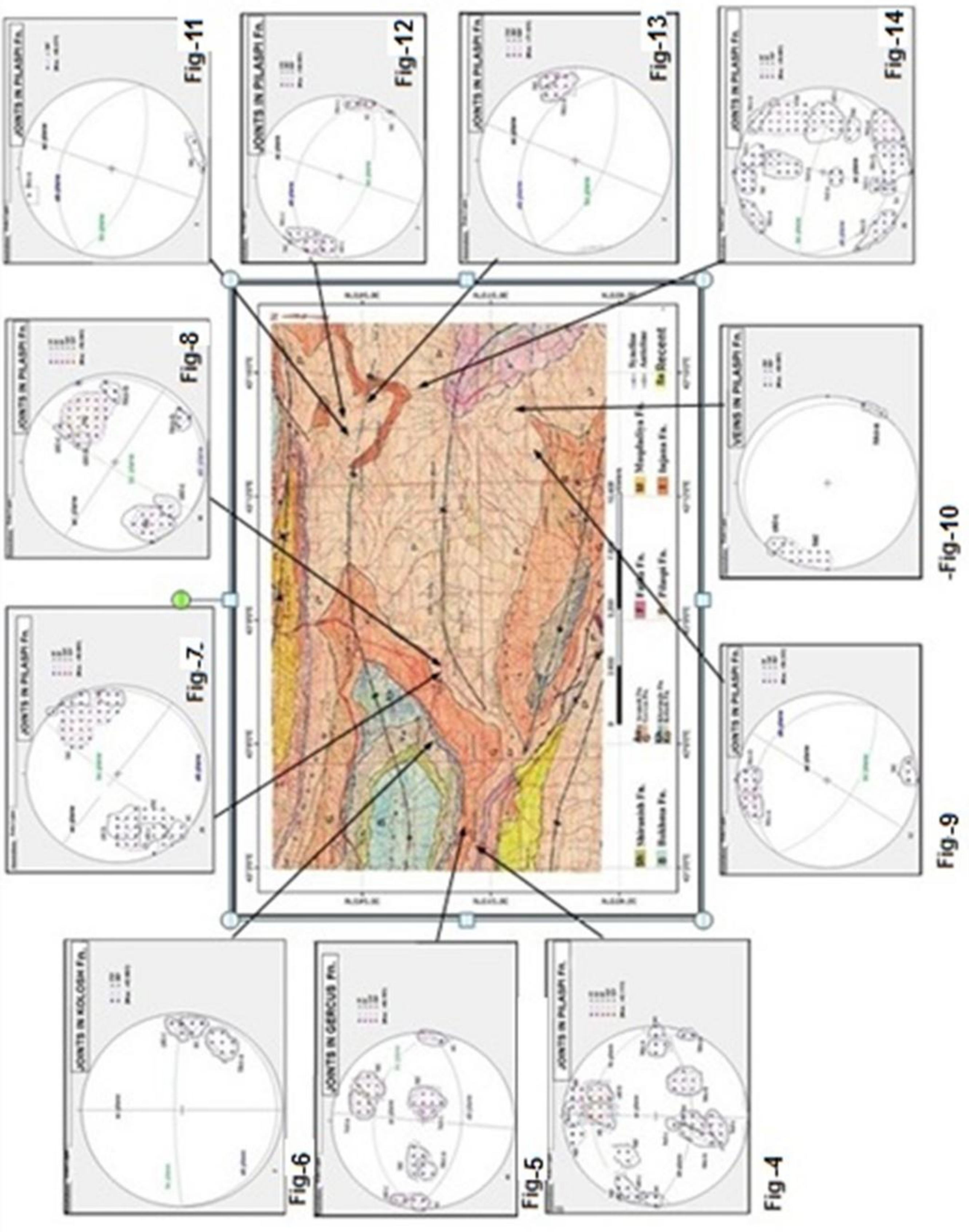

Figure 2- show the stations distribution in the study area (Geological Survey, 1961)

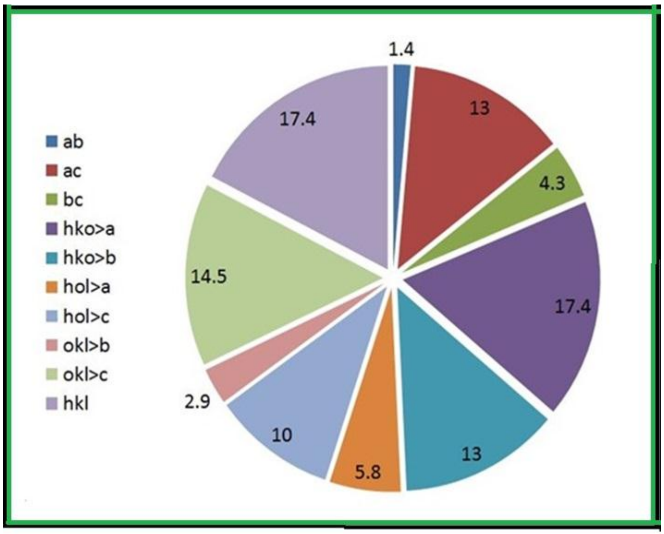

Figure 3- illustrates the joints ratio in the study area

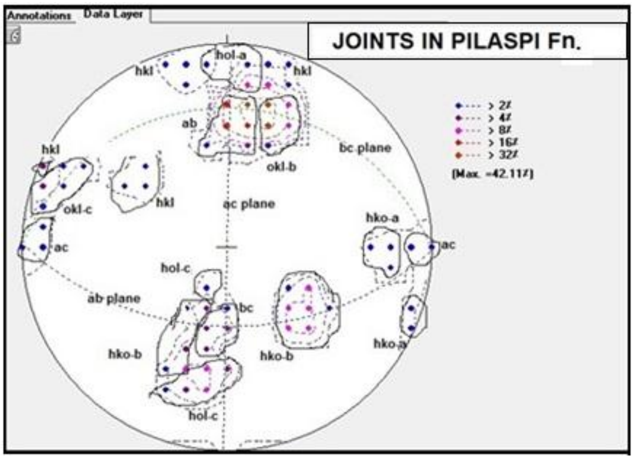

Figure 4- Synoptic Joint planes of Pila Spi Formation in the Southern Dome of SE Plunge of Bekhair anticline

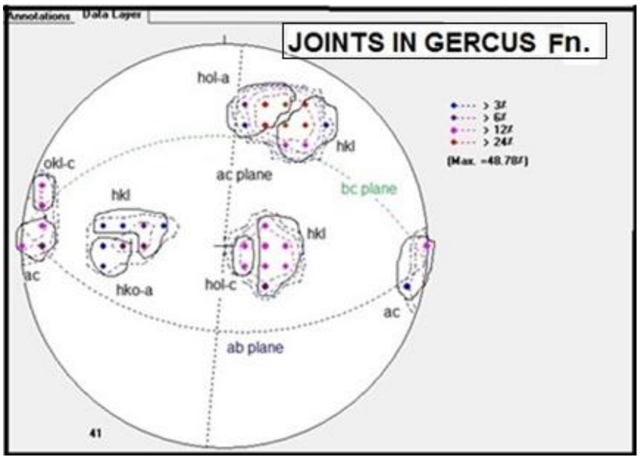

Figure 5- Synoptic Joint planes of Gercus Formation in Southern Dome of SE Plunge of Bekhair anticline

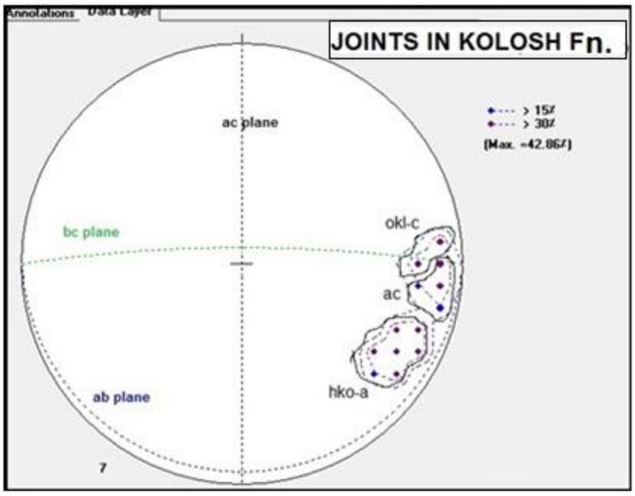

Figure 6- Synoptic Joint planes of Kolosh Formation in the Southern Dome of SE Plunge of Bekhair anticline

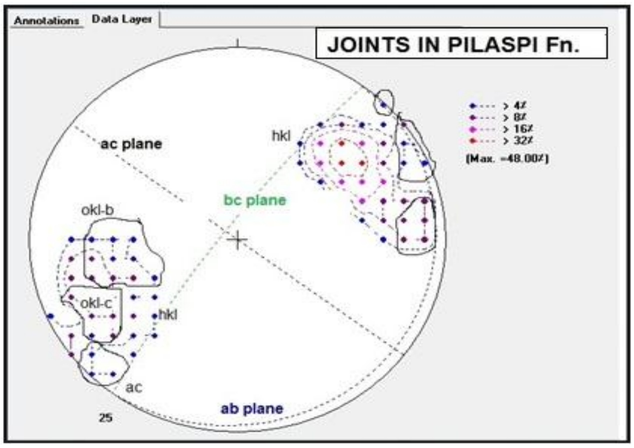

Figure 7-Synoptic joint planes of Pila Spi Formation in area middle of plunge of Bekhair anticline (Bablu-Check point)

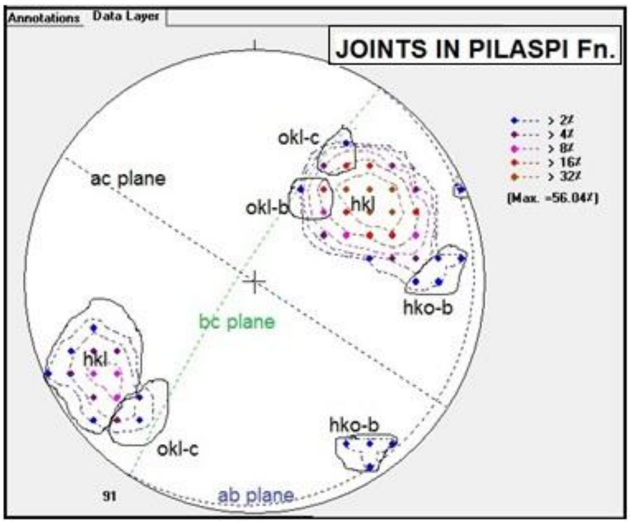

Figure 8- Synoptic joint planes of Pila Spi Formation in area middle of plunge of Bekhair anticline (Bablu)

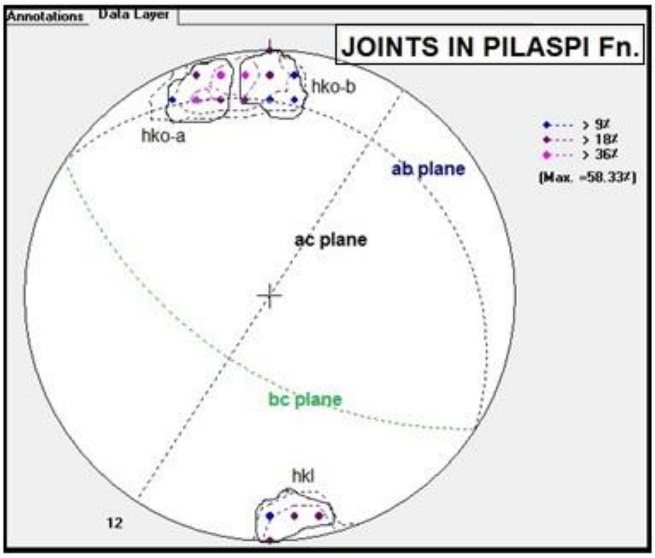

Figure 9- Synoptic joint planes of Pila Spi Formation in NE limb of Brifca anticline

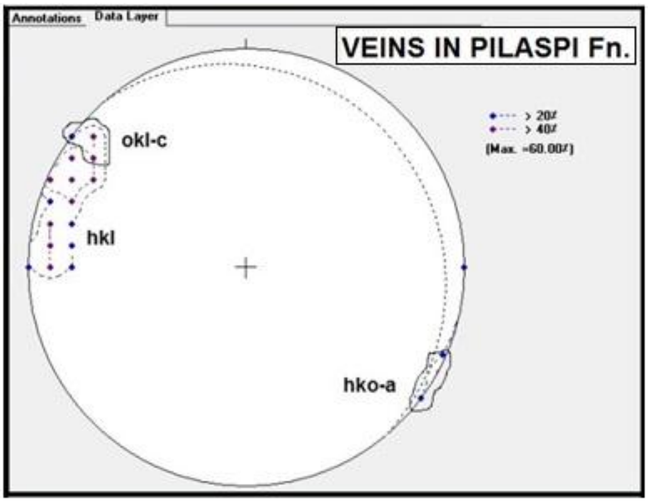

Figure 10- Synoptic vein planes of Pila Spi Formation in NE limb of Brifca anticline

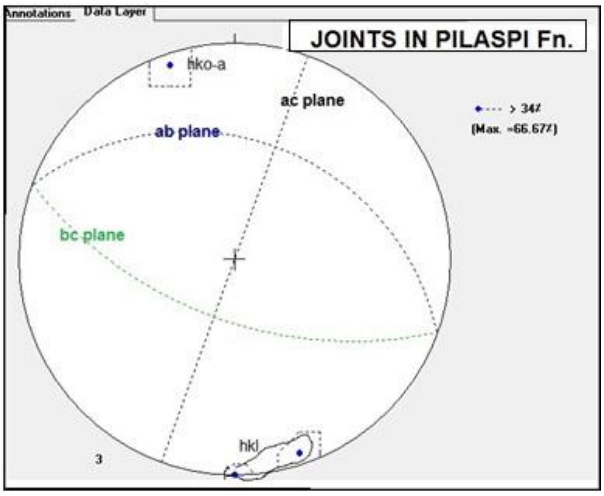

Figure 11- Synoptic joint planes of Pila Spi Formation in NE limb of Benarinke anticline (Gomal valley 1)

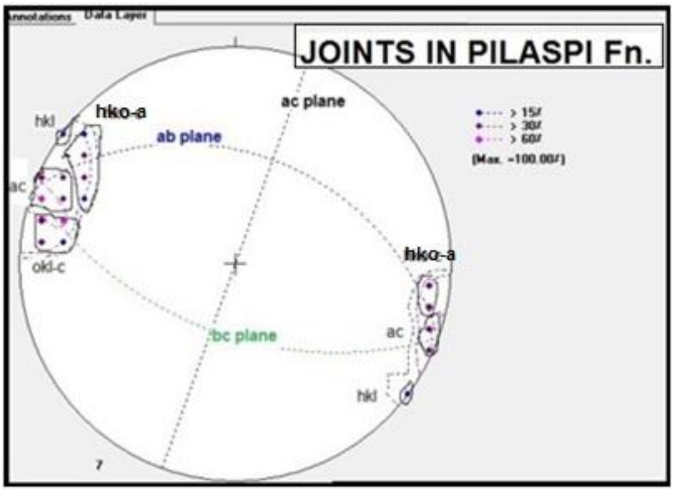

Figure 12- Synoptic joint planes of Pila Spi Formation in NE limb of Benarinke anticline (Gomel valley 2)

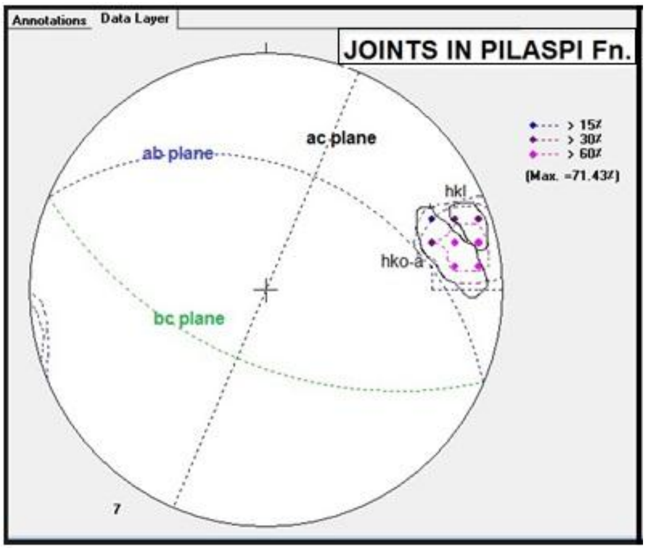

Figure 13- Synoptic joint planes of Pila Spi Formation in NE limb of Benarinke anticline (Gomal valley 3)

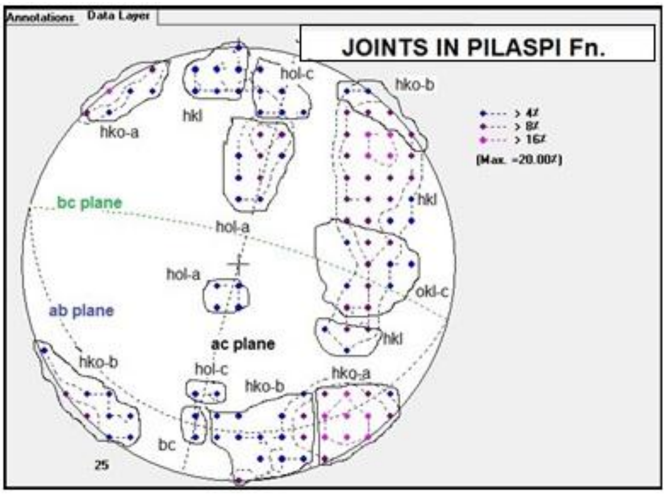

Figure14- Synoptic joint planes of Pila Spi Formation in SW limb of Benarinke Anticline

Kinematic analysis of the joints in the study area

Geologists use their measurements of rock geometries to understand histories of strain in the rocks. Strain can take the form of brittle faulting and ductile folding and shearing. Brittle deformation takes place in the shallow crust, and ductile deformation takes place in the deeper crust, where temperatures and pressures are higher.The kinematic analysis explains the relation between the fracture sets and systems with the stages on folding. From the distribution of joints in the study area, it can be noticed that the stress caused **(ac)** fracture sets and **hko** acute about **(a)** is coincides with the regional stress that form the folds where the maximum principle stress **(σ1)** is oriented NE-SW parallel to the tectonic axis **(a)** and the minimum principle stress **(σ3)** is parallel to the tectonic axis **(b)**. This system of stress is compression stress lead to shorten the layers in perpendicular direction to the fold axis and extension them parallel to the fold axis.

While the extension stress was determined in the form of **hko-b** where the **(σ1)** oriented horizontally in NW-SE direction parallel to the tectonic axis **(b)** and **(σ3)** is parallel to **(a)** axis and **hol-c** where the stress analyzed into two component; the vertical one helps in uplifting and horizontal one helps in the extension of the layer parallel to the strike of the fold and the tectonic axis **(b)**.

The wide distribution of **okl-c** (14.5%) and **hol-c** (10%) indicate high percentage of Tectonic uplifting more than local vertical stresses or due listric faults [13]. The **hkl** fracture system cuts the three tectonic axes, caused during fracturing and faulting in different directions and represent local stresses in the area of plunges. It indicates that it was associated with more than one phase of deformation.

Fault

Faults are one of the most important fractures in detecting the tectonic indicators for deformational areas and distinctive feature in foreland zone. It was defined as fractures with a relative displacement parallel to their planes in a certain direction and magnitude, proved by the slickenside and fault breccias or Mylonite [6-9-14**}.** Most general and commonly used terms are based on the apparent relative movement of the fault blocks. Most earth scientists classified the faults depending on the fault dip angle and the direction of slip along the fault plane in to normal fault, Reverse and Strike-Slip fault[15-16].

Faults in the study area

Many faults were observed in the study area within the scale of exposed rocks. Different types were observed and recorded during the field works which are resulted by the applied stress to the area and the associated local stress.In the middle area of the broad plunge of Bekhair anticline near Bablu village a thrust and reverse faults, trending NE-SW were recorded in back slope of Pila Spi Formation (Plate 16).They classified as **okl-b** according to the relation between the fracture surface and tectonic axes. In Pila Spi Formation of southwestern overturned limb of Brifca anticline near Afrikia village, a normal fault was observed (Plate 17) that oriented northwest-southeast and inclined to southwest with angle approximetly 45º. The fault is classified as **(hol-c)** fracture set, as the fault plane strike is parallel to the tectonic axis **(b)** intersect the tectonic axes **(a)** and(**c)**.

Reverse Fault was determined in back slope of Gercus Formation in the northeastern limb of Brifca anticline where the beds dip toward northwest in the area of the plunge Figure-18. The fault is classified as **okl-c** fracture subsystem as the fault plane is parallel to the tectonic axis **(a)** and cuts the tectonic axes **(b)** and **(c)**.

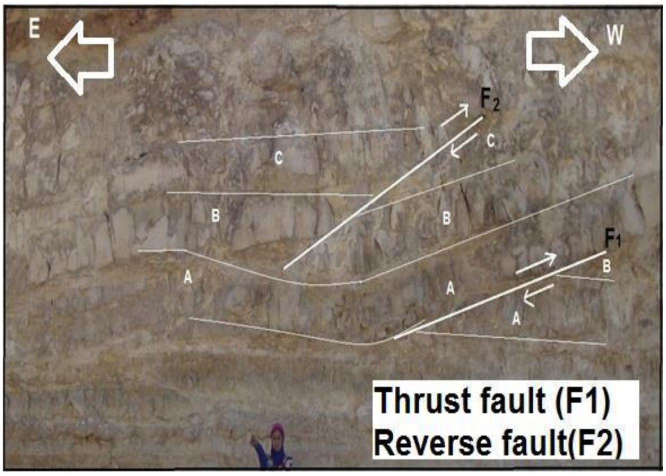

Plate 16- Faults in Pila Spi Formation in the area middle of Bekhair Plunge near Bablu village

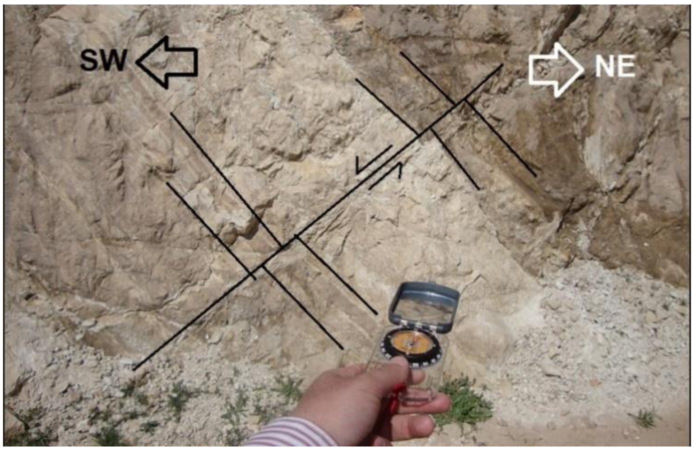

Plate 17- Normal Fault in Pila Spi Formation in overturned SW limb of Brifca anticline

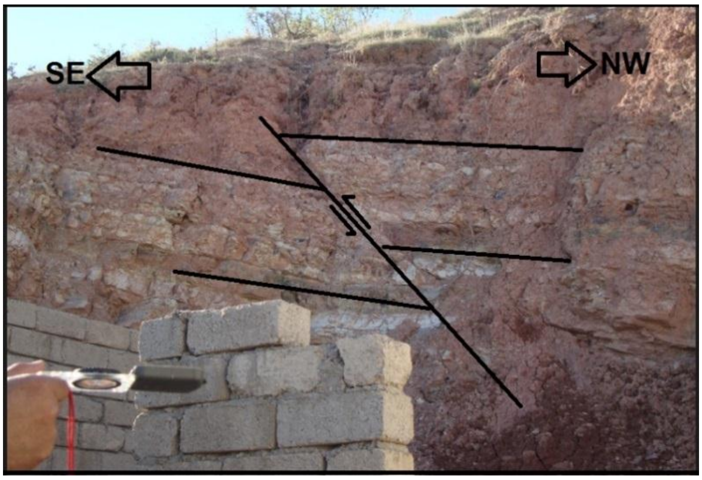

Plate 18- Reverse Fault in back slope of Gercus Formation in the northeast limb of Brifca anticline

Another south dipping normal fault was determined in Pila Spi Formation in NE limb of Benarinke anticline. It is formed within horizontal beds at the hinge zone may be due to stretching process over the crest of the .anticline Plate-19.

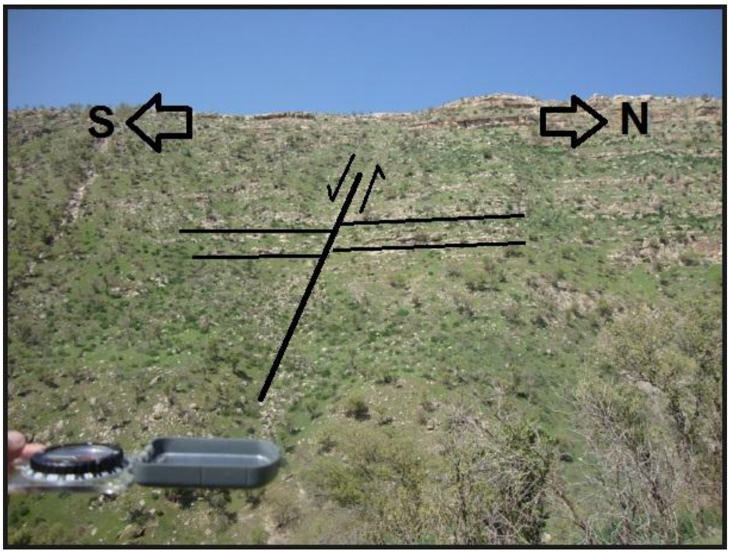

Plate 19- Normal Fault in Pila Spi Formation in NE limb of Benarinke anticline

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