Compressional and Extensional Tectonic Phases in Safeen, Bana Bawi, and Haibat Sultan anticlines NE Iraq, determined from Microtectonic Elements

Nagheen A. Abdul Majeed, Munther A. Taha[1] and Ali Z. Almayahi

Department of Geology/ College of Science-University of Basrah, Basrah-Iraq.

[1]Department of Geology/ College of Science-University of Diyala, Diyala-Iraq.

Email: nagheensg@yahoo.com

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Abstract

The study area includes parts of the High Folded and Foothill Zones of Northeast Iraq. A series of intense folding namely Safeen anticline in the High Folded, Bana-Bawi, and Haibat Sultan anticlines in the Foothill zone. The fold axes trend in northwest-southeast direction present structural analysis; it is concluded that the study area is affected by four tectonic phases. Two of the compressional while the other two are extensive phases, both of them phases perpendicular in fold axes lie in i.e NE – SW direction or parallel to fold axes lie in i.e NW – SE direction. The first compressive phase corresponds with systems hOl-a & hkO-a, with reverse faults striking NW-SE and strike-slip fault enclosing angles larger than 45° with the folds axes. This phase was followed by extensive tectonic phase as releasing phase, which corresponding with the normal faults directed NW-SE and hOl-c shear joints. The region was then affected by second compressive phase corresponding with reverse faults striking NE-SW, strike-slip faults enclosing angles smaller than 45° with the folds axes and Okl-b & hkO-b shear joints systems Okl-b & hkO-b. Lastly the region has been affected by second extensive phase corresponding with shear joints system and NE-SW striking normal faults. Also tension joints ac, bc, and ab were studied in these study results were ac joints correspond with the first compressive phase direction of that caused Zagros folds in Iraq, and bc joints correspond first extensive releasing phase.

Keywords: High folded zone, Foothill zone, Compressional phase, Extensional phase

1-Introduction

The studied area is located between longitudes (44˚ 21' 47.62") and (44˚ 46' 23.55") east and latitudes (36˚ 02' 33.48") and (36˚ 19' 5.51") north within Iraqi Kurdistan Region (Fig.1).

Kurdistan region occupied the northeastern corner of Arabian Plate, structurally the study area located within northwestern segment of Zagros Fold-Thrust Belt and the total area is about 787.05 Square Kilometers and forms part of the high fold zone of the Alpine Foreland Folds Belt in northern Iraq (Fig. 1).

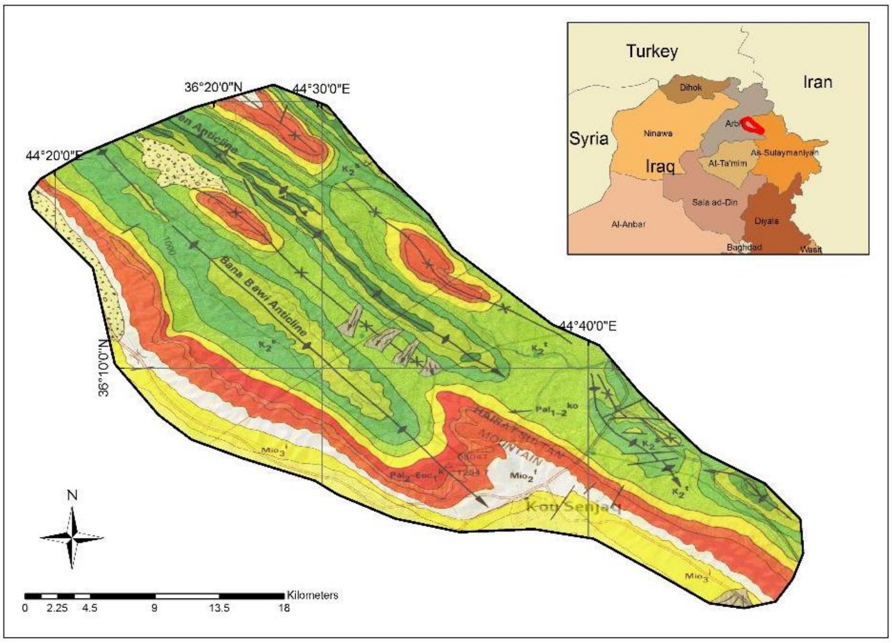


Fig. 1: Location map and major folded structures of the study area.

Fractures considered as one of the most important channels for fluid current in carbonate reservoirs rocks. Natural fracture systems can have a dramatic effect on reservoir behavior and can act as permeable flow channels [1, 2, 3, 4, 5, 6 and 7]. These studies show that fracture style is controlled by mechanical stratigraphy and petrophysical properties of the rock such as porosity. The spatial distribution of fractures is a multivariate problem, where fracture advantage like orientation, length, spacing and apertures are functions of location within the fold, sedimentary texture and mechanical bed thickness. The forms of fracture could also be controlled by the evolution of fluid pressures through burial and the evolution of the stress field during uplifting. Fractures in fold-thrust belts can be created either pre-folding or post-folding e.g. [8 and 9].

Zagros Fold and Thrust Belt have been created, when the Eurasian and Arabian Plates have been collided and Zagros Mountains have been formed. This event started in the Late Cretaceous, through the extensive Alpine–Himalayan orogenic system [10 and 11]. According to recent measurements by [12] the velocity of collision between the two tectonic plates in the last 10 Ma. is approximately 1.6 – 2.2 cm/yr. [13], postulate that this is the minimum rate of continental collision, (Fig. 2).

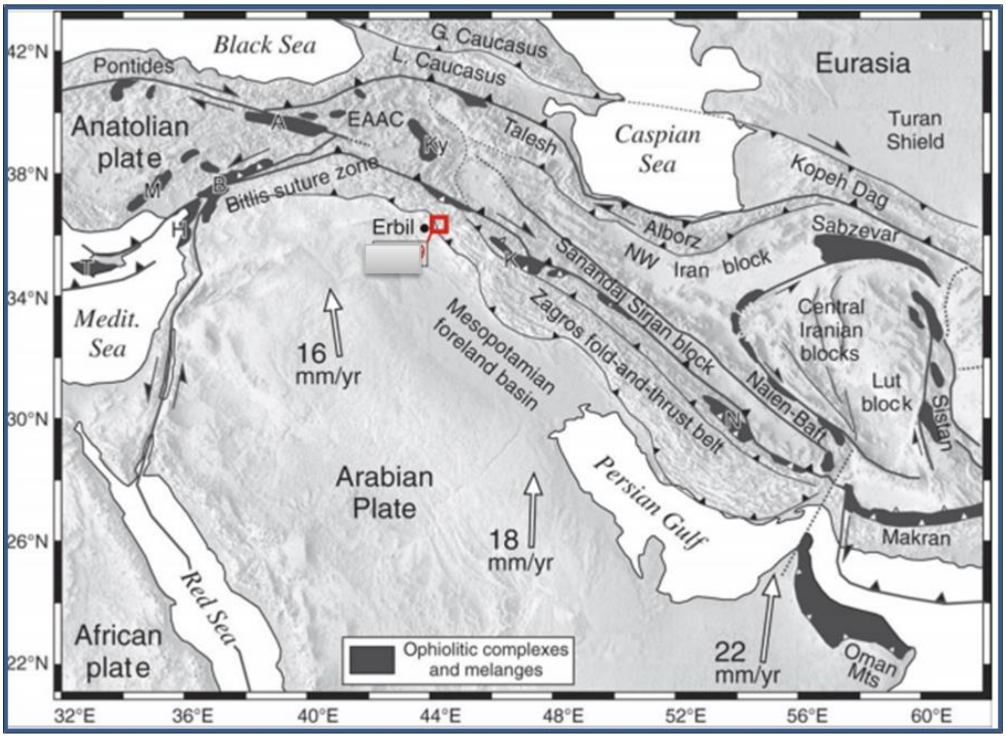


Fig. 2: Major Tectonic elements of the Arabian and Iranian plates, the red square represents the study area, the map is modified from (Emami, 2008 in Al-Hakari, 2011[14]).

In the northeastern part of the present-day Arabian Peninsula, during Triassic and Jurassic; the rifting events and passive continental margin phases were alternation, while the southern Neo-Tethyan Ocean opened during Late Tithonian to Cenomanian, the period from Turonian to Eocene was a witness of a foreland basin creation around the margin of the Arabian Plate and the closing of Neo-Tethys ocean. During Oligocene until present day continent-continent collision was permanent [15].

According to [16 and 17] in the simply folded belt, the deformation started between 5-8 Ma., these deformations divided into northwest-southeast oriented folding and thrusting with northwest-southeast to north-south trending dextral strike slip faults in Zagros Mountains. In the southern part of Zagros in Iran, the studies of tectonics, structures and geomorphology are influenced by the active deformation happened there. Zagros belt implicate four units from northeast to southwest each one has a special characteristic of deformation (Fig. 2):

1- Sanandaj-Sirjan metamorphic zone.

2- Thrust dominated Imbricated Zone.

3- Simply Folded Belt.

4- Mesopotamian foreland basin with buried folds, which extends to the Arabian Gulf in southeastern direction (Homke et al., 2017).

2- Materials and Methods

In order to accomplish the job of this research, it must be done through collecting data from field by measurements and observations during field work and from satellite imagery. The data include attitude of strike, dip and dip directions, striations or slickenside's (slickenline) direction and for the striations, either trend and plunge or rake angles were required, and the type of fault, was also used by the aid of remote sensing images from Google Earth. The attitude data were acquired using Silva compass, used the right-hand rule right (R.H.R.R.) for data measurement and representation.

Note: ••• represent poles to limbs of the fold, ... axial plane of fold in all projections.

■ σ1 ● σ2 ▲ σ3

Many of the geological softwares were utilized for analyzing the data like FaultKinWin 7.5 Program, 2016. (By Richard W. Allmendinger), this program used for Paleostress analysis from faults slip data. From these data the software plots the faults planes with the striation and calculates the attitude of (σ1, σ2 and σ3).

3- Results and Discussions

a-Joints

Two types of joints (tension and shere) were found in the study area. The (ac) tension sets might be produce from the effect of the main horizontal compression stress, which is responsible for the creation of folds, they are probably formed by water pore pressure or natural hydraulic fracturing that accompanied tectonic events, the presence of crystalline minerals supports this opinion. While the type (bc) tension sets which are parallel to the anticline axes, could be caused by the local extensional stress due to buckling in the outer arcs of the folded strata. The shear fracture systems appear either as individual sets or as conjugate joints.

The (ac) joint and (hkO) system acute about (a) are related to the same compression force ($\sigma 1$), when ($\sigma 1$) axis was parallel to tectonic axis (a) with N-S direction for example, ($\sigma 2$) vertical to bedding plane and ($\sigma 3$) parallel to the tectonic (b) axes (fold axes) with E-W direction, this lead to strata extension parallel to (b) axes and shortening perpendicular to the axes of the folds, and all of these represent regional stresses.

When tectonic uplift occurs, then the vertical tectonic stresses lead to strata uplifting and, this creates (hOl-c) joint system and sometimes (Okl-c) that depending on the ($\sigma 2$) direction.

(hOl-c) form by secondary vertical stress ($\sigma 1$) and $\sigma 2$ parallel to fold axis (ab), and $\sigma 3$ bisect the obtuse angle. The system (hkO-b) and (bc) set were created when the inversion in regional tectonic stress direction inversed where $\sigma 1$ became parallel to (b) axis in E-W direction as example, $\sigma 3$ parallel to (a) axis in N-S as example and $\sigma 2$ remaine vertical. The inversion of stress system represents extension stage of fold.

Joint planes data in Bana bawi anticline were collected form 23 stations in both limbs of the anticline from Shiranish, Kolosh, Khurmala , Gercus, Pilaspi and Fatha formations. In Safeen anticline were collected through 16 stations in both limbs of the anticline from Shiranish, Tanjero, Kolosh, Khurmala and Pila Spi formations. In Haibat Sultan anticline were collected through 13 stations in both limbs of the anticline from Shiranish, Tanjero, Fatha and Injana formations. The tension joints (ac, bc, and ab) were found in the three folds, the study results ware (ac) are joints correspond with the direction of the compression stress causing Zagros in Iraq, and (bc) joints correspond with the direction of the extension stress. As for the shear joints, the result gave two compressive directions: the first most common maximum stress direction in the three folds NE-SW trend which represented in shear joints (hkO-a &hOl-a) and the second NW-SE trend which represented in shear joints (hkO-b &Okl-b). And two extension directions: the first most common minimum stress direction in the three folds NE-SW trend which represented in shear joints (hOl-c) and the second is NW-SE trend which represented in shear joints (Okl-c). Below are some Stereographic projections illustrating types of joints in study area (Fig.3).

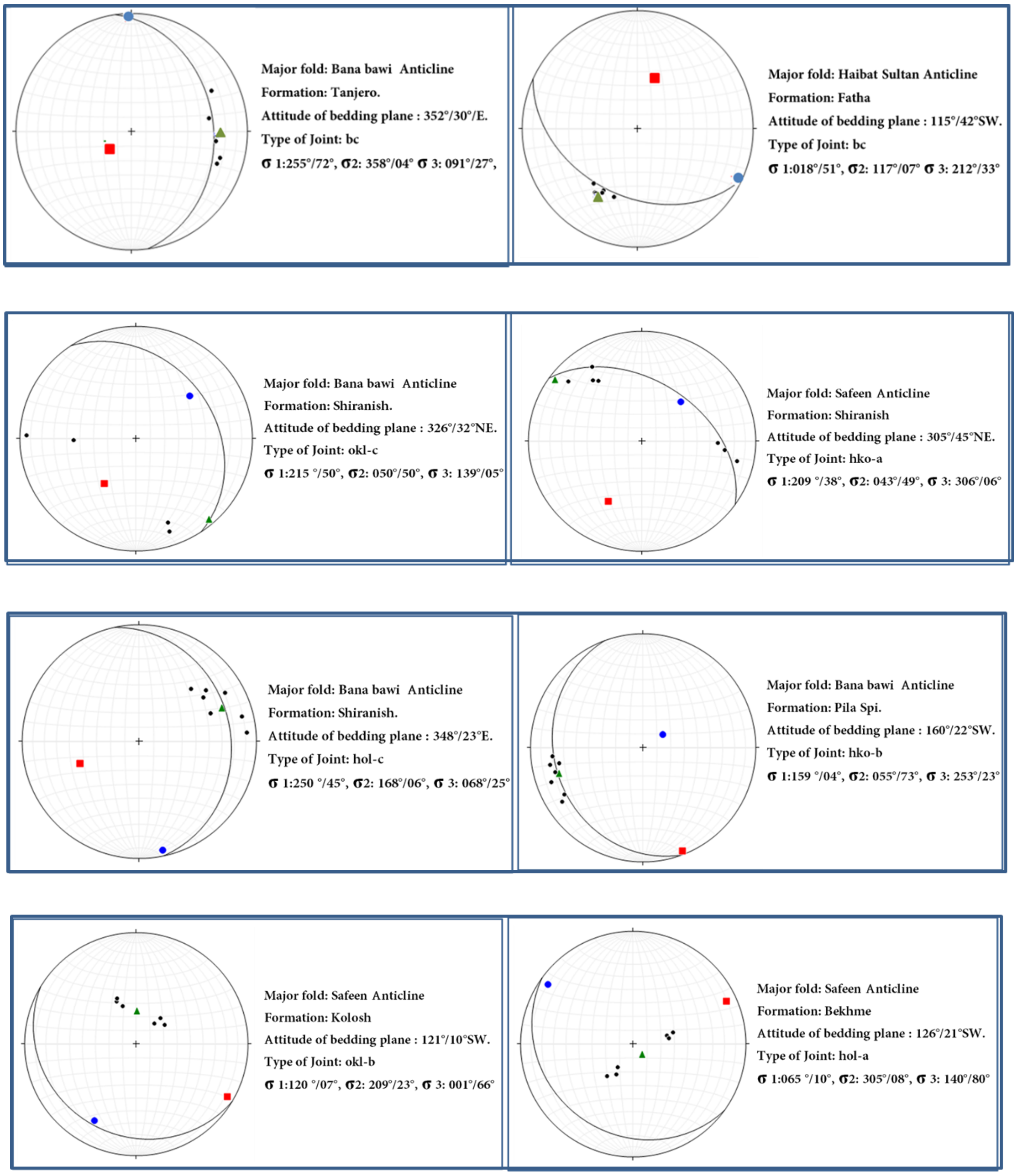


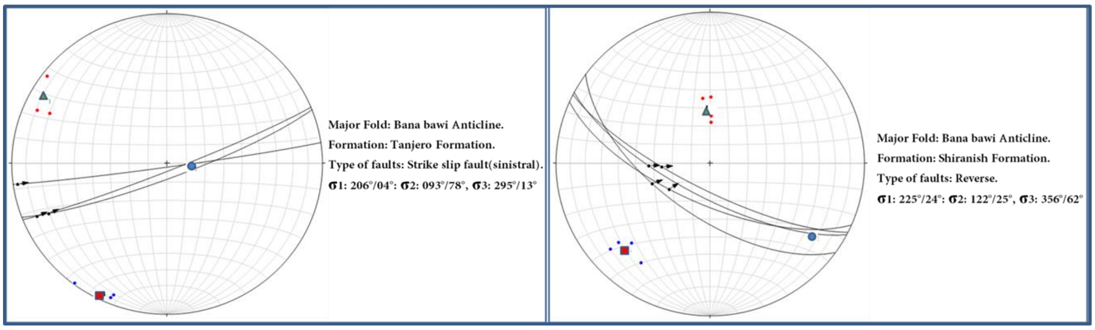
Fig. 3: Stereographic projection of the some joints poles in the study area.

b-Faults

We studied the type of motion on the surfaces of the faults that we observed in study area. Fault slip data for the paleostress analysis in Bana Bawi and Safeen anticlines collected from (12) stations while from (14) stations in Haibat Sultan anticline. The motion on the surfaces of the faults deduced through the presence of striations, Sixty one faults were measured in Bana Bawi anticline they emerged several directions of two types of compression and extension, but the most common directions were strike-slip faults E-W, N-S, and NW-SE directions type represented by reverse faults towards E-W and NE-SW. Fifty seven faults were measured in Safeen anticline gave compression and extension in different directions but the more common trend is NW-SE, NE-SW for reverse faults, and E-W, N-S, NE-SW, and NW-SE for strike slip faults (sinistral). Twenty-one faults were measured in Haibat Sultan the more common trends are NE-SW and NW-SE for reverse faults, and NNW-SSE, and NW-SE for strike slip faults (dextral). The results gave two compressive directions: The first compressive stress direction affected the study area in Zagros mountain trend, lies in NE – SW, corresponded with reverse and strike-slip faults, the extensive stress, correspond with normal faults (NW-SE) direction, The region was then affected by second compressive stress parallel to the folds axes's (NW-SE), this phase corresponds with reverse and strike-slip faults. The regional second extensive stress, parallel to the fold axes's (NW-SE) corresponds normal fault, which (NE-SW) direction.

Below are some Stereographic projection types of faults in study area (Fig.4).

- represents compression phase.
- represents extension phase.



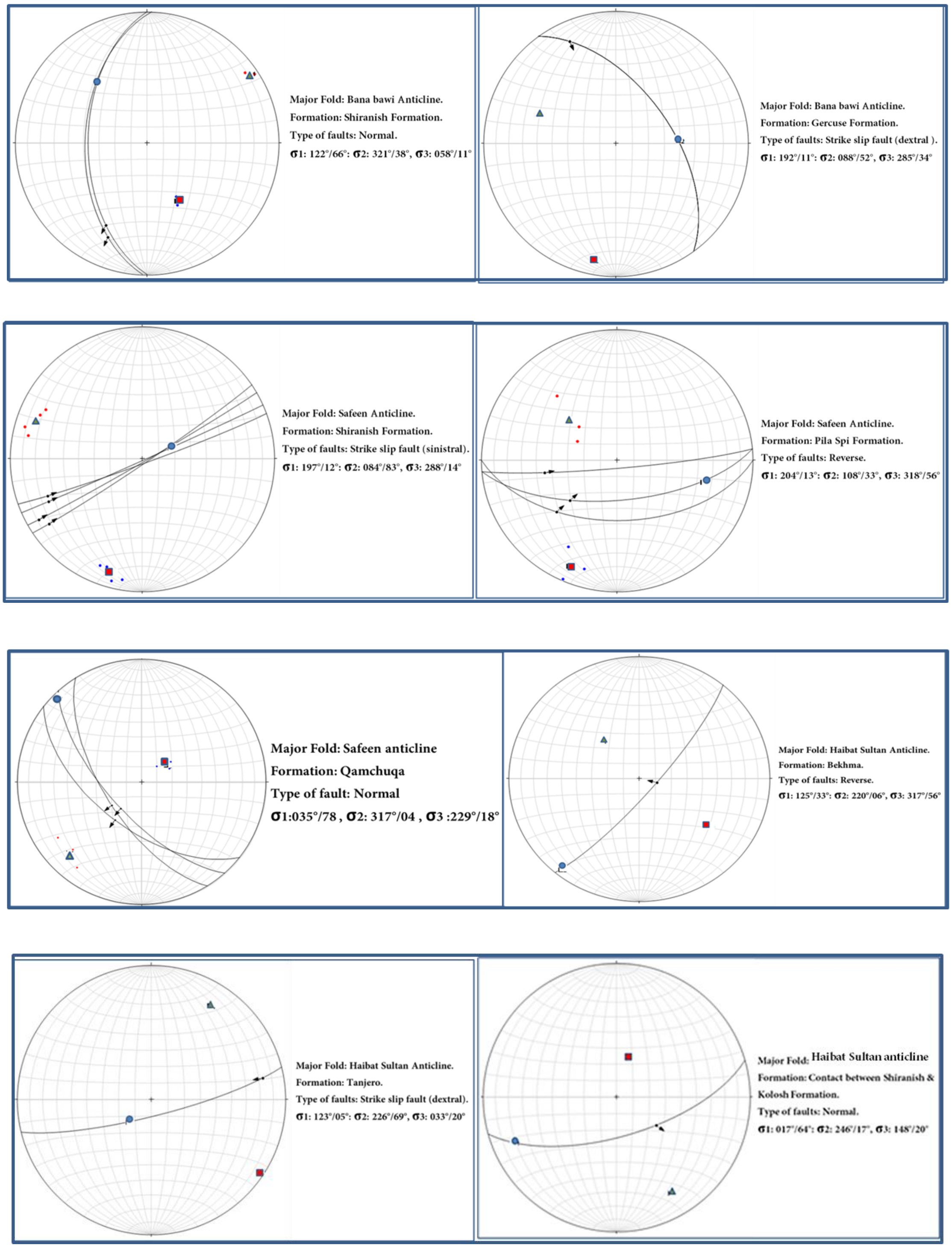


Fig. 4: Fault-slip data analyses of some faults in study area.

c-Stylolites

The Stylolites were analyzed and classified geometrically, two sets of stylolite surfaces were recorded; one parallel to bedding planes where stylolite teeth tend perpendicular to the bedding and indicate maximum compression due to the overburden load. This type might be "non-tectonic in" origin, however, the horizontal stylolite indicates that the region is affected by extension phase, and these stylolite surfaces corresponds to the extension stress (NE-SW and NW-SE) direction in the study (Fig.5).

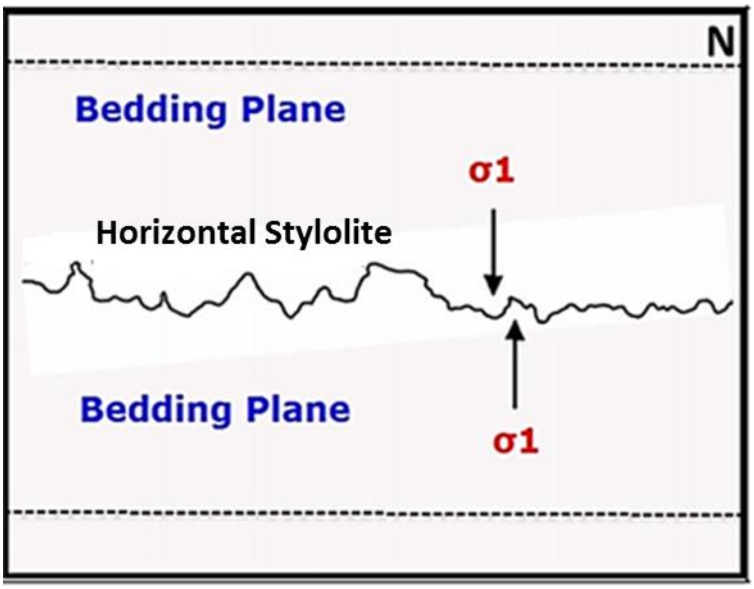


Fig. 5; Sketch showing the bedding parallel stylolites .

The other set is perpendicular to the bedding planes as a result of tectonic activity where stylolite teeth tend parallel to the maximum compressive direction caused folding in the, and these trends corresponds to the compression stress in (NE-SW and NW-SE) direction (Fig.6).

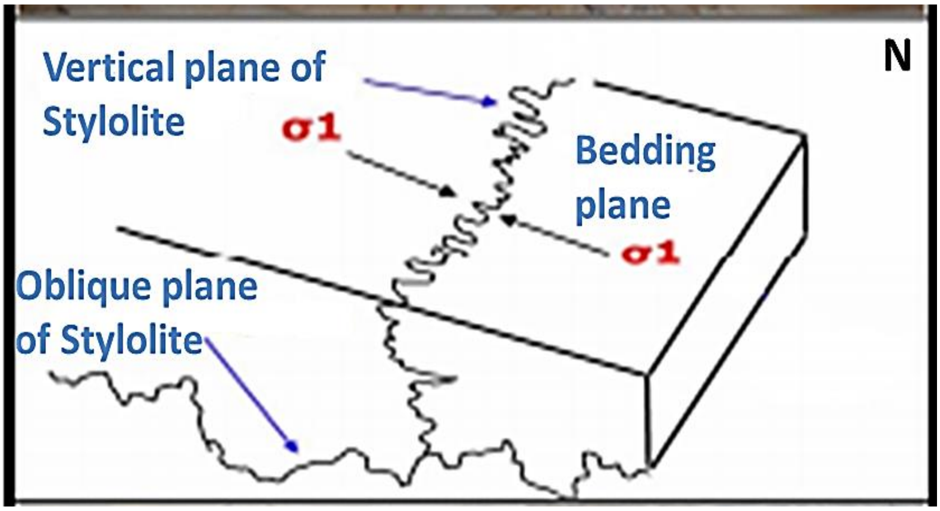


Fig. 6:Vertical and oblique Planes of Stylolites .

d-Veins (Tension gashes)

The veins were analyzed and classified geometrically, they appeared in several en enechelon, planner and Strockwork tension gashes shape with many directions in the study area, but they mostly trend in NE-SW and NW-SE direction, and these trends corresponds with to the compression and extension stresses in the study area.

4-Conclusions

The study area affected by four tectonic phases of stresses according to structural analysis and motion on the surface of the faults through the presence of the striation. Two of them are compressional; one is perpendicular to folds axes and the a another one is parallel to sub parallel to fold axes and two phases are extensional phases (two extensional phases) one of them is perpendicular to folds axes and another one is parallel to sub parallel to fold axes, they have been resulted from uplifted of the study area. These tectonic stresses directions were deduced from the dynamic analysis of the faults, geometrical analysis of the joints, stylolite seams and veins.

The first NE-SW compressive direction which effected the study area towards Zagros domain, corresponds with shear joints system (hOl-a & hkO-a), and with reverse and strike-slip faults. This phase is followed by extensive tectonic phase as releasing phase, it is corresponded with normal faults which (NW-SE) direction, and with shear joints system (hOl-c). The region was then affected by second compressive tectonic phase parallel to the fold axes’s) NW-SE), this phase corresponds with reverse and strike-slip faults, and with shear joints system (Okl-b & hkO-b). Lastly the region has been affected by second extensive phase to the fold axis’s) NW-SE) and corresponds with the shear joints system (Okl-c) and with normal faults in (NE-SW) direction (Fig.7). We studied the tension joints (ac, bc, and ab) in the three folds, the study results were (ac) joints correspond with the direction of the compression stress causing Zagros in Iraq, and (bc) joints correspond with the direction of the extension stress.

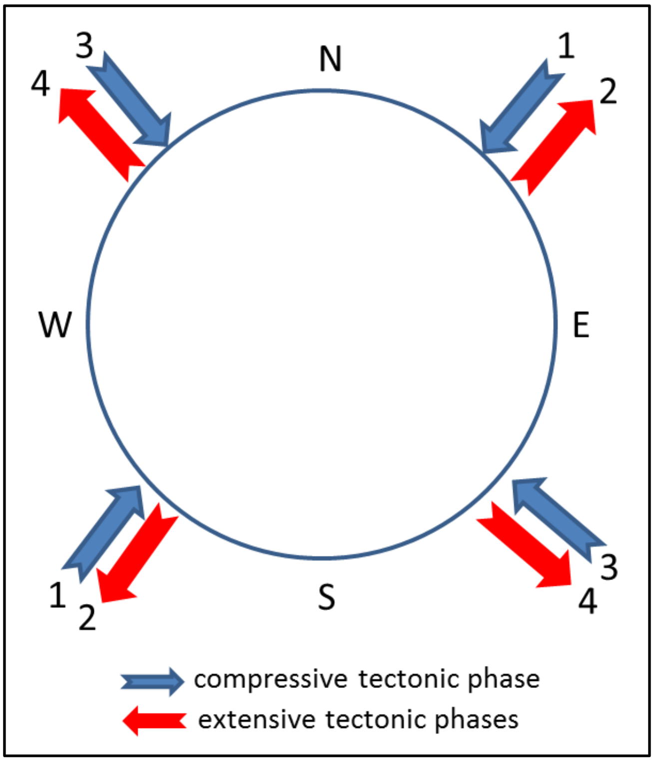


Fig.7: Summarizes the tectonic phases in study area.

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تحديد الطور التكتوني الانضغاطي والتمددي في الطيات المحدبة سفين, بنباوي وهيبت السلطان شمال شرق العراق باستخدام عناصر المايكروتكتونيك

ناغين عبدالجليل عبدالمجيد[1], منذر علي طه[2] و علي زباري المياحي [1]

[1] قسم علم الارض/ كلية العلوم- جامعة البصرة، البصرة-العراق.

[2] قسم علم الارض/ كلية العلوم- جامعة ديالى، ديالى-العراق

المستخلص

تضم منطقة الدراسة جزء من منطقة الطيات العالية والطيات الواطئة. سلسة من الطيات وهي سفين, بنباوي وهيبت السلطان. الطيات الواطئة تضم طيات هيبت السلطان وبنباوي وتضم الطيات العالية طية سفين, محاور هذه الطيات يتوافق مع الاتجاه العام لزاكروس شمال غرب-جنوب شرق. تحليل ألمعلومات ألتركيبية أظهرَ إلى إن منطقة الدراسة خلال تاريخها ألجيولوجي تعرضت إلى اربعة إجهادات رئيسية: إثنان منهما إنضغاطيان واثنان تمدديان. ألأجهادين الانضغاطي والتمددي بالاتجاه شمال شرق-جنوب غرب الذي يكون عمودي على محاور الطيات, والاجهادين الاخرين الانضغاطي والتمددي موازي لمحاور الطيات. الاجهاد الانضغاطي الاول الذي تأثرت به منطقة الدراسة باتجاه زاكروس NE-SW يتوافق مع اتجاه محاور الطيات الرئيسية ومع انظمة الفواصل القصية hOl-a & hkO-a ومع الفوالق المعكوسة والمضربية, تبع ذلك طور الاستطاله الذي يتزامن مع الفوالق الاعتيادية التي اتجاهها NW-SE و مع انظمة الفواصل القصية hOl-c, ثم تبع ذلك طور انضغاطي ثاني باتجاه NW-SE يتوافق مع الفوالق المعكوسة والمضربية ومع انظمة الفواصل القصية Okl-b & hkO-b, واخيرا حصل طور تمددي اخر باتجاه NW-SEيتوافق مع الفواصل القصية Okl-c والفوالق الاعتيادية ذات الاتجاه NE-SW. درست الفواصل الشدية bc, ac, ab في الطيات الثلاثة وكانت نتائج الدراسة ان فواصل ac تتوافق مع اتجاه الاجهاد الانضغاطي المسبب لزاكروس في العراق, وفواصل bc تتوافق مع اتجاه الاجهاد التمددي.