ROCK JOINTS ANALYSIS TO DETERMINE THE MAIN STRESS FIELD IN BUSTANAH STRUCTURE NORTHEAST OF IRAQ

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ABSTRACT

Joints are among the most widespread geologic structures as they are found in most each exposure of rock. They differ greatly in appearance, dimensions, and arrangement, besides they occur in quite different tectonic environments. This study is important because joints provide evidence on what kind of stress produced them (history of deformation) and also because they change the characteristics of the rocks in which they occur. The Measured data of joints from the studied area which are located in the high folded zone – Northeast of Iraq, were classified according to their relationship with the tectonic axes by projecting them stereographically using Schmidt net in GEORient ver.9.5.0 software. The joint systems revealed the orientation of the major stress field that caused the area deformation. Two dominant joint systems were found in most stations of the studied area, which are $hko>a$ (first place) and $hko>b$ (second place). The main stress field direction from the joint's classification is North East – South West which coincides with the opening of the red sea and the collision between Arabian and Iranian tectonic plates. The North West direction (which comes in the second place) it might be due to the rotational movement (counterclockwise) of the Arabian plate in addition to the effect of local stress in the area.

Keywords: Rocks; Joints; Stress; Bustanah; Fracture; Tectonic

INTRODUCTION

The most common geological structures that are created in the upper crust are joints (Weinberger, et al; 2010). Any thin natural planar crack that is not a fault, bedding, or cleavage and is larger than the grain size of the rock is a joint in the broadest sense of the word; Most Joints show no observable displacement parallel to their walls and are therefore not developing faults, as can be seen by correlating details of the rock across the fracture (Suppe, 1985). They profoundly control the shape of many spectacular landforms, and play an important role in the sub-surface transport of fluids such as water and hydrocarbons (Pollard and Aydin, 1988; Gross and Eyal, 2007). The previous studies on this area are based on the

data gained from the interpretation of aerials photographs at scale 1:42000. Another field checking during 2006-2012 has done by (Sissakian and Fouad, 2014). Structural geology of the area has a significant role, it's influenced by incidence faults and highly jointed of carbonate formations in the area (Fatah et al., 2020). The study aims to analyze the fracture yield with the folding and to determine the direction of forces that caused it.

GEOGRAPHICAL LOCATION

It lies geographically in the northern part of Iraq within the area of Erbil, about 11 Km from the center of Koisinjak city. It is located between Latitudes ($N36^{\circ} 10' 12'' - N36^{\circ} 06' 36''$) and Longitudes ($E44^{\circ} 39' 18'' - E44^{\circ} 42' 54''$) (Fig. 1).

Fig. 1. Location map of the study area

TECTONIC SETTINGS

Jassim and Goff (2006) divided Iraq into three tectonic units. They are Unstable Shelf, Stable Shelf and the Zagros Suture Zone. The Unstable shelf unit is divided into three parts; they are: Foothill Zone, High Folded Zone, and Imbricate zone. The study area is located within the

High Folded Zone (Fig. 2) that covers most of the Iraqi Kurdistan region. The Unstable Shelf had been the most obviously subsiding part of the Arabian Plate from the time when the opening of the Southern Neo-Tethys in the Late Jurassic. Most extreme subsidence happened during the Late Cretaceous ophiolite obduction onto the North East edge of the Arabian Plate and during Miocene – Pliocene continental collision (Jassim and Goff, 2006).

The Unstable Shelf is therefore portrayed by basic patterns (structures) and facies changes that are corresponding to the Zagros-Taurus suture belts. Surface folds are a typical feature of the unit (Maher T. Zainy et al. 2017). The location of the high folded zone is between the Zakho area, on the Turkish border in the North West, and the Derbendikhan-Halabja area nearby the Iranian border in the South East (Garzic et al., 2019). The distance across the zone varies from 25 to 50 km. It is also affected by transversal blocks. The zone faced an irregular uplifting in the Cretaceous and Paleogene time (the beginning of the Cenozoic Era) and strongly distorted in the Late Tertiary (Al-Qayim et al., 2012). Harmonic folds with Mesozoic limestone in their cores and Palaeogene and Neogene (The second period in the Cenozoic Era, it follows the Palaeogene Period) limestone and elastics on their limbs are what the high folded zone includes (Jassim and Goff, 2006). Bustanah structure might be as asymmetrical syncline trending NW-SE followed to the west by asymmetrical anticline trending in the same direction. (Sissakian and Fouad 2014).

Fig. 2. Tectonic map of the study area (Jassim and Goff, 2006)

TOPOGRAPHY

The basement topography affects strongly on the shape of geomorphological phenomena (Thomas 1989). The area is characterized by hills and mountains of different elevations to flat topography (Fig. 3). The more distinct mountain is Haibat Sultan Mountain.

Fig. 3. Topography of the study area

STRATIGRAPHY

The exposed rocks of the sedimentary sequences range in span from Late Cretaceous to Paleocene-Lower Eocene. These sequences include the following formations describing from older to younger (Fig. 4).

Fig. 4. Geological map of the study area (Sissakian and Fouad, 2014)

1. Kometan Formation (Late Cretaceous)

Kometan formation was defined by Dunnington, in 1935 from the Kometan village near Endezah in NE Iraq (Jassim and Goff, 2006). It is characterized as well-bedded pale brown dense limestone and fractured (Fig. 5). Sediments of the Kometan Formation were deposited in diverse environments ranging from shallow shelf to open marine (Jassim and Goff 2006).

Fig. 5. Kometan Formation in the study area

2. Shiranish Formation (Late Cretaceous)

This formation was defined by Henson (1940) from the High Folded Zone, Northern Iraq near the village of Shiranish Islam, NE of Zakho, (Bellen et al., 1959 and Buday, 1980) Shiranish Formation was broadly exposed. It forms smooth-edged hills and highly variance topography. The formation contains thin-bedded incompetent greenish-brown and grey to blue marl and marly limestone. The lower contact with the underlying Kometan formation is disconformable; the upper contact with the overlying Tanjero Formation is conformable and gradational. It was recognized by the existence of green clastic sediments (Bellen et al, 1959, Jassim and Goff, 2006) (Fig. 6).

3. Tanjero Formation (Late Cretaceous)

It was first described by Dunnington, in 1952. The clastic sediment of this formation goes to the typical formations of miogeocynclinal area of Iraq (Bouday, 1980). It is flysch sediment (Jassim and Goff, 2006). It is widely exposed in the area (Fig. 7). The lithology is characterized by alteration of dark green marl, marly limestone, sandstone, siltstone, and conglomerate in the upper part. The upper contact is commonly unconformable with the overlying Kolosh Formation (Bellen et al., 1959). The formation is deposited in a deep trough formed in the Zagros foreland due to the obduction of ophiolite as indicated by flysch type clastic (Sissakian and Fouad 2014).

Fig. 6. Shiranish Formation in the study area

Fig. 7. Tanjero Formation in the study area

4. Kolosh Formation (Early- Late Paleocene)

It was first described by Dunnington in 1952 from Kolosh village, North of Koisinjaq, in the High Folded Zone, Northeast of Iraq (Jassim and Goff, 2006). It is widely uncovered to the west of the research area (Fig. 8). The lithology is black clastic sediment like shale sandstone, siltstone, and claystone. The upper contact with the overlying Gercus Formation is conformable and gradational (Jassim and Goff 2006). The formation is deposited in the open marine platform of variable salinity and mixed fauna of shallow and deep water (Aqrawi et al., 2010).

Fig. 8. Kolosh Formation in the study area

MATERIALS AND METHODS

Joints are among the most common of all geological feature, hardly any outcrop of rock exist that does not have some types of joints through it. They are important both for the information they provide regarding the sequence of the tectonic event during which the joints formed and the physical characteristics they tell to the rock in which they occur (Twiss and Moores, 2007). Data of joint planes were collected from the study area through 10 stations with unsystematic distribution depending on the ease of access for each location in Table 1. Strike and dip were measured for the joint planes as well as the attitude of the bedding plane which contains the joints and find the type of fractures with respect to three orthogonal tectonic axes according to Hancock (1985) classification.

Table 1. The coordinates of each station in the study area

Station No	Latitude	Longitude	Elevation (m.)
St. A	N 36 08 04.9	E 44 42 12.1	608
St. B	N 36 09 0.39	E 44 42 19.5	592.3
St. C	N 36 07 19.1	E 44 41 13.2	652
St. D	N 36 07 12.5	E 44 41 14.2	644.4
St. E	N 36 07 37.7	E 44 41 36.3	654
St. F	N 36 07 38.1	E 44 41 18.5	628.6
St. G	N 36 09 29.5	E 44 41 01.6	598.9
St. H	N 36 09 22.4	E 44 40 46.7	611.2
St. I	N 36 09 59.1	E 44 39 51.0	562.2
St. J	N 36 08 14.8	E 44 41 59.1	610

RESULTS

Joint Analysis

The collected data were processed by GEOrient ver. 9.5.0 software that produces synoptic joint planes for each location. The main jointing mechanisms are reactions of the host rock to a regional or local stress field, influence of pore pressure and hydro-fracturing, stress relaxation due to rock uplift, and/or jointing due to material shrinking (columnar joints in basalts) (Engelder, 1985 and Bahat et al., 2005). Therefore, they can be classified according to the basis of origin into:

- 1- Shear Joints: Joints caused by shear stresses.
- 2- Tension Joints: Joints that resulted from extensional stresses.
- 3- Columnar Joints. These joints are formed in igneous rocks that are formed during the cooling of lava when it derives out of the earth in a melted state.

Fractures (joints) are two dimensional surfaces, they are either parallel to two tectonic axes, or one tectonic axis or cut the three ones (Ladeira and Price, 1981). The fractures of the study area were described and classified geometrically in proportion (percentage) to the orthogonal tectonic axes (Fig. 9).

Fig. 9. Joints proportion in the study area

Over the distribution of the joints in the study area and the proportion of each fracture system or subsystem, it can be realized that the main compression stress was illustrative in the form of the shear joint system (hko) acute about (a) which is in the direction of NE – SW. (hko) acute about (b) subsystem came in the following place as a shear joint system that is compatible with the fold axis or direction of the plunge of the study area NW – SE. The planes of (ac) set fractures that is in the third place are parallel to tectonic axes (a) and (c), whereas a tectonic axis (b) is perpendicular to them. In other word, (ac) sets are perpendicular to the hinge line of a folded layer. These tension fractures (joints) might be the end result in the outer arc of a folded layer. The Joint plane's data of the study area illustrated stereographically for each station separately in the Fig.10.

Fig. 10 a. Synoptic joint planes for the studied stations

Fig. 10 b. Synoptic joint planes for the studied stations

Fig. 10 c. Synoptic joint planes for the studied stations

Kinematic Analysis of Joints

The analysis describes the relationship between the extension and shear fractures with the stages of fold development and the regional tectonic forces affected the area. The measurements of rock geometries can be used to understand histories of strain in the rock. From the distribution of the joints in the area, it can be noticed that the stress caused (hko acute about a) fracture sets and (ac) fracture sets coincide with the regional stress that forms the fold where the maximum principal stress (σ_1) is oriented NE-SW direction parallel to (a) tectonic axis. And minimum principal stress (σ_3) is in the direction of NW-SE parallel to (b) tectonic axis. The compressional stress leads to shortening the layers in the perpendicular direction to the fold axis and extension parallel to the fold axis. In another side the extension stress was determined in the form of (hko acute about b) where (σ_1) is horizontal in NW-SE direction parallel to the tectonic axis (b) and (σ_3) is perpendicular to it, and (hol acute about c) where analyzed into two components, the vertical one helps in uplifting and horizontal one helps in extension of the layers parallel to the strike of the fold and the tectonic axis (b). The low distribution of (okl acute about c) which is (7%) indicates local vertical stress with little effect of uplifting. While the high distribution of (hol acute about c) (13%) refers to a strong tectonic force for uplifting. The (hkl) fracture system caused during folding in different directions cuts the three tectonic axes and represents local stress associated with all stages of fold development.

CONCLUSIONS

The area is a part of the High Folded Zone of the Zagros simply folded belt in northeastern Iraq. The exposed rocks range in age from late Cretaceous up to the early – late Paleocene represented by four formations which are: Kometan, Shiranish, Tanjero, and Kolosh formations. Joint analysis showed the geometrical and genetic relationship with the principal tectonic axes, as the main compression stress was representative in the form of shear joint system hko acute about (a) which is in the direction of NE-SW, this corresponds the collision between Arabian and Eurasian tectonic plates that has mainly happened during the Miocene. Most of the structures in the Northeastern part of Iraq were shaped out due to the same effect. Whereas hko acute about (b) (which comes in the second place) it might be due to the rotational movement (counterclockwise) of the Arabian plate in addition to the effect of local stress that might become from the plunging. Extension stress was characterized by tension fracture set (ac) which is abundant in the outer arc of a folded layer or to be formed by uplifting due to local stress. It can be derived from the above fracture analysis that the area

might be simply folded layers to form a minor fold (syncline and anticline) or shape that looks like a dome structure.

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