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Fracture Pattern Analysis of the Upper Cretaceous-Eocene Carbonates along with the Ghumawan Dome, Hazara Basin

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Abstract: Deformational history of the Hazara basin indicates a primitive collision of the two landmasses that undergoes an episodic deformation with NE-SW structural trend. Panjal Thrust (PT) and Main Boundary Thrust (MBT) demarcate the northern and southern extremities of the basin, respectively. The area bounded between these two thrusts is the core consideration of the present research. Different stratigraphic units juxtapose along the Hazara Kashmir Syntaxes (HKS), while the strike-slip component is indicated by imbrication due to thrusts. The study is amied to analyze the paleo-stresses along with developed fracture patterns. Field data were collected via Circle Inventory Method from various localities of the Ghumawan dome, Hazara basin. The zones of upper Cretaceous to Eocene carbonates were mainly targeted during the data collection. Win-Tensor was the key software that helps to analyze the paleo-stresses and fracture pattern of the study area. NW-trending fracture pattern was observed with a highly non-symmetric to dense fracture pattern. The local thrust system lead to severely de-shape the study area. N-S oriented σ1 indicated the compressional tectonic condition that prevailed during deformation of this area. Some segments also show extensional features i.e. normal faulting.

Keywords: Ghumawan dome, fracture pattern, Hazara basin, Hazara Kashmir syntaxis, paleo-stresses, win-tensor.

Introduction

Pakistan lies at the triple junction of Indo-Pak, Arabian and Eurasian plates. An intra-oceanic transform boundary i.e., Murray ridge, divides the first two plates. Iranian and Afghan microplates accrete with the Eurasian plate during Cretaceous to Paleocene time (Treloar and Izatt, 1993; Kazmi and Jan, 1997; Gaina et al., 2015). The collisional phase of Indo-Pak and Eurasian landmasses results in several episodic deformations of the region (Powell, 1979; Aitchison *et al.,* 2007; Van Hinsbergen *et al*., 2012; Zheng and Wu, 2018). Due to compressional and trans tensional phases of the collision, various folding and faulting structures emerged in the northern and western margin of the Indo-Pak plate, respectively. In addition to this, northward dipping while south verging thrusts developed as MKT (Main Karakorum Thrust), MMT (Main Mantle Thrust), MCT (Main Central Thrust), MBT (Main Boundary Thrust) and SRT (Salt Range Thrust) (Fig. 1) (Gansser, 1964; Tahirkheli, 1979; Yeats and Hussain, 1987; Mukherjee 2013 a, b).

Geological Setting

Hazara Basin lies within the tectonostratigraphic zone of Lesser Himalayas and trending in NE-SW (Chaudhry et al., 1998; Ahsan and Chaudhary, 2008). The northward collision of Indo-Pak and Eurasian landmasses resulted in some post-Eocene structural features by the episodic and polyphase deformation (Chaudhry and Ghazanfar, 1990; Ghazanfar *et al*., 1990). Ghumawan Anticline is one of those developed structures that lie near Nawanshehr on Abbottabad-Thandiani Road (Lat 34°10’14.42” N, Long 73°16’42. 07” E). The northward and southward extremities of the area were marked by PT and MBT respectively (Umar *et al.,* 2015). Due to strike-slip movement, imbrication sheets exist between the two thrusts. Throughout, these thrusts juxtapose metamorphic and sedimentary rock sequences, also steepen and merge in a sub-vertical thrust along the western limb of the HKS (Hazara-Kashmir syntaxis). The present study deals with fracture pattern, density, orientation and the paleo-stresses that develops these present fractures. In addition to analysis of Paleo-stress directions along with the effect of megathrusts on the rock sequence.

Hazara basin contains rock units ranging in age from Precambrian to Cambrian, and then Jurassic to Miocene. Both clastic, as well as carbonate deposition was active during the evolution of the basin. Rock units of Upper Cretaceous-Eocene are the scope of the paper (Fig. 2).

Kawagarh Formation of the Cretaceous age contains sandy limestone with shale interbedswhere thethickness varies from 20-85 m. Lockhart limestone of middle Paleocene age mainly consists of nodular limestone but in the upper part, intercalations of shales are present. It varies in thickness from place to place i.e., type locality (90 m) and Hazara basin (50 m). Shallow water conditions prevailed during the deposition of the Lockhart limestone. Nodular to bedded limestone with subordinate shale is the dominant lithology of Margala hill limestone of early Eocene age that shows shelf environmental setting. Calcitic veins are abundant throughout the rock unit and range in thickness from 80 to 100 m in the type locality.

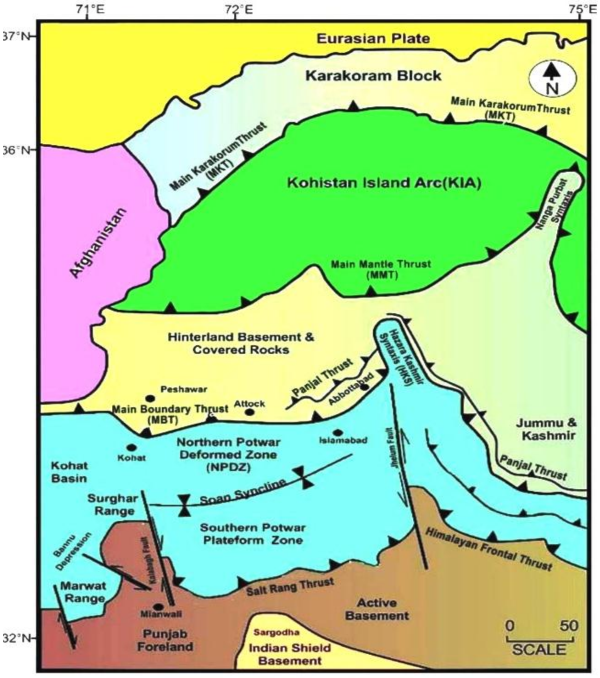

Fig. 1 Generalized tectonic map of northern Pakistan (modified after Kazmi and Rana, 1982; Ghazanfar *et al.*, 1990).

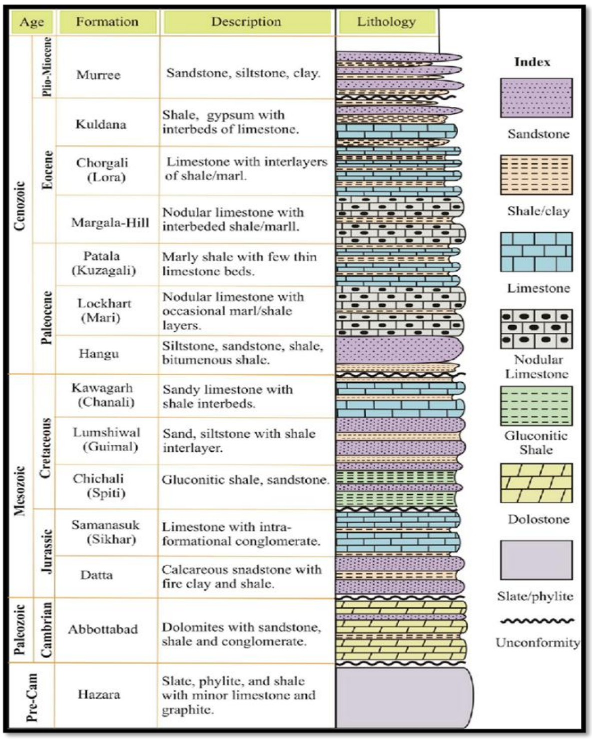

Fig. 2 Stratigraphic sequence of the Hazara basin (modified after Latif, 1970).

Materials and Methods

Data collection was solely based on Circle Inventory Method. While opting and applying this method, first of all, coordinates of the study area and each circle were recorded. Both bedding plane and bedding surface were used for this purpose and marked a circle of about 40-100 cm radius on them. Ten such circles were drawn on Ghumawan anticline where the length, width, density and orientation of all these circles were recorded on the sheet (Table 1). Upper Cretaceous-Eocene rock units were considered for fracture measurement. Win-Tensor (free) software was used for Paleo-stress analysis to determine the fracture patterns.

Table 1 Locational data of the measured stations.

Circle Name	Latitude	Longitude
Station 1 (C1)	34^0 09’48’’	73^0 16’44’’
Station 2 (C2)	34^0 09’48’’	73^0 16’45’’
Station 3 (C3)	34^0 09’46’’	73^0 16’44’’
Station 4 (C4)	34^0 10’08’’	73^0 16’41’’
Station 5 (C5)	34^0 09’50’’	73^0 16’30’’
Station 6 (C6)	34^0 10’07’’	73^0 16’41’’
Station 7 (C7)	34^0 10’55’’	73^0 14’10’’

Results and Discussion

Field Observation

The northward and southward extremities of the study area were marked by PT and MBT, respectively. Due to these megathrusts, the study area is highly deformed with NS-trending non-symmetric fracture pattern. Such severe deformation might be due to the local thrust system of the Hazara Basin while fracture density ranges from medium to high. In addition to this, calculation of joint density was also taken into consideration.

Station 1

The first circle was drawn with a radius of 35 cm on the outcrop surface of the Margala hill limestone. NW-trending (N63°W) bed dips in NE direction. NS-oriented stress pattern (σ1) was observed with three joint sets and medium fracture density (Fig. 3).

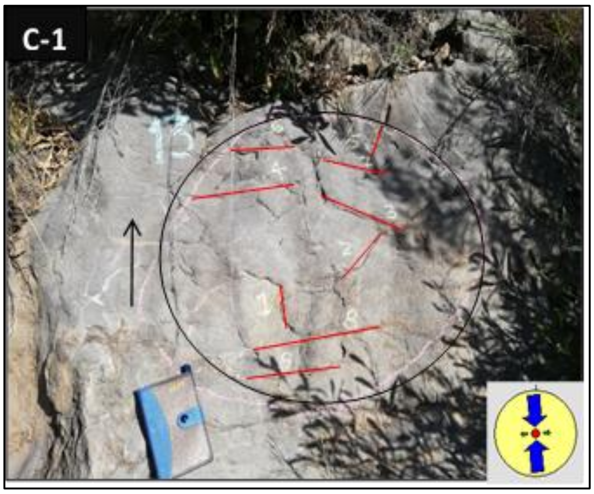

Fig. 3 Circle 1 (C-1) shows medium fracture density while joint density is 6.84 m^{-1}. The radius of the circle is 35.5 cm and the area is 3970.5 cm² (0.39 m²). Three joint sets were observed.

Station 2

Surface exposure of the Kawagarh Formation was decided for the measurement of the fracture pattern in which a circle with a 35 cm radius was drawn. The bed strikes in NE direction (N34°E) with NW dip direction (Fig. 4). Two joint sets were observed with medium fracture density.

Fig. 4 Circle 2 (C-2) showing medium fracture density and joint density are 7.68 m^{-1}. Radius of the circle is 35 cm and the area is 3846.5 cm² (0.38m²). Two joint sets were observed.

Station 3

Margala hill limestone was selected for the fracture measurement in which a radius of 35 cm circle was drawn. NW striking (N63°W) bed that dips in NE direction. σ1 oriented in NE-SW direction with single joint set and medium to high-density fractures (Fig. 5).

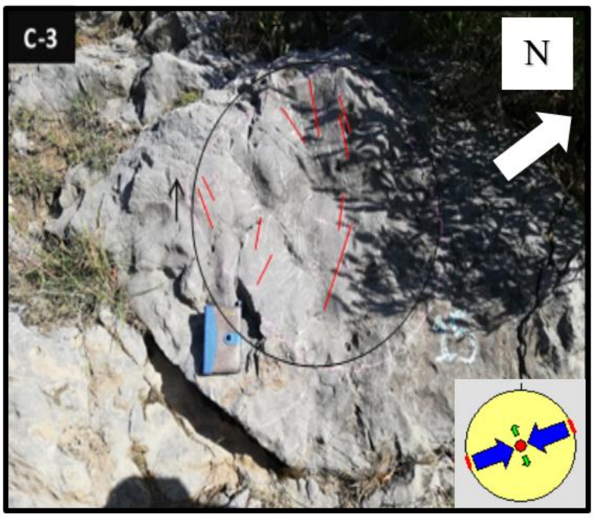

Fig. 5 Circle 3 (C-3) showing medium to high fracture density and joint density is 4.79 m^{-1}. The radius of the circle is 35 cm and the area is 3970.5 cm² (0.39m²). Two joint sets were observed.

Station 4

Surface exposure of Lockhart limestone was decided for the measurement of the fracture pattern in which a circle with a 45 cm radius was drawn. The strike direction of the bed is in NW (N80°W) with NE dip direction (Fig. 6). Two sets of joints were observed with medium to high fracture density.

Fig. 6 Circle 4 (C-4) showing medium to high fracture density and joint density is 4.58 m^{-1}. The radius of the circle is 45 cm and the area is 6358.5 cm² (0.63m²). Two joint sets are observed.

Station 5

To determine the fracture orientation and fracture length, the next circle was marked on the surface of the Margala hill limestone. The radius of the circle was selected as 35 cm. The bed dips in NW with extending in NE direction, i.e., N60°E. It contained two sets of joints with medium fracture density (Fig. 7). NS-oriented stress pattern σ1 was observed for this station

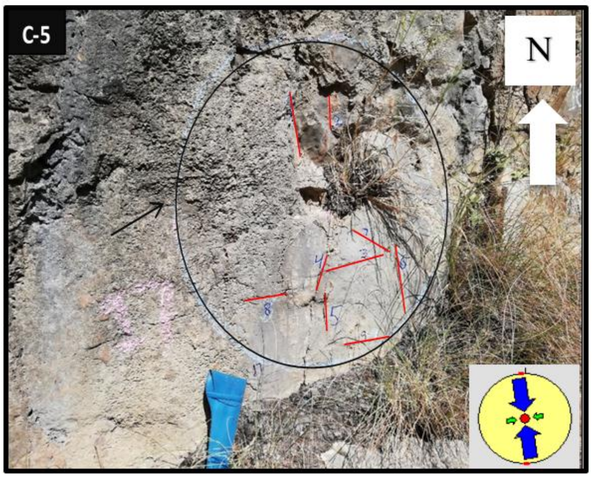

Fig. 7 Circle 5 (C-5) showing medium to high fracture density and joint density is 4.97 m^{-1}. The radius of the circle is 35 cm and the area is 3970.5 cm² (0.39m²). Two joint sets are observed.

Station 6

Lockhart limestone was selected for the fracture measurement in which a radius of 40 cm circle was drawn. NW striking (N40°W) bed that dips in NE direction was observed (Fig. 8). The orientation of σ1 is in the NS direction with two joint sets and highly dense fractures.

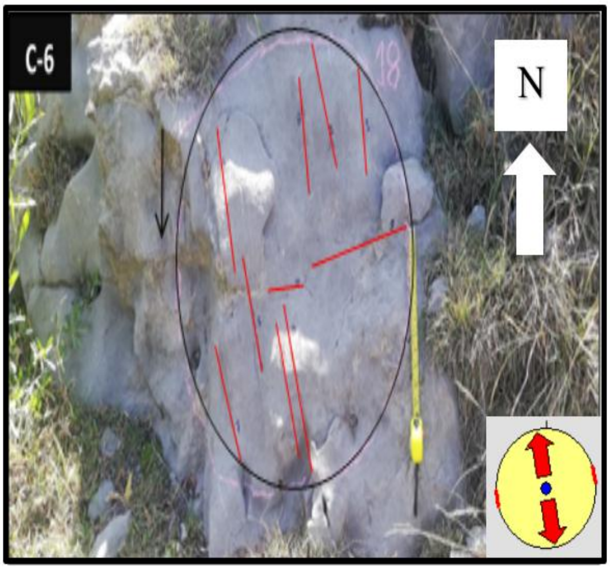

Fig. 8 Circle 6 (C-6) shows a high fracture density and joint density is 8.22 m^{-1}. The radius of the circle is 40 cm and the area is 5042 cm^2 (0.50m^2). Two joint sets are observed.

Station 7

The last circle was drawn with a radius of 33 cm on the outcrop surface of the Margala Hill Limestone. The bed is NE-trending (N51°E) that dips in SE direction. NS-oriented stress pattern (σ1) is observed with two sets of joints and medium fracture density (Fig. 9).

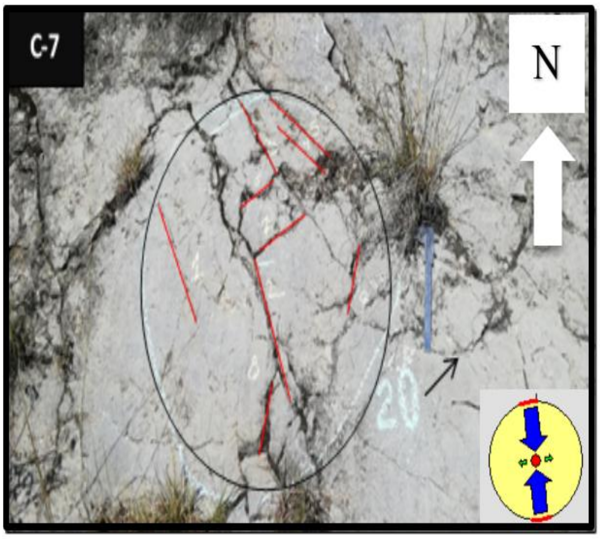

Fig. 9 Circle 7 (C-7) showing medium fracture density and joint density are 9.29 m^{-1}. The radius of a circle is 33 cm and the area is 3420 cm^2 (0.342m^2). Two joint sets are observed.

The circles are plotted on google imagery near the dome and the overall orientation of σ1 is almost NS (Fig. 10).

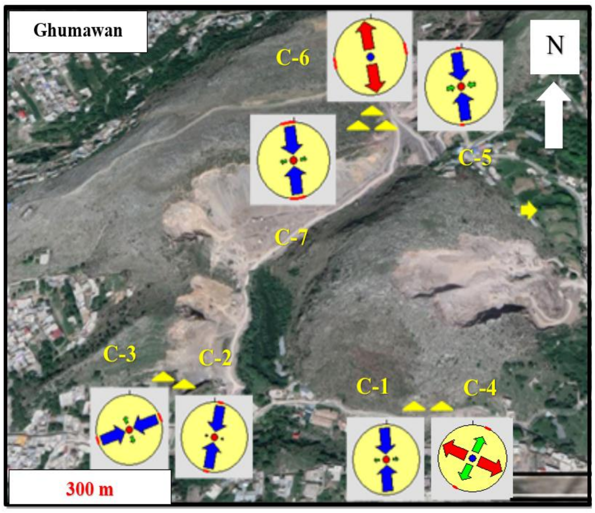

Fig. 10 Overall Win-Tensor results plotted on google imagery. It shows the orientation of the fracture pattern of the measured circles that developed in the study area.

Table 2 Length, cumulative length and trend of circles.

Circle 1		
Sr. No	Trend	Length (cm)
1	N14°W	15.24
2	N41°E	24.13
3	N70°W	44.45
4	N80°E	53.34
5	N20°E	12.7
6	N81°E	16.51
7	N80°W	44.45
8	N82°E	38.1
9	N84°E	19.05
Cumulative Length		267.97 (2.67m)

Circle 2		
Sr. No	Trend	Length (cm)
1	N60°W	48
2	N62°E	70
3	N80°W	29
4	N70°E	40
5	N35°E	37
6	N22°E	38
7	N33°E	30
Cumulative Length		292 (2.92 m)

Circle 3		
Sr. No	Trend	Length (cm)
1	N20°W	22.86
2	N14°W	12.7
3	N11°W	22.86
4	N10°E	8.3
5	N20°E	38.1
6	N39°W	19.05
7	N30°E	20.32
8	N30°W	19.05
9	N24°W	13.97
10	N11°E	10.16
Cumulative Length		187.37 (1.87 m)

Circle 4		
Sr. No	Trend	Length (cm)
1	N83°E	40
2	N83°E	19
3	N03°W	70
4	N39°W	37
5	N30°W	30
6	N44°W	28
7	N46°W	17
8	N38°W	16
9	N26°W	17
10	N40°W	15
Cumulative Length		289 (2.89 m)

Circle 5		
Sr. No	Trend	Length (cm)
1	N70°W	22.86
2	N57°W	12.7
3	N15°E	30.48
4	N37°W	33.02
5	N64°W	19.05
6	N80°W	27.94
7	N59°E	12.7
8	N22°E	12.7
9	N21°E	22.86
Cumulative Length		194.31 (1.94 m)

Circle 6		
Sr. No	Trend	Length (cm)
1	N10°W	27
2	N12°W	57
3	N11°W	67
4	N20°W	30
5	N20°W	49
6	N15°W	26
7	N25°W	27
8	N10°W	34
9	N77°E	50
10	N88°E	44
Cumulative Length		411 (4.11 m)

Circle 7		
Sr. No	Trend	Length (cm)
1	N87°W	50.8
2	N82°W	63.5
3	N85°E	45.72
4	N63°E	13.97
5	N64°E	17.78
6	N10°E	40.64
7	N09°E	15.24
8	N42°W	30.48
9	N40°W	40.64
Cumulative Length		318.77 (3.18 m)

Conclusion

Ghumawan area lies in the Hazara basin and is a part of the Lesser Himalayas with σ1 oriented in almost NS direction on northern, southern, eastern and NW-SE sides of the dome. Due to the local segment of the fault, an east directed stress pattern existed on the SW part of the dome. In addition to this, due to the different limb segments of the dome, some extensional features (normal faulting) were also observed on the NW side of the study area. Different fracture set indicates an overall compressional regime.

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