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Vol. 22 & 23, (June 2012 & 23),p.013-23, 18 Figs.,05 Tables.

Geological Mapping and Structural Analysis of a Part of Kala-Chitta Range, Kahi Village, Nizampur Khyber Pakhtunkhwa.

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ABSTRACT

The study area located in the vicinity of Kala-Chitta Range is intensely deformed, which along with the Attock-Cherat and Margala Hill Ranges represent the uplifted southern margin of the Peshawar-Campbellpur basins of northern Pakistan. The Kala-Chitta Range lies in the Upper Indus Basin. It is a part of the active Himalayan Foreland-Fold and Thrust Belt which has progressively been verged southwards in a series of top to the south thrust imbricates along Main Boundary Thrust (IVIBT), fabricating the regional fault system of North Pakistan.

Sedimentary rocks assemblages of Jurassic to Paleocene age namely Datta, Shinawari, Samana Suk, Lumshiwal, Kawagarh, Lockhart and Patala are exposed in the study area.

Complex structural geometry of the area entails a number of thrust faults and different folds in en-echelon manner, which imply intense deformation and shortening. The area is highly fractured and the fracture pattern of the area is indicative of Himalayan deformation.

1. INTRODUCTION

The Kahi village is located in the Nizampur valley of Khyber Pakhtunkhwa. The study area is situated at the northern bank of the Indus River and southern flank of Attock-Cherat Ranges. It is restricted between Longitudes 72° 04' 49"E - 72° 07' 25" and Latitudes 33° 47' 17'N - 33° 50' 09'N (Figure 1). The Kala-Chitta Range forms the northern edge of the Southern Deformed Fold and Thrust Belt (SDFTB) and is in alignment with the Hazara Mountains (Margalla Hills) towards east while Samana Range towards west. Tectonically, the study area is within the zone of active folding and thrusting in the foreland of the 2500 km long Himalayan mountain belt in Pakistan which shows complex structural pattern (Yeats and Hussain, 1987).

2. PRESENT WORK AND OBJECTIVES

The main purpose of the investigation is to describe the style of deformation and relationship between minor and major structures. This work is carried out with the following objectives:

- Preparation of a detailed geological map of the area.
- Preparation of a geological cross section.
- Fracture analysis of Jurassic rocks and Lumshiwal Formation in order to understand the stress orientations.

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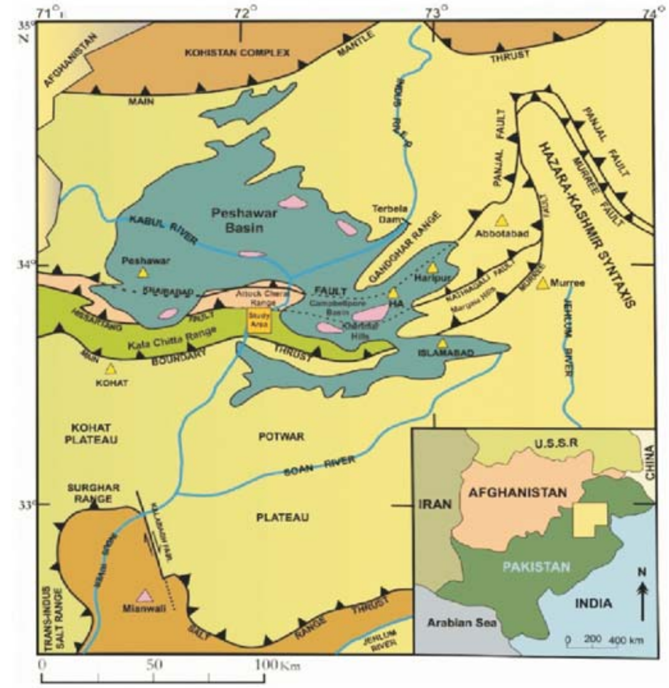

Figure 1- Generalized tectonic map of Northern Pakistan, showing regionally significant structural boundaries and geographic localities. Inset shows the location of study area (adapted from Calkins et al., 1975 and Yeats and Hussain, 1987).

3. MAPPING METHODOLOGY

Geological investigations are primarily based on field work and accurate mapping. However, with the advent of new techniques in image analyses and remote sensing, geological mapping is greatly assisted by analytical studies of satellite images prior to conducting the fieldwork.

The contour map for the study area was generated with the help of Global Mapper software using 30 arc seconds Digital Elevation Model (DEM) data. Then the map is treated in Surfer to get a more clear visualization of the contour data (Figure 2).Traverses were made along all the contacts and their exact location on the map was marked at about regular intervals. The direction of strike and amount of dips were calculated at suitable places and marked on the map.

Various traverses were made across each formation. Those sections were chosen where maximum possible geological details could be observed. The cross sections were drawn approximately at right angles to the regional strike direction. The 3D map of the area is constructed using Surfer with the help of Digital Elevation Model data (Figure 3).

Corel Draw software was used to draw the final map of the area. The profile for the cross section AB was generated with the help of Global Mapper software using Digital Elevation Model (DEM) data. The surface map of the area is also constructed in Surfer (Figure 4).

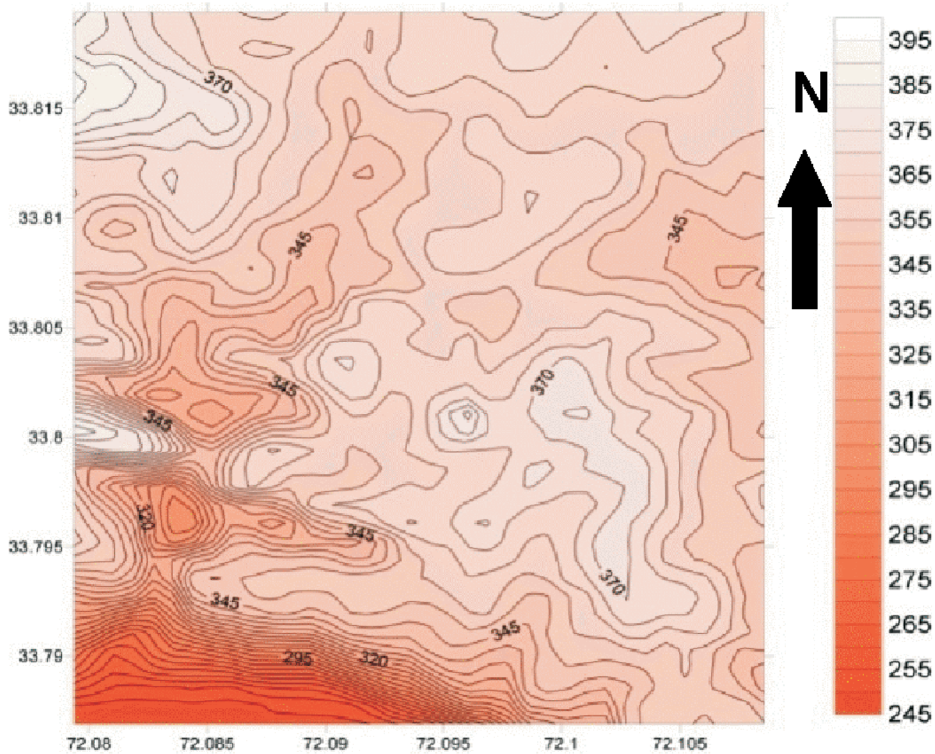

Figure 2 - Contour map of the study area.

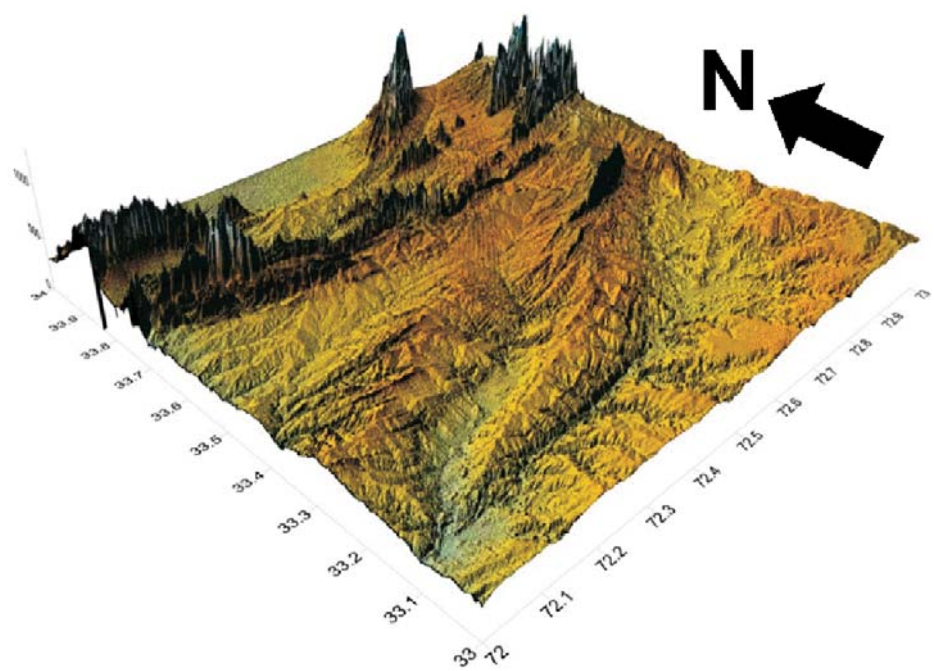

Figure 3 - 3D surface map of the study area.

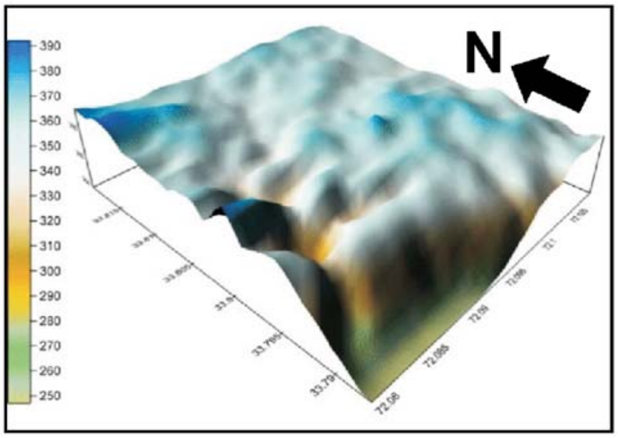

Figure 4 - Surface map of the area showing different elevations.

4. TECTONIC FRAMEWORK OF THE STUDY AREA

The Kahi area is located in the Himalayan foothills of northwestern Pakistan. It is part of fold-thrust belt near the southern margin of Pakistani Himalaya. The Kala-Chitta Range is a constituent of the Hill Ranges of Northern Pakistan (Yeats and Lawrence, 1984).

North of the Kala-Chitta Range, the Attock-Cherat Range and the Peshawar Basins are located (Burbank, 1982). The Kherimar Hills and Gandghar Range are located to the northeast of the Kala-Chitta Range (Hylland, 1990; Talent and Mawson, 1979). The Hissartang Thrust demarcates the boundary between the Attock-Cherat Range and Kala-Chitta Range in Nizampur area (Figure 5), where it separates the southern block of Attock-Cherat Range from Kala-Chitta Range (Yeats and Hussain, 1987). The movement along the Hissartang Fault deformed the rocks of the Kala-Chitta Range (Ghauri et al., 1991). Farther east the Kala-Chitta Range, forms the southern margin of the Nizampur Basin (Yeats and Hussain, 1987).

The Kala-Chitta Range is thrusted southward along the MBT, forcing Siwalik foreland basins still farther south (Yeats and Hussain, 1987). Farther south of Siwaliks, Mesozoic and Cenozoic strata similar to that of Kala-Chitta Range occur in the Kohat Plateau and Surghar Range (Meissner et al., 1974). The MET marks the southern boundary of the study area where the Kala-Chitta Rangelies in the hanging wall and Kohat-Potwar Plateau in the footwall (McDougall and Hussain, 1991). In the eastern Kohat Hills the MET is named as Murree fault, which further extends to form a loop around Hazara Kashmir Syntaxis (Monalisa and Khwaja, 2005).

5. STRATIGRAPHY OF THE STUDY AREA

In the northern part of the study area Jurassic sequence includes Datta, Shinawari and Samana Suk Formations. Above the Jurassic sequence are rocks of Cretaceous age including Kawagarh and Lumshiwal Formations. Lying above the Cretaceous sequence, there are rocks of Paleocene age including Lockhart Limestone and Patala Formation. Hangu Formation of Early Paleocene age is not exposed (Figure 6).

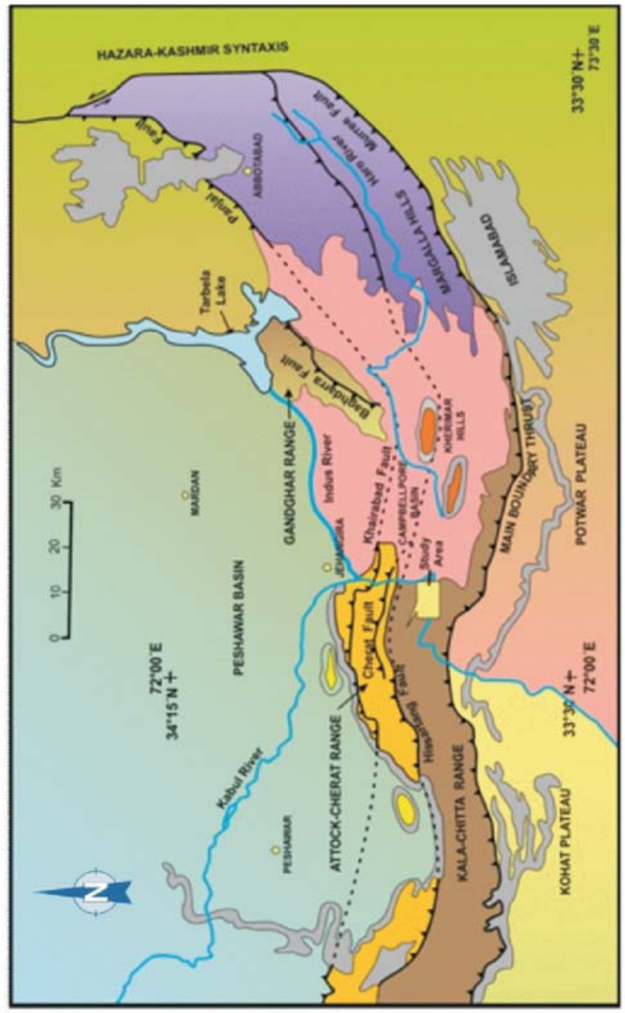

Figure 5 -Tectonic map of the Hill Ranges, showing suggested correlation of the Panjal, Nathiagali and Murree Faults in the east with the Khairabad, Cherat, Hissartang Faults and Main Boundary Thrust in the west (adapted from Burbank and Tahirkheli, 1985, Yeats and Hussain, 1987).

6. STRUCTURAL GEOLOGY

The Kala-Chitta Range represents the sediments of Mesozoic and Tertiary age. The study area, being very close to the MBT, has undergone intense deformation and shortening resulting in thrust faults and various large and small scale folds. The geological map of the study area, constructed during this research work is shown in Figure 7.

6.1 FOLDS

Regionally the rocks exposed in the Kala-Chitta Range are believed to be highly folded. Cotter (1933), in his pioneer work of the stratigraphy and structure of the Kala-Chitta Range, interpreted the tectonic style of the Kala-Chitta Range as isoclinal folding.

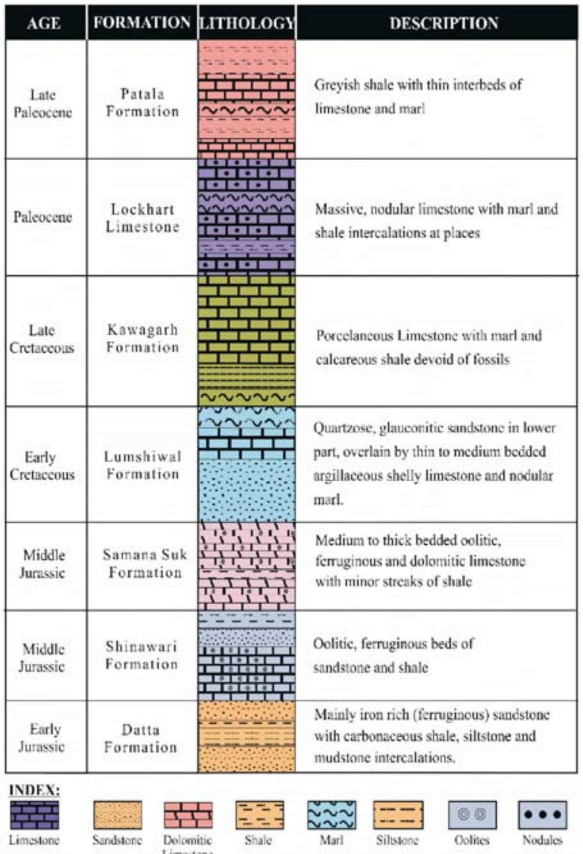

Figure 6 - Stratigraphic column of the study area (not to scale).

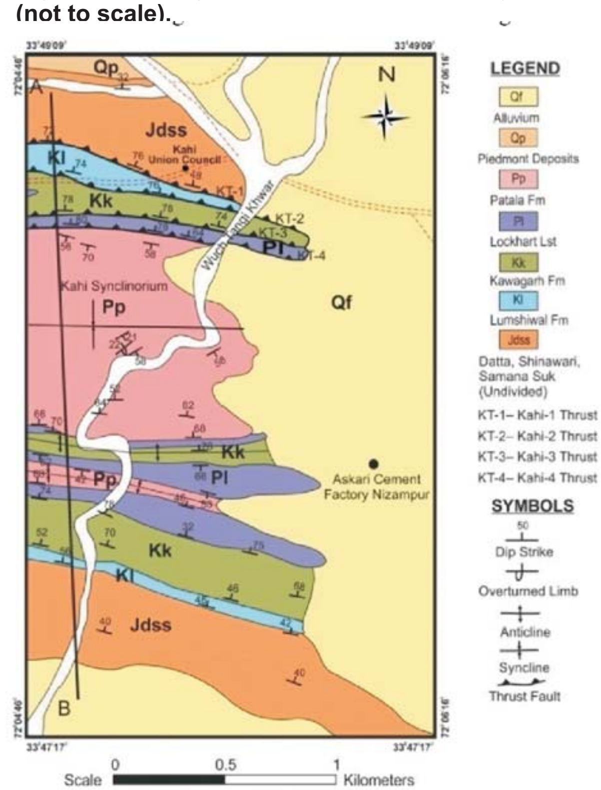

Figure 7 - Geological map of the study area.

6.1.1 KAHI SYNCLINORIUM

In the central part of the study area is a big synclinorium named as Kahi Synclinorium. This synclinorium has Patala Formation in its core and Lockhart Limestone at its limbs. The sequence is thrusted from the north while the sequence is normal conformable towards the south.

6.1.2 CONCENTRIC FOLDS

In the study area Patala Formation is in places perfectly folded in concentric synclinal folds (Figure 8).

6.2 FAULTS

The Kala-Chitta Range is believed to have formed as a result of Late Cenozoic movements along thrust faults. It brings the strongly deformed Jurassic, Cretaceous and Tertiary rocks to the surface along the thrust faults (Ghauri et al., 1991).

6.2.1 KAHI THRUSTS

While traversing from north to south in the study area, the first major structure encountered in the northern part of the area is the Kahi-1 (KT-1) Thrust. Along this thrust Jurassic rocks are thrusted over Lumshiwal Formation of Cretaceous age. It is roughly east-west oriented with a dip of 45° towards north. Kahi-2 (KT-2) Thrust is present next to the Kahi-1 (KT-1) Thrust. Along this thrust, Lumshiwal Formation of Middle Cretaceous age is thrusted over Kawagarh Formation of Late Cretaceous age. It is also roughly east-west oriented with a northward dip.

Kahi-3 (KT-3) Thrust is an east-west oriented fault which occurs to the south. Along this thrust, Kawagarh Formation of Cretaceous age is thrusted over Lockhart Limestone of Paleocene age. It has a dip of 76° (Figure 9).

Kahi-4 (KT-4) Thrust is a south-verging thrust which occurs to the south of the Kahi-3 (KT-3) Thrust. Along this thrust, Lockhart Limestone of Middle Paleocene age is thrusted over Patala Formation of Late Paleocene age. It is roughly east-west oriented with a dip of 60° (Figure 10).

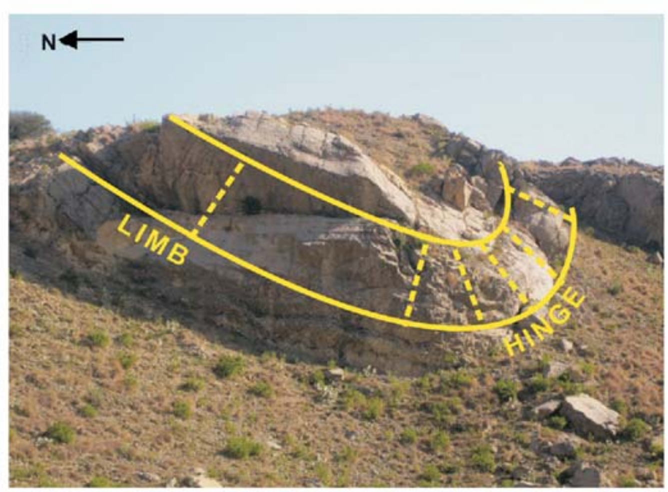

Figure 8 - Photograph showing the concentrically folded Patala Formation.

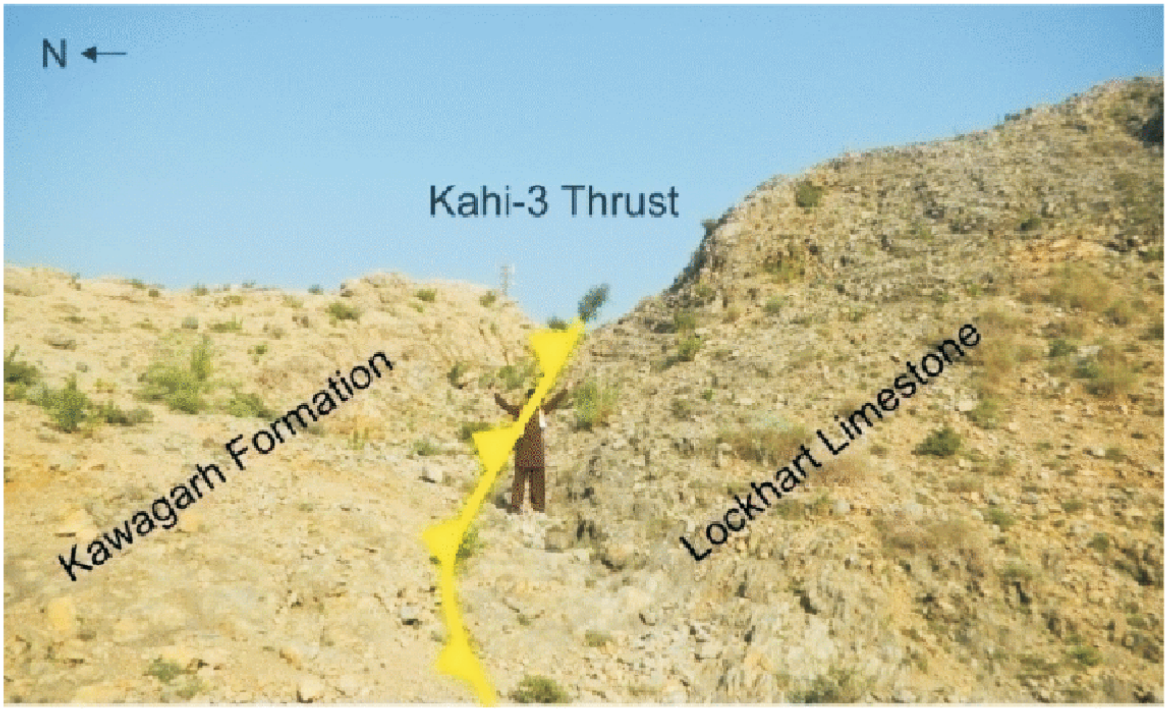

Figure 9 - Photograph showing faulted contact between the Kawagarh Formation and Lockhart Limestone.

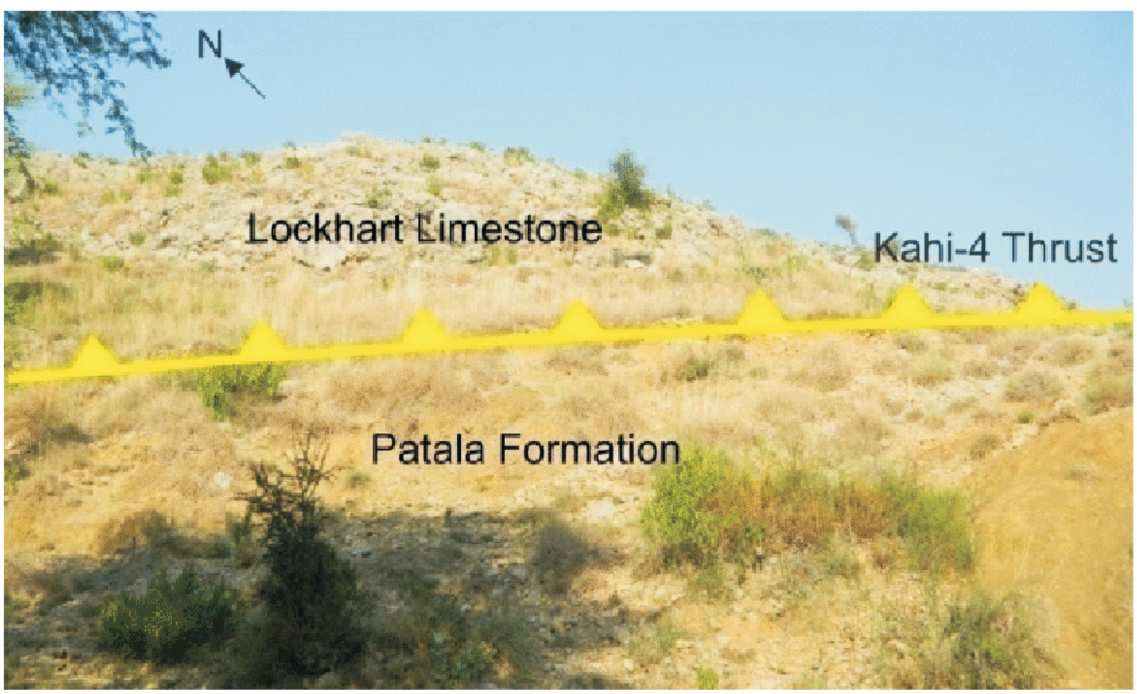

Figure 10 - Photograph showing faulted contact between the Lockhart Limestone and Patala Formation.

6.3 GEOLOGICAL CROSS-SECTION

In order to explain the surface and subsurface geometries of the exposed structural features, a geological cross-section along line AB of the map has been constructed (Figure 11).

The structural transect along the section line AB is perpendicular to the trend of the major structures present in the area and is north oriented (Figure 11). The northern most part of the area is covered by the Jurassic rocks i.e. Datta, Shinawari and Samana Suk Formations. Folding and faulting is very intense in Patala Formation. It may be the reason because it is composed of competent and incompetent lithologies. The incompetent lithology is shale and competent lithology is limestone.

There is a big synclinorium in the Patala Formation called as Kahi Synclinorium. It has Patala Formation in the core and Lockhart Limestone at the limbs (Figure 11). There is an anticline and syncline besides the Kahi Synclinorium. This anticline contains Kawagarh Formation in the core and Lockhart Limestone at the limbs while the syncline consists of Patala Formation at the core and Lockhart Limestone at the limbs. The southeastern part of the study area contains a normal conformable sequence including Kawagarh, Lumshiwal, Datta, Shinawari and Samana Suk (undivided) Formations.

Overall the structural style of the study area is characterized by south verging high angle reverse faults associated with stresses released during collision tectonics. Such minute observations might be described in regional tectonic framework (thin skinned or thick skinned).

7. FRACTURE ANALYSIS

The area has experienced a number of deformational phases which are evident by analyzing the area. Fracture analysis is carried out in the area in order to build the kinematic concept of the area.

Two basic approaches are used to collect the orientation data at the sample station:

Circle-inventory Method

Scan line / Traverse Method

The fracture analysis was carried out in undifferentiated Datta, Shinawari, Samana Suk and Lumshiwal formations. These formations are cut by various sets of fractures. Data was recorded from selected outcrops, where the fractures were best exposed. Five stations were marked at different locations. The description and the interpretations of these fractures are described as under:

7.1 STATION # 1

At location 33°48' 48" N, 72° 04' 55 E, dominant NNW-SSE striking and steeply dipping fracture sets are observed in Lumshiwal Formation. The bedding (S_o) strikes 105° with a dip of 72°. A line was drawn across the outcrop face. The fractures that intersected the scan-line are numbered from right to left. Data along each fracture that intersect the scan-line was measured including their orientation (dip and strike) and their interval. The scan-line is 230 cm in length. Ten major fractures intersected the scan-line and their measurements of dip and strike are noted as shown in table 1.

Table 1 - Orientation data of fractures at station # 1.

Fracture No.	Strike	Dip
1.	020	72
2.	160	82
3.	174	81
4.	169	79
5.	178	85
6.	170	80
7.	158	84
8.	178	79
9.	176	78
10.	179	70

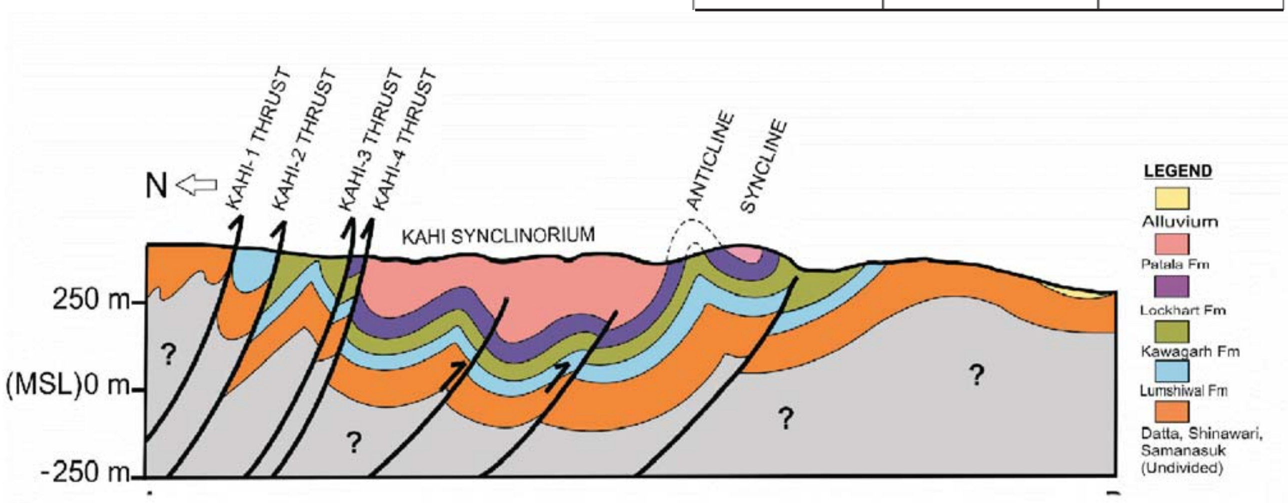

Figure 11 - Geological cross-section along line AB of figure 5.

The Right Hand Rule is followed while measuring the orientation data. The frequency of fractures along the scan-line is 0.043 f/cm. The amount of extension accommodated by these fractures is estimated to be about 9.0 % (Figure 12).

Mathematical calculations showing the amount of extension accommodated by fractures is given below:

Length of Scan-line = Lf = 230 cm
Total Fracture Interval = L_o = 211
Extension = e = $(Lf - L_o)/L_o$
= (230-211)/211
=0.09=9.0%

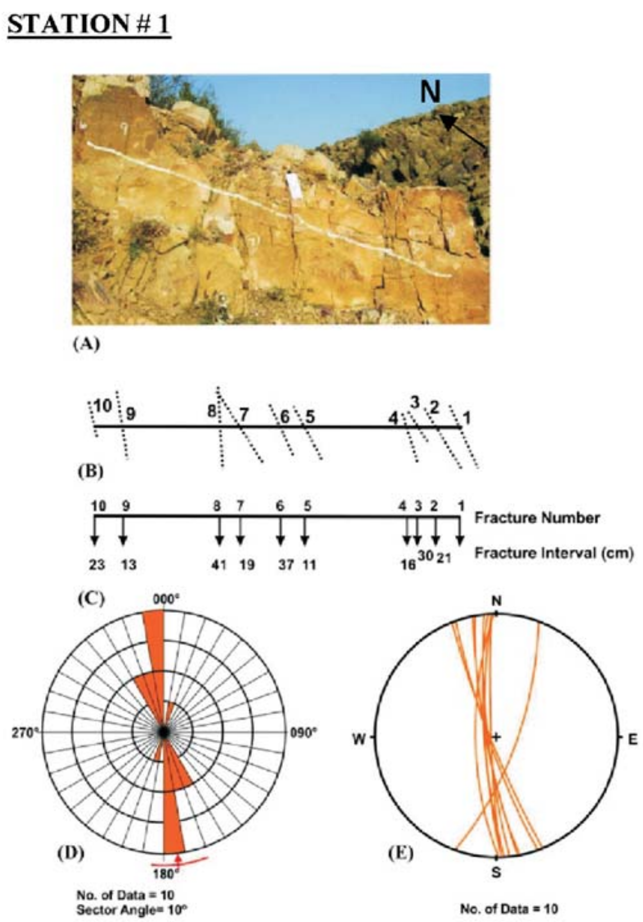

Figure 12 - Field photograph showing fractures at 33°48' 48 N, 72°04 55 E (A), sketch of fractures with a scan line (B), sketch showing the fracture interval (C), rose diagram of the data (D) and stereo-plot of the data (E).

7.2 STATION # 2

The second station was selected at location 33° 48' 50.3 N, 72° 04' 52" E, dominant NNE-SSW to NE-SW striking and steeply dipping fracture sets are observed in Lumshiwal Formation. The bedding (S_o) strikes 198° with a dip of 48°. A line is drawn across the outcrop face. The fractures that intersected the scan-line are numbered from left to right. Data along each fracture that intersects the scan-line is recorded including their orientation (dip and strike) and their interval. The scan-line is 207 cm in length. Eight major fractures intersected the scan-line, and their measurements of dip and strike were recorded as shown in table 2.

The frequency of fractures along the scan line is 0.038 f/cm. The amount of extension accommodated by these fractures is estimated around 232 % (Figure 13).

Mathematical calculations show owing the amount of extension accommodated by fractures is given below:

Length of Scan-line = Lf = 207 cm
Total Fracture Interval = L_o = 168
Extension = e = $(Lf - L_o)/L_o$
= (207-168)/168
= 0.232 = 23.2%

Table 2 - Orientation data of fractures at station # 2.

Fracture No.	Strike	Dip
1.	036	86
2.	086	80
3.	032	80
4.	034	32
5.	028	80
6.	027	75
7.	020	71
8.	020	60

STATION # 2

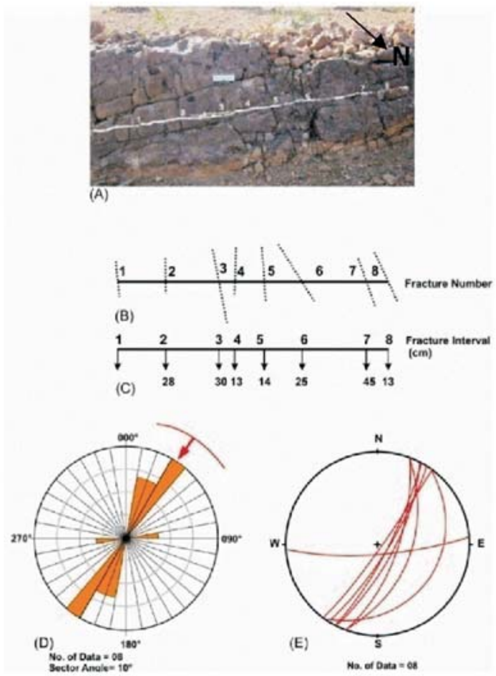

Figure 13 - Field photograph showing fractures at 33°48' 50.3"N, 72° 04' 52" E (A), sketch of fractures with a scan-line (B), sketch showing the fracture interval (C), rose diagram of data (D) and stereo-plot of data (E).

7.3 STATION # 3

This station is selected at location 33° 48' 48" N, 72° 04' 52.6" E, dominantly NNW-SSE to NW-SE striking and steeply dipping fracture sets are observed in Lumshiwal Formation. Scan-line method is used to collect the fracture data. The bedding (S_o) strikes 097° with a dip of 70°. A line is drawn across the outcrop face. The fractures that intersected the scan-line are numbered from left to right. Data along each fracture that intersect the scan-line is recorded including both orientation (dip and strike) and interval. The scan-line is 110 cm long. Five major fractures intersected the scan-line, and their dip and strike are measured as shown in table 3.

The geological map showing the location of stations with the help of rosettes is shown in Figure 14.

The frequency of fractures along the scan line is 0.038 f/cm. The amount of extension accommodated by these fractures is estimated around 4.76 % (Figure 15).

Mathematical cal calculations showing the amount of extension accommodated by fractures is given below:

Length of Scan-line = Lf = 110 cm
Total Fracture Interval = L_o = 105
Extension = e = $(Lf - L_o)/ L_o$
= (110-105)/105
= 0.0476 = 4.76%

Table 3 - Orientation data of fractures at station # 3.

Fracture No.	Strike	Dip
1.	180	88
2.	174	85
3.	160	87
4.	155	82
5.	164	80

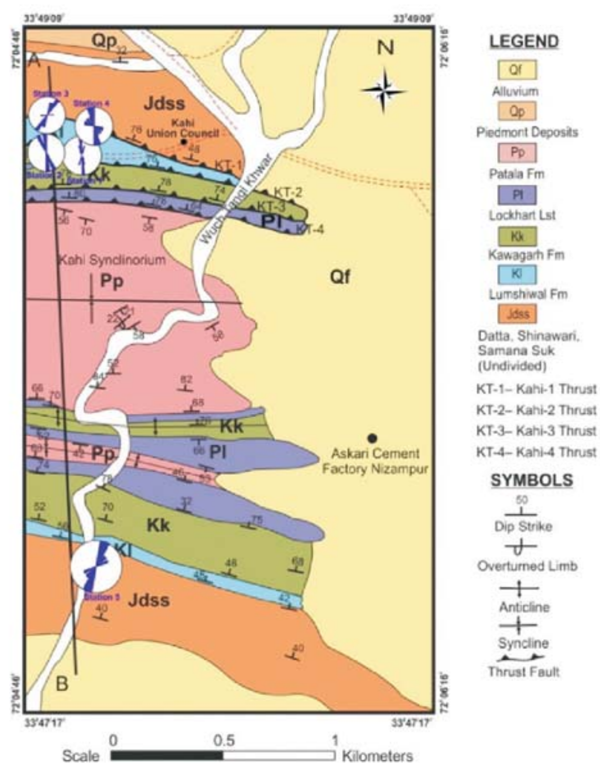

Figure 14 - Geologic map showing the location of stations with the help of rosettes.

STATION # 3

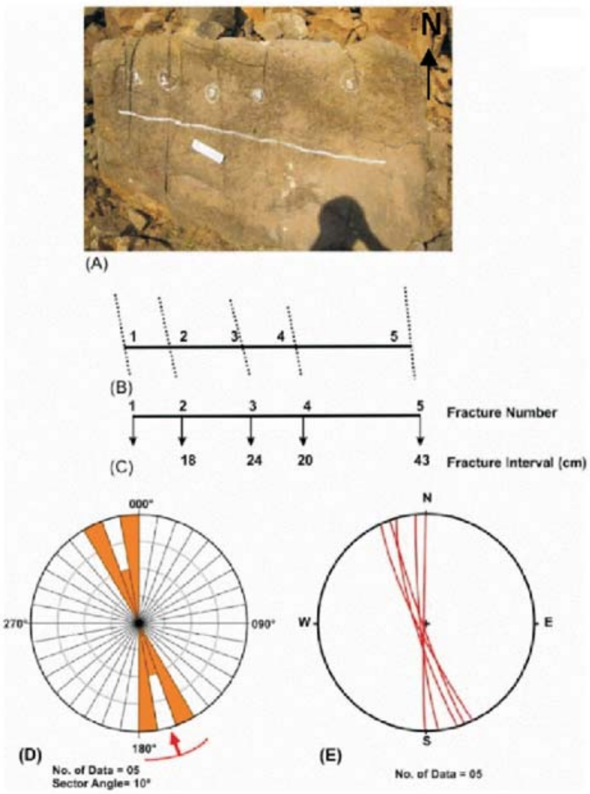

Figure 15 - Field photograph showing fractures at 33°48' 48" N, 72°04' 52.6" E (A), sketch of fractures with a scan-line (B), sketch showing the fracture interval (C), rose diagram of the data (D) and stereo-plot of the data (E).

7.4 STATION # 4

The fourth station is selected at location 33° 48' 49.5" N, 72° 04' 56" E. The fractures at this station are dominantly NNW-SSE to NW-SE striking with steep dips. These fractures are recorded in Lumshiwal Formation. The bedding (S_o) strikes 103° with dip value of 72°. A circle of 55 cm radius is drawn on the selected bed face with the help of chalk. Eight fractures are encountered within the inventory circle which were systematically arranged (Figure 16).

The dip, strike and length of the fractures are measured as shown in table 4.

The fracture length density within the circle is 0.0524 cm^{-1}. Mathematical calculations showing density of fractures within the circle is given below:

Fracture Length density within the circle:
Total Length = 498 cm
Radius of the Circle = 55 cm
Area of the circle = 9498.5 cm^2
Density = 498/9498.5 = 0.0524 cm^{-1}

Table 4 - Orientation data and length of fractures at station # 4.

Fracture No.	Strike	Dip	Length (cm)
1.	176	85	27
2.	172	81	60
3.	166	85	62
4.	160	79	94
5.	168	77	32
6.	120	73	58
7.	135	54	105
8.	105	60	60

STATION # 4

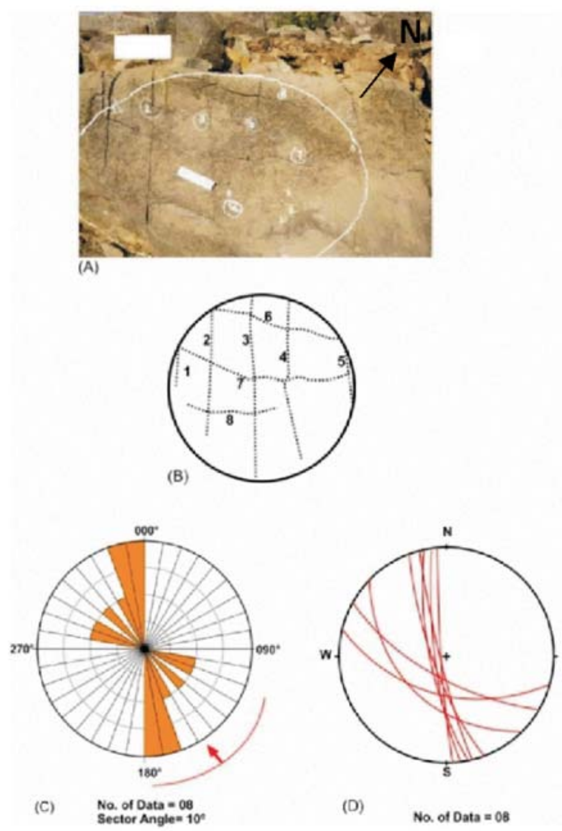

Figure 16 - Field photograph showing fractures at 33°48' 49.5"N, 72°04' 56"E (A), sketch of fractures with inventory circle (B), rose diagram of the data (C) and stereo-plot of the data (D).

7.5. STATION # 5

At location 33° 47' 46.1 N, 72° 05' 51.8" E, fractures are dominantly NNE-SSW to ENE-WSW striking with steep dips. These fractures are recorded in Jurassic rocks. The bedding (S_o) strikes 284° with a dip value of 68°. The fractures are recorded using the circle-inventory method. A circle of 56 cm radius is drawn on the selected bed face with the help of chalk. Seven fractures are encountered within the inventory circle which are systematically arranged (Figure 17). The dip, strike and length of the fractures are measured as shown in table 5.

The fracture fracture length d density within the circle is 0.0528 cm^{-1}.

Mathematical calculations showing density of fractures within the circle is given below:

Fracture Length density within the circle:
Total Length = 520 cm
Radius of the Circle = 56 cm
Area of the circle = 9847.04 cm^2
Density = 520/9847.04 = 0.0528 cm^{-1}

Table 5 - Orientation data and length of fractures at station # 5.

Fracture No.	Strike	Dip	Length
1.	018	72	45
2.	032	69	67
3.	025	71	63
4.	050	82	60
5.	062	70	92
6.	020	68	96
7.	028	84	97

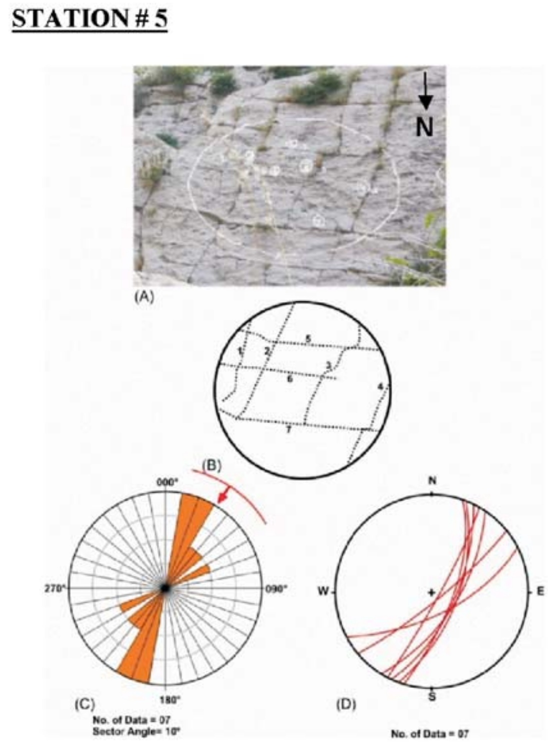

Figure 17 - Field photograph showing fractures at 33° 47' 46.1"N, 72°05'51.8"E (A), sketch of fractures with inventory circle (B), rose diagram of the data (C) and stereo-plot of the data (D).

7.6 RESULTS

The combined data from all the five stations are plotted on the rose diagram, stereo-plot, pole diagram and the pole density diagram (Figure 18).

Most of the fractures in the study area strikes in almost N-S direction (Figure 18A). The almost N-S striking fractures indicate 6i (principal stress direction) (Figure 18A) in the NNW-SSE direction and 63 in the NEE-SWW direction.

7.7 LIMITATIONS OF THE STUDY

The fractures are not developed well in the Patala Formation due to its predominantly shaley composition. The fractures in Lockhart Limestone are also not recordable due to its nodular character. Therefore, the main focus of the current fracture analysis in the study area are undifferentiated Datta, Shinawari, Samana Suk and Lumshiwal Formations.

The study is based on limited fracture analysis data, of a smaller area. Therefore, the orientation of fractures cannot be compared with regional tectonics, but can be used to depict the local stress directions. Further investigation is

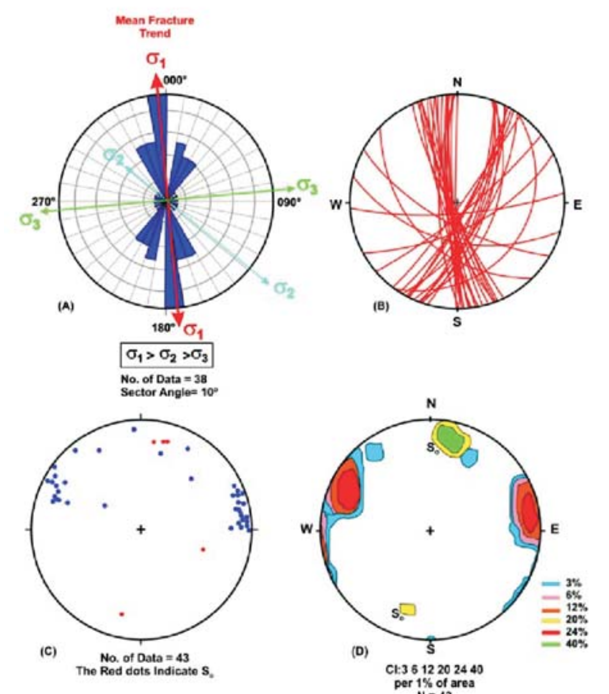

Figure 18 - Presentation of the acquired data on rose diagram (A), stereo-plot (B), pole scatter (C) and pole density diagram (D).

needed to compare the fracture orientations with regional tectonics. At present the fracture orientation suggests Riedel shears resulting from a north-to-south directed deformation.

CONCLUSION

The study area comprises of litho-stratigraphic units ranging in age from Jurassic to Paleocene.
The area is severely deformed marked by the southward verging thrust faults. (Kahi-1, Kahi-2, Kahi-3, Kahi-4).
Majority of the structures in the study area are oriented east-west.
The structural trend of the area shows north-south oriented compressional stresses.
The tectonic transport direction is from north to south.
The study area is dominated by extensional fractures. Most of these fractures are oriented NNW-SSE.
The relative proportions of hydrocarbons oriented NNW-SSE.

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