Journal of Himalayan Earth Sciences Volume 50, No 2, 2017, pp. 93-113

Joints/Fractures analyses of Shinawah area, District Karak, Khyber Pakhtunkhwa, Pakistan

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Submitted: 08/03/2017, Accepted on 04/10/2017, Published Online: 30/11/2017

Abstract

Kinematic compatibility of the western and eastern limbs of the Makarwal Anticline has been studied in the Shinawah and its adjoining area of Takhti-e-Nasrati, District Karak, KPK to understand the propagated structures and general structural model of the area. The study area is tectonically active and observed the deposition of post Pleistocene gravel deposits. In the Shinawah Nala, even younger gravel deposits are present indicating recent to sub-recent tectonic activity. Moreover, the channel avulsion of different nalas in Kurram River also reveals the existence of younger active deformations. Standard procedure has been adopted for the calculation of joint density and their other attitude data. For this purpose, the circle inventory and rectangular method has been espoused. The circle inventory method is valuable where highest numbers of fracture sets are exposed. The obtained data through this could be used for the establishment of their frequency diagrams and statistical density calculations. The shear zones that generally cut across the strata are typical cataclastic strike slip in character showing distinct asymmetric kinematic indicators of redial assemblages (Marwar, 1989). It is observed regionally, where the shear zones cut across each other; evolve a composite geometry of the conjugate joint patterns viewing mesoscopic displacements. Tensional joint sets of orthogonal symmetry are well developed. The pattern of these joint sets is observed systematic in nature and may have evolved in response to the forced folding deformational and uplifting phase of the Makarwal Anticline. This fusion of joints and conjugate fractures is properly penetrated on the strata of Dhok Pathan Formation. The general structural trend of the area is north-south. The younger joints are dipping toward east and crosscutting the older joint sets developed on the eastern limb of Makarwal Anticline. This frontal faulted limb of the Makarwal Anticline is highly deformed and eroded while exposing the older formations and splays of Surghar Thrust dipping towards west. Thus, we interpret that the origin of the shear zones in the studied area is dynamically related with the neo tectonic of the Makarwal Anticline, while tensional joints are episodically related with the formation and uplifting of the Makarwal Anticline. The synchronous relationship of tensional joints and shear zones further suggests that Makarwal Anticline could be developed as a result of inversion tectonic as positive flower structure under transtensional regime.

Keywords: Kinematic compatibility, Joints/Fractures analyses, Shinawah area, Pakistan.

1. Introduction

The study area lies between geodetic coordinates as longitudes 71° 03′ 57″ E to 71° 05′ 15″E and latitudes 32° 51′ 12″ N to 32° 54″ 30′ N. It is 123km on road distance from Peshawar on the Indus Highway leads to Karachi and could be accessed easily from different parts of the country through net of mettled roads (Fig. 1).

A detailed geological map of the study area is prepared at a scale 1: 2000 for plotting of structures and lithological units (Fig. 2). Circle inventory and rectangular methods are used to calculate the joint / fracture density in the field by measuring their attitude data, density, type and relative frequency distribution of the existing joint sets. It is intended to know the kinematics of evolved structures through joint / fracture investigation in the area.

2. Tectonic Setting

The collision of Indian Plate with the Eurasian plate produced the spectacular Himalayas along some 2500 km long Indo-Pakistan plate margin. Pakistan constitutes north western part of the Indian plate and south eastern part of Afghan-Helmand Plate. The tectonic in Pakistan is controlled by convergent as well as Transform tectonic with the Afghan-Helmand block. The Indian plate moved northward at the rates of 3 to 5 cm/yr. (Johnson et al., 1976). Highly deformed Kohat Plateau is located on the southern edge of the thrust wedge and is structurally elevated relative to surrounding area. Bannu Basin is located to the south of Kohat plateau and is filled with recent sediments. The Surghar Range is an arcuate mountain belt of the outermost Himalayan orogeny and constitutes the eastern closure of the Trans-Indus Salt ranges of northwest Pakistan, (Ali et al., 2014) (Fig. 3). The Salt and Trans-Indus ranges are the surface appearance of the leading edge of the foreland fold-and-thrust belt and surrounded along the frontal periphery by the Main Frontal Thrust (MFT), (Khan et al., 2012). The Surghar Range displays EW trend along the southern outskirts of the Kohat Plateau and changes orientation to NS along the eastern border of the Bannu Basin (Fig. 3), Khan and Opdyke, (1993).

The Surghar Thrust is the outer most and youngest tectonic expression of the range extended for more than 65km along the range front and dipping at an angle of 40º to 45° to north and west to forms a bend shape between the Western Salt Range and Bannu Basin (Gee, 1945 & 1989).

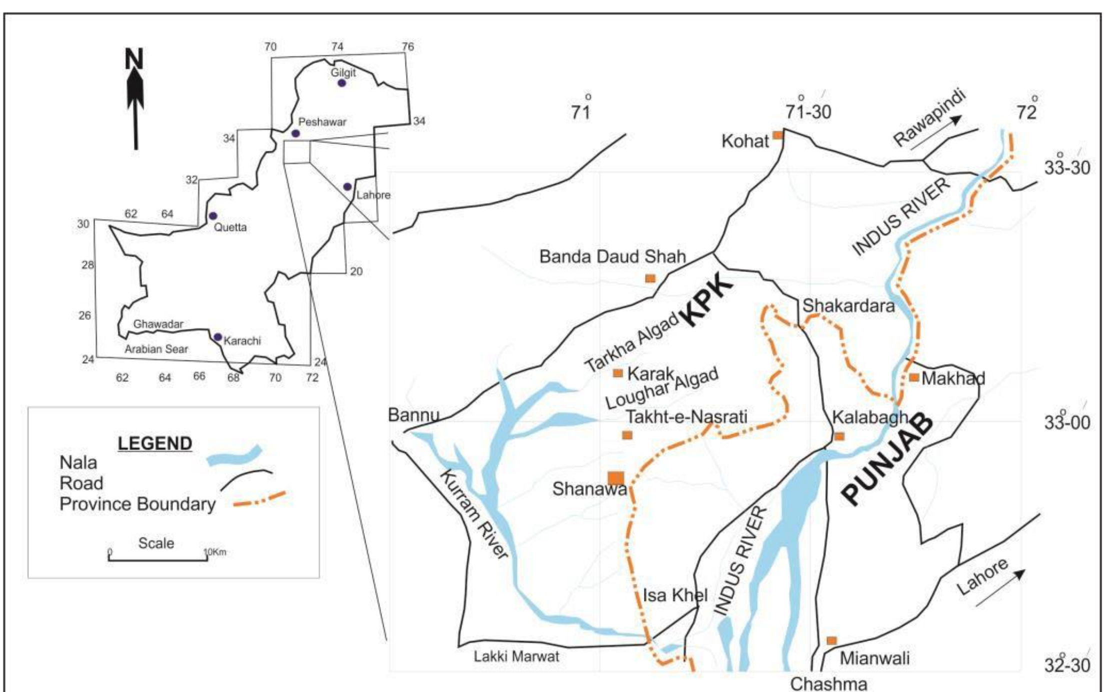


Fig.1. Location map of the study area

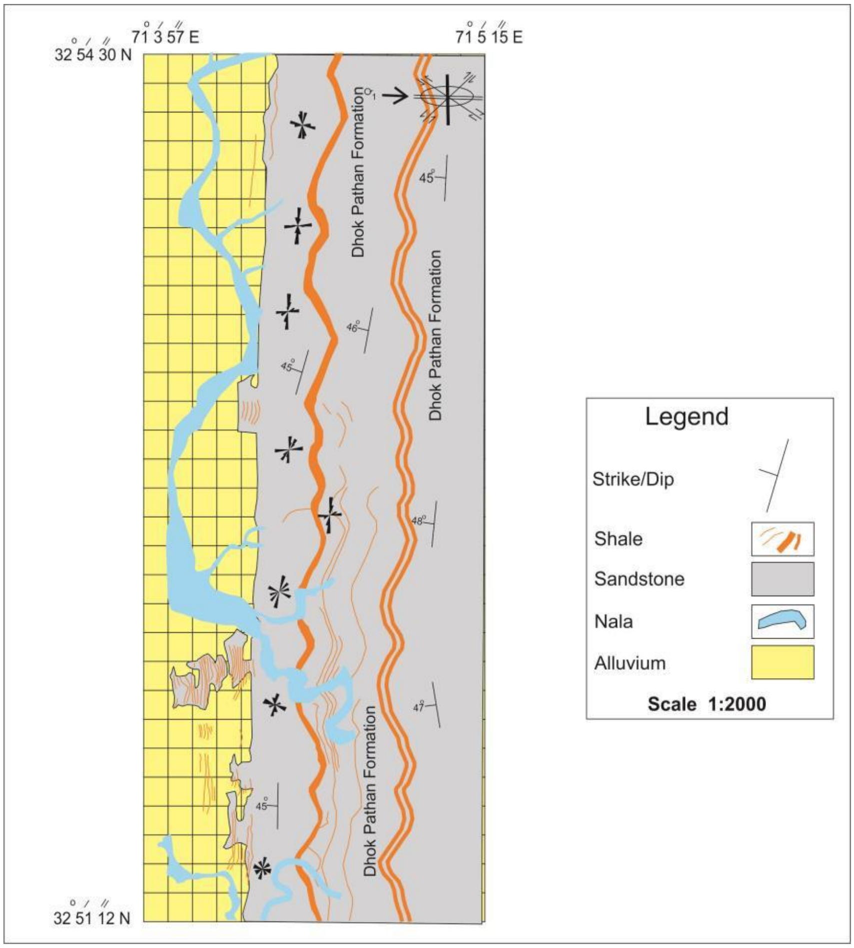


Fig. 2. Geological map of the study area showing frequency of the rose diagram.

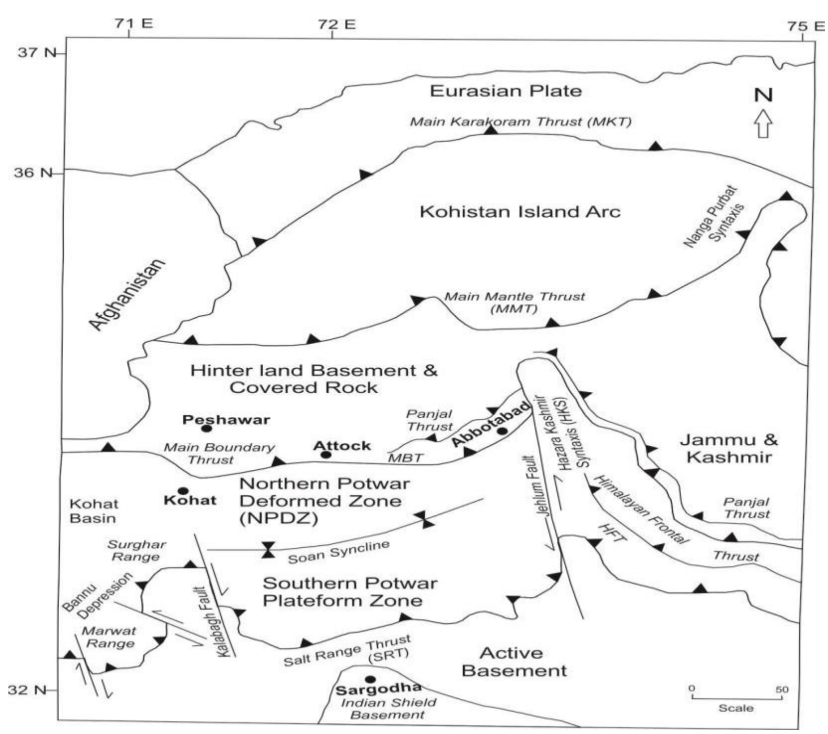


Fig. 3. Tectonic map of North Pakistan (Modified after Kazmi and Rana, 1982).

The Kohat-Potwar plateaus along with its associated frontal ranges, including the Salt and Trans-Indus ranges of north Pakistan represent the frontal fold-and-thrust belt of suitable environment for the accumulation of hydrocarbon in the northwestern Himalaya (Ahmad, et al., 2003). The Southern Deformed Fold Thrust Belt (SDFTB) of north Pakistan can be divided into two main tectonic and hydrocarbon districts and frontal ranges. The Potwar Plateau (PP) to east and Kohat Plateau (KP) to west and Trans-Indus ranges to the north and northwest of the Indus River (Fig. 3). Towards south the PP is bounded by the Salt Range Thrust (SRT), whereas the northern highly deformed part of the PP is called the Northern Potwar Deformed Zone (NPDZ) (Baker, et al., 1989). KP is the western most part of the SDFTB, while the southeastern boundary of the KP is marked by the Surghar Range where Mesozoic strata emplaced southwards onto the Punjab Foreland in the south. The Marwat-Khisor ranges lie south of Bannu Basin and form an essential part of the Trans-Indus ranges. These ranges are marked by Khisor frontal thrust system along which Cambrian rocks are thrust over the Punjab Foreland in the south (Blisniuk, et al., 1998 and Alam, et al., 2008, 2005 & 2014).

Foreland fold-and-thrust belts throughout the world are conspicuous features of the convergent plate tectonic habitat. The Kohat-Potwar fold and thrust belt along with its frontal ranges of the Northwestern Himalayas is one of these. The Salt and Trans-Indus ranges constitute the mobile flank of the Kohat and Potwar fold and thrust belt and is mostly characterized by decollement thrust-fold assemblages. Thrusting along with associated folding is certainly the main source of accommodating shortening within these orogenic belts. The most recent thrusting is believed to have occurred along the frontal thrust system in the Salt Range to the east and in the Trans-Indus Ranges to the west (Blisniuk et al., 1998). The Trans-Indus ranges represent the leading deformational front of the Kohat fold and thrust belt and Bannu Basin in North Pakistan (Ahmad et al, 2005).

Trans-Indus Ranges Thrust and Salt Range Thrust in the south along which the Eocambrian to Pleistocene continental shelf sequence of Salt Range are thrusted southward over the Indo Gangetic Foredeep. The narrow Himalayan foreland fold and thrust belt in India broadens to more than 100 Km along series of lobes in Pakistan (Fig. 3; Lillie et al., 1987). The Trans Indus Ranges turns first to the south in Surghar Range near Makarwal anticlinal area, forming the Kalabagh re- entrant and then to North West making a plunge indicated by lower Middle Siwaliks (Eagle Hill). Near Dara Tang enters into Marwat Range with upper Siwaliks and upper Middle Siwalik beds making a dog leg structure in Kurrum River. The Khisor Range starts from south of the Kurram river and runs in NE-SW direction parallel to Marwat Anticline up to Pezu ultimately coalesces with Suleiman Range in the south. All these ranges of Trans Indus Rages encircling and dipping towards saucer shaped Bannu Basin showing sharp change in their strike. Moreover, these contain a number of large faults along the margin of the basin.

In between the Marwat - Khisor Ranges there is a tight asymmetric synclinal basin known as Abdul Khel Syncline (Alam, 2008). The Khisor Range seems to be a part of an old anticline whose northern extension has been exterminated.

3. Neo tectonic studies

3.1. Depositional setting of terraces

The study area is mainly comprised of three different levels of terraces which represent three different tectonic phases of deformation. The difference between one-terrace levels to other level indicate tectonically calm period in which erosional processes remained active. Height of different terrace levels show the age difference of these terraces, the higher the level of terrace the older it is in the age and vice versa. In the study area the oldest terrace level is Shanawa and youngest is Braga Gala-Zhira. The following are the major levels observed in the area.

A

B

Fig. 4. **A**) Dhok Pathan Formation, **B**) Fresh fragmentation reveals youngest tectonic activities.

3.2. Terraces levels

1) Shanawa Terrace
2) Shava Terrace
3) Braga Gala Zhira Terrace

Geologically the studied terraces levels are quite stable for erosion. The fractures and other deformational elements in the older rocks are observed discontinuous in the overlying younger gravel deposits. The younger deposits vary in thickness ranging from 3m to 8m respectfully.

3.3. Shanawa nala

Shanawa Nala is the broad nala and is also famous as Maidan nala. This nala was studied from the eastern limb of Makarwal Anticline up to the Shah Salim area. No Terraces were observed in the Shanawa Nala. Recent deposits occur at different locations and lying horizontally on the titled rocks of different formations. The older fractures and joints are continuous in these recent deposits. Both the younger and older gravel deposits do not exist, while the appearance of recent gravel deposits observed an intact form. This phenomenon indicates that the area is tectonically active and its consequence the both the younger and older deposits were missing. During the study of different nalas at least one level of gravel deposit is identified in the Shanawa nala.

3.4. Recent gravel deposits

The recent gravel deposits are deposited by the nalas system and present along the present day stream course. These deposits are observed in intact form showing the absence of any most recent tectonic activity. As these deposits are very young their study without help cannot determine the true picture of the neo-tectonic of the area, hence the sub-recent or relatively older deposits are found absent showing recent tectonic activity.

3.5.Shava nala

The Shava nala is located in north of the Shanawa at a distance of about 7km. This nala is the main feature in the area which is connected to small thanga i.e bothen tanga, shogai thanga, azghi thanga, kolola thanga and shaga thanga from north to south. This nala was studied from the eastern limb of Makarwal Anticline up to Machaki area. No Terraces deposits were found in this nala. The recent deposits occur at various sites and are lying horizontal. The older fractures and joints are not present due to unconsolidated nature of these deposits. The deposition of both older and younger gravel is not found. The occurrence of recent gravel deposits with lack of older and younger gravel deposits indicates the instability in this geological terrain reveals occurrences of recent tectonic activity due to which the older and younger deposits are missing. During the study of different nalas and their tributaries in the area at least one level of gravel deposits was observed in the nala.

3.6. Recent gravel deposits

These are the youngest gravel deposits, which have been deposited by the nalas and their tributaries along the present day flow track. These deposits where present are unruffled which reveals absence of any most recent tectonic activity. As these deposits are very young their study alone cannot determine the true picture of the neo-tectonic of the area, hence sub recent or relatively older deposits were explored, but were not present which is an indication of recent tectonic activities in the area

3.7. Zhira nala

Zhira nala is situated in the north of Shanawa area at a distance of about 12 km. This nala was studied from the eastern limb of Makarwal anticline up to the main Takht-e-Nasrati- Shahslim road. No Terraces deposits were observed in this Nala. The recent deposits were observed at various places and were lying horizontally. The older fracture and joints are not present due to unconsolidated nature of these deposits. The younger and older gravel deposited are also missing. The presence of recent gravel deposits with absence of younger and older gravel deposits indicates that area is not stable and has a recent tectonic activity due to which younger and older deposits were completely vanished. During the study of Zhira nala and its tributaries at least one level of gravel deposits was identified.

3.8. Recent gravel deposits

These youngest gravel deposits have been deposited along the nala trend and reveals undeformed stratification which represents no recent tectonic activities in the area. As these deposits are quite young their study alone cannot determine the true picture of the neo-tectonic of the area, consequently sub recent deposits were explored but were not found which reveals recent tectonic activities in the area.

3.9. Loughar nala

The Loughar Nala is located in Takhti-e-Nasrati area about 20km north of Shanawa area. The Loughar Nala is the main nala in the area of interest. Small nalas and thanga connect to the Loughar Nala to form the main stream. This nala was studied from Sarki Loghar to Chokara area. No terraces were found in this nala. The recent deposits occur at different levels are lying horizontal on the inclined strata of different formations. The fractures and joints are not present due to unconsolidated nature of these deposits. The older and younger gravel deposits were not observed. The presence of recent gravel deposits with absence of older and younger gravel deposits indicates that area is unstable and due to recent tectonic activity the older and younger gravel deposits was disturbed and eroded. During the study of various nalas system in the area at least one level of gravel deposits has been recognized.

3.10. Recent gravel deposits

These are the youngest gravel deposits, which have been deposited by the nalas along the present day flow course. These deposits where present are undisturbed showing absence of any most recent tectonic activity. As these deposits are very young their study alone cannot determine the true picture of the neo-tectonic of the area, hence sub recent deposits were searched, but were missing indicating recent tectonic activities in the area.

4. Channel avulsion in Bannu Basin

All the nala system developed in the area is flowing from east to west. This stream system is drop in the Kurrum River and changing the flow orientation at approximately 90^o. This phenomenon of the channel avulsion is generally associated with active strike-slip movement (Fig. 5). Nalas like Shanawa, Shava Zhira, Loughar and Balanzin are flowing from east to west in the Shinghar Range. When these nalas congregate to the Kurrum River channel avulsion take place approximately at 90^o. Conversely the small streams from Marwat Range are flowing from south to north or south-west to north-east direction, when reaches the Kurrum River their channel avulsion take place at the same degree. Similarly, nala system from Bhittani Range is flowing from west to east, when these small streams reach the Kurrum River change the direction at 90^o. This phenomenon emerges due to presence of active faulting.

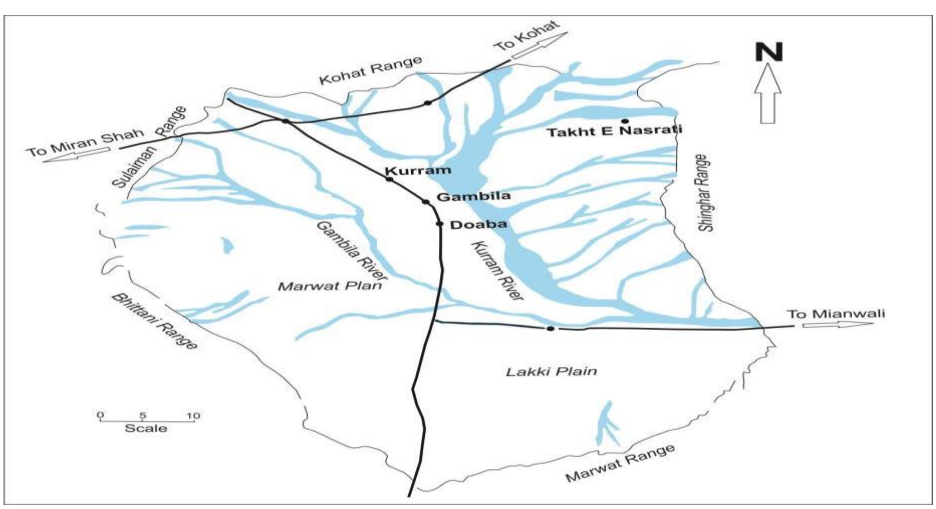


Fig. 4. Map showing ground water conditions and Channel Avulsion in Bannu Basin.

5. Stratigraphy of the area

The strata exposed in the study area ranging in age from Late Miocene to Early Pleistocene. The rocks are composed of fluvial molasses commonly recognized as Siwalik Group Rocks. The equivalent nomenclature is adopted as the lower, middle and upper Siwaliks in the Shinghar Range. These are the Chinji, Nagri, Dhok Pathan and Soan formations respectively as tabulated below:

Table 1. Stratigraphic framework of the study area.

AGE	FORMATION	LITHOLOGY
Late Pliocene to Early Pleistocene	Soan	Conglomerate, Sandstone and Shale
Middle Pliocene	Dhok Pathan	Recurrence of Sandstone and Shale
Early Pliocene	Nagri	Sandstone and Shale
Late Miocene	Chinji	Shale, Siltstone and Sandstone

5.1. Soan Formation

It is mainly comprised of compact, massive conglomerate with subordinate interbeds of multicolored sandstone, siltstone and shale (Alam, 2008). The ratio of different rock type changes within short intervals. The conglomerate contains a variety of pebbles and boulders. It is massive and is mainly comprised of pebbles and boulders of limestone, quartzite, porphyritic rocks, sandstone, gneiss, schist, diabase, etc. The pebbles ranges in size from 5 cm to 35 centimeters. Mudstone and sandstone are intercalated. The Mudstone is orange, brown, pale pinkish to red and soft. The sandstone is gray, greenish gray, coarse grained and soft. It is more than 300 m thick in the study area (Marwat Well-1 data and Structural transects across the mapped area). It has a disconformable contact with the underlying Dhok Pathan Formation that is marked by sharp coarsening of clastics and by the appearance of massive, densely packed conglomerate. The preserved fauna indicates a late Pliocene to early Pleistocene age for the formation, (Pascoe, 1963). Coarse fan shaped deposits of Soan Formation reflect the onset and progression of a sudden and strong orogenic upheaval in southern Himalayas.

5.2. Dhok Pathan Formation

The Dhok Pathan Formation represents dominantly braided system, characterized by thick sandstone, trough bedded, incomplete rhythm and coarse material depicting high hydrodynamic conditions, while the upper part represents meandering system in some places characterized by frequent over bank deposits. This formation exhibits excellent development of cyclic deposition of alternate shale and sandstone sequence. Sandstone is light to dull grey, poor to moderately cemented, friable and medium to coarse grained. The heavy mineral layers are abundant. Carbonaceous material is present in the form of wood logs. Hard, well cemented sandstone bands are numerous. Clay balls and pebbles are present along the cross set of paleo-channels. The Shale is of varying colours and it shows orange, brown, dull red, greenish and yellowish grey to chocolate shades. The upper part of the formation frequently comprises on conglomerate. This facies may observe mostly in the form of layers and lenses. It is 500 m thick in the study area. Fossils of mammals are quite frequently present. The fauna indicates an early to middle Pliocene age and with exclusive middle Pliocene age in the Kohat-Potwar Province, (Pascoe, 1963).

5.3. Nagri Formation

A thick sequence of massive sandstone with abundant paleo-channels and very few shales mark the Nagri Formation. Sandstone is medium to coarse grained, light grey to greenish grey. Occasionally the sandstone is bluish to reddish gray, calcareous and fairly to weakly cemented. Trough cross bedding are common in sandstone but at places horizontal bedding are also present. Pebbles of varied composition are present, mostly embedded along cross bedding of the paleo-channel. Shale is dark grey to light brown in color. In the lower portion wood logs with limonitic staining have also been observed. Some petrified wood and fossil remains such as teeth of elephant are also present. Numerous heavy minerals bands of varying thickness have also been observed. The thickness of the Nagri Formation is 950 m in the study area. The upper contact of the formation with the overlying Dhok Formation is Transitional. It can be easily marked through colour alteration and also by typical inter bedding of shale and sandstone of the overlying younger formation (Alam, 2008).

5.4. Chinji Formation

It consists of maroon to brownish red colored clay with subordinate sandstone. The sandstone is grey to brownish gray in color. It is fine-to medium-grained, thin-to medium-bedded, hard, calcareous and occasionally gritty. The clay is bright red, friable and valley forming. It is associated with claystone at places. The claystone is compact on fresh surface.

Circle Inventory Method for Evaluating Fracture Density in Shanawa Area.

SHANAWA AREA

Station 1:

Toposheet No. 38 p/1
Formation: Dhok Pathan
Unit: Sandstone 1
Lithology: Sandstone

Method: Circle Inventory
Area of Circle = $3.14 m^2$
Radius of Circle = 1m
Joint = Three sets.

Sr. No	Trend	Length (F)	Sr. No	Trend	Length (F)
1	N 20° E	0.26	10	N 95° E	4.5
2	N 10° E	3	11	N 70° E	4.21
3	N 15° E	5	12	N 79° E	5.3
4	N 20° E	3.06	13	N 78° E	5
5	N 19° E	6	14	N 80° E	4.2
6	N 19° E	5.16	15	N 40° E	5.25
7	N 19° E	3.33	16	N 42° E	6
8	N 85° E	5.2	17	N 48° E	5.25
9	N 82° E	1.2	18	N 49° E	4.33
Cumulative Length			76.25 feet (23.24m)		

Joint Density = Length/Area Circle 23.24/3.14=7.40m^{-1}

SHANAWA AREA

Station 2:

Toposheet No. 38 p/1 — Method: Circle Inventory

Formation: Dhok Pathan — Area of Circle = 3.14^{m}

Unit: Sandstone1 — Radius of Circle = 1m

Lithology: Sandstone — Joint = Three sets

Sr. No	Trend	Length (F)	Sr. No	Trend	Length (F)
1	EW	4.5	11	N65º E	6.00
2	N 81º W	4.25	12	N 6 º E	2.23
3	EW	1.33	13	N70º E	2.10
4	N 84 o W	5.25	14	N 65o E	2.25
5	N 85 o W	1.12	15	N 68o E	3.25
6	N 85 o W	1.25	16	N 68o E	5.33
7	N 86 o W	5.00	17	N 70o E	4.08
8	N 82 o W	4.33	18	N 69o E	1.42
9	N 81 o W	1.35	19	N 65o E	1.16
10	N 82 o W	4.25	20	N 68o E	1.00
Cumulative Length			61.35 feet = 18.70m		

Joint Density = Length/Area Circle 18.70/3.14 = 5.95m^{-1}

SHANAWA AREA

Station 3:

Toposheet No. 38 p/1 — Method: Circle Inventory

Formation: Dhok Pathan — Area of Circle = 3.14^{m}

Unit: Sandstone1 — Radius of Circle = 1m

Litho logy: Sandstone — Joint = Three sets

Sr. No	Trend	Length (F)	Sr. No	Trend	Length (F)
1	EW	1.20	11	N 20º E	3.5
2	EW	3.00	12	N 25º E	2.21
3	EW	4.00	13	N 18º E	3.00
4	N82 º E	2.25	14	N 20º E	4.00
5	EW	2.33	15	N 10º E	3.22
6	N 78 º E	3.16	16	N 05º E	3.10
7	N 80 º E	4.33	17	N 18º E	5.00
8	N 10 º E	5.00	18	N 80º E	2.25
9	N 15 º E	1.20	19	N 75º E	4.00
10	N 25 º E	1.50	20	N 10º E	3.00
Cumulative Length		61.28 feet = (18.67m)			

Joint Density = Length/Area Circle 18.67/5.94m^{-1}

Station 4:

Toposheet No. 38 p/1
Formation: Dhok Pathan
Unit: Sandstone1
Litho logy: Sandstone

Method: Circle Inventory
Area of Circle = 3.14^{m2}
Radius of Circle = 1m
Joint = Three sets

Sr. No	Trend	Length (F)	Sr. No	Trend	Length(F)
1	N 70 º E	2.00	13	N 10º E	3.00
2	N 25 º E	1.0	14	N 15º E	5.15
3	N20 º E	4.00	15	N 12º E	3.30
4	N72 º E	3.16	16	N 25º E	5.00
5	N78 º E	4.33	17	N 70º E	4.22
6	N75 º E	5.00	18	N 80º E	5.12
7	N80 º E	0.30	19	N 18º E	1.00
8	N10 º E	5.00	20	N 80º E	4.25
9	N25 º E	2.00	21	N 70º E	4.00
10	N15 º E	2.20	22	N 20º W	5.00
11	N10 º E	5.00	23	N 80º E	3.25
12	N25 º E	3.00	20	N 10º E	2.00
Cumulative Length			80.28 feet = (24.47m)		

Joint Density = Length/Area Circle 29.831/3.14=7.79m^{-}

Station 5:

Toposheet No. 38 p/1
Formation: Dhok Pathan
Unit: Sandstone1
Lithology: Sandstone

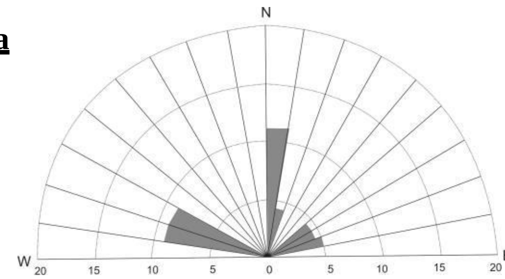
Method: Circle Inventory
Area of Circle = 3.14^{m2}
Radius of Circle = 1m
Joint = Three sets

Sr. No	Trend	Length (F)	Sr. No	Trend	Length (F)
1	N20 º E	3.26	13	N20 º E	2.00
2	N15 º E	4.00	14	N35 º E	4.25
3	N10 º W	2.10	15	N32 º E	3.10
4	N22 º E	3.00	16	N35 º E	6.00
5	N85 º E	5.25	17	N20 º E	5.40
6	N19 º E	5.00	18	N80 º E	3.30
7	N80 º E	2.30	19	N15 º E	5.00
8	N720 º E	6.30	20	N10 º E	4.20
9	N25 º E	1.25	21	N75 º E	2.00
10	N25 º E	3.25	22	N10 º W	6.00
11	N70 º E	4.00	23	N75 º E	3.25
12	N15 º E	5.00	20	N08 º E	1.00
Cumulative Length		90.21 feet = (27.50m)			

Joint Density = Length/Area Circle 27.50/3.14=8.75m^{-1}

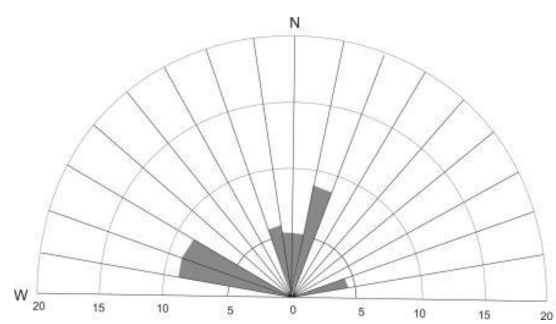
Average joints density in Shanawa Area Calculated from five inventory Station = 7.16 m

<u>Rose Diagram of Fracture Orientation Data, Shanawa Area</u>



Station 1:- Shrin Thanga Toposheet No. 38 p/1
Formation: Dhok Pathan Method: Rectangular
Class interval: 10 Join = Three Sets
Lithology: Sandstone Unit: Sandstone1
Area of the Rectangle L=23, W=07

71^{o} -80^{o}	61^{o} -70^{o}	0 -10^{o}	11^{o} -20^{o}	51^{o} - 60^{o}	61^{o} - 70^{o}	71^{o} - 80^{o}
N 75^{o} W	N 70^{o} W	N10^{o} E	N12^{o} E	N60^{o} E	N69^{o} E	N75^{o} E
N 71 W	N65^{o} W	N10^{o} E	N20^{o} E	N60^{o} E	N69^{o} E	N76^{o} E
N 78^{o} W	N70^{o} W	N10^{o} E	N20^{o} E	N60^{o} E	N70^{o} E	N75^{o} E
N 78^{o} W	N65^{o} W	NS	N15^{o} E	N60^{o} E	N65^{o} E	N75^{o} E
N75^{o} W	N 65^{o} W	NS				N80^{o} E
N71^{o} W	N65^{o} W	NS				
N 80^{o} W	N60^{o} W	N10^{o} E				
N 80^{o} W	N65^{o} W	NS				
		N10^{o} E				
		Ns				
		Ns				
		NS				



Station 2:- Rama Thanga Toposheet No. 38 p/1
Formation: Dhok Pathan Formation
Class interval: 10
Lithology: Sandstone
Unit: Sandstone 1
Method: Rectangular
Area of the Rectangle L=35, W=19

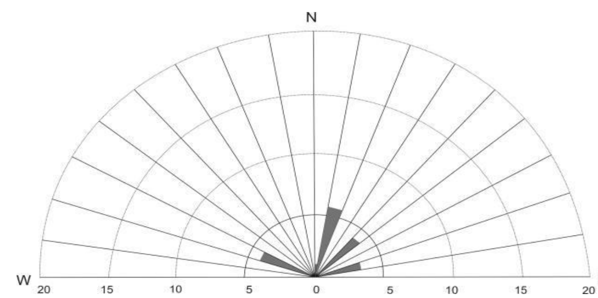
71^{o} -80^{o}	61^{o} -70^{o}	11^{o} -20^{o}	10^{o} -0	0 -10^{o}	11^{o} -20^{o}	71^{o} -80^{o}
N 80^{o} W	N 65^{o} W	N18^{o} W	N10^{o} W	N5^{o} E	N20^{o} E	N80^{o} E
N 80^{o} W	N65^{o} W	N16^{o} W	N10^{o} W	N5^{o} E	N15^{o} E	N75^{o} E
N 75^{o} W	N70^{o} W	N12^{o} W	N10^{o} W	N10^{o} E	N10^{o} E	N78^{o} E
N 75^{o} W	N68^{o} W	N15^{o} W	N5^{o} W	NS	N20^{o} E	N72^{o} E
N75^{o} W	N 70^{o} W	N20^{o} W	N10^{o} W	Ns	N20^{o} E	
N80^{o} W	N65^{o} W	N14^{o} W			N15^{o} E	
N 80^{o} W	N60^{o} W				N15^{o} E	
N 75^{o} W	N70^{o} W				N20^{o} E	

Station 3:-

Toposheet No. 38 p/1

Method:	Circle Inventory
Formation:	Dhok Pathan Formation
Area of Circle =	$3.14m^2$
Class Interval:	10
Unit:	Sandstone 1	Radius of Circle = 1m
Lithology:	Standstone	Joint = Three sets.

61° -70°	0 -10°	11° -20°	41° -50°	71° -80°
N 70° W	N 10° E	N12° E	N40° E	N80° E
N 65° W		N15° E	N42° E	N72° E
N 68° W		N20° E	N48° E	N75° E
N 70° W		N15° E	N45° E	
		N18° E		
		N19° E		

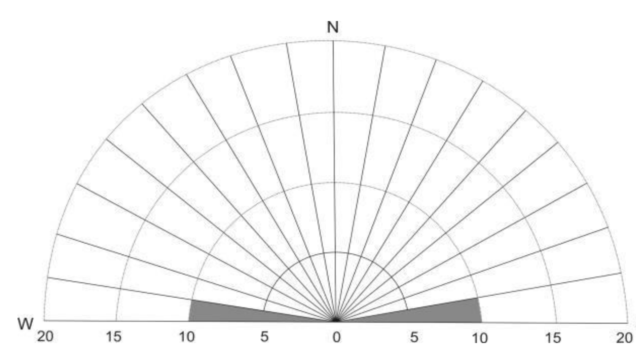


Station 4:-

Toposheet No. 38 p/1

Method:	Circle Inventory	
Formation:	Dhok Pathan Formation	
Area of Circle =	$3.14m^2$	
Class Interval:	10	
Unit:	Sandstone 1	Radius of Circle = 1m
Lithology:	Standstone	Joint = Three sets.

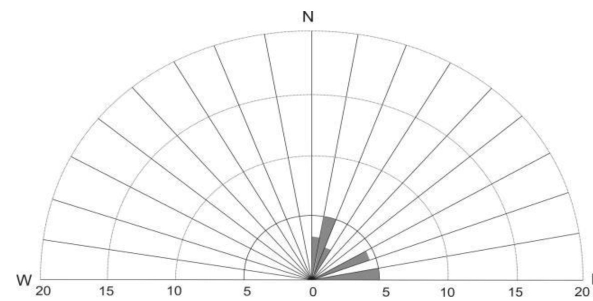
81° -90°	61° -70°
EW	N65° E
N 81° W	N62° E
EW	N70° E
N 84° W	N65° E
N 85° W	N68° E
N 85° W	N68° E
N 86° W	N70° E
N 82° W	N69° E
N 81° W	N65° E
N 82° W	N68° E



Station 5:-

Toposheet No. 38 p/1
Method: Circle Inventory
Formation: Dhok Pathan Formation
Area of Circle = $3.14m^2$
Class Interval: 10
Unit: Sandstone 1
Radius of Circle = 1m
Lithology: Standstone
Joint = Three sets.

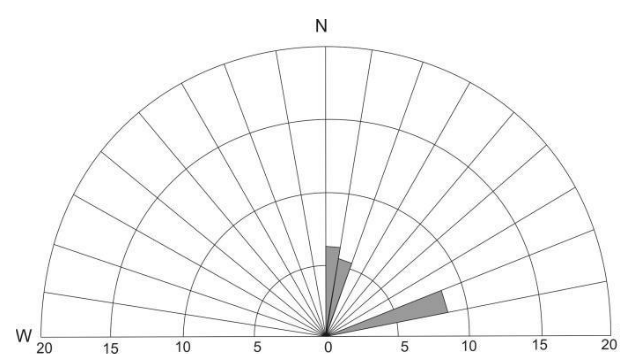
0 -10 °	11 ° -20°	21 ° -30 °	71° -80 °	81 ° -90
N 10 ° E	N 20° E	N23° E	N78° E	EW
N 10 ° E	N 20 ° E	N25° E	N80° E	EW
N 05 ° E	N 15 ° E		N80° E	EW
	N 18 ° E		N75° E	N82 ° E
	N 18 ° E			EW



Station 6:- Shanawa Area

Toposheet No. 38 p/
Formation: Dhok Pathan Formation
Area of Circle = $3.14m^2$
Class Interval: 10
Unit: Sandstone 1
Radius of Circle = 1m
Lithology: Standstone
Joint = Three sets.

0 -10 °	11 ° -20°	71° -80 °
N 8 ° E	N 15° E	N70° E
N 10° E	N 12 ° E	N80° E
N 5 ° E	N 18 ° E	N78° E
N 7° E	N 20 ° E	N80° E
N 5 ° E	N 15 ° E	N70° E
N 10° E		N72° E
		N78° E
		N75° E

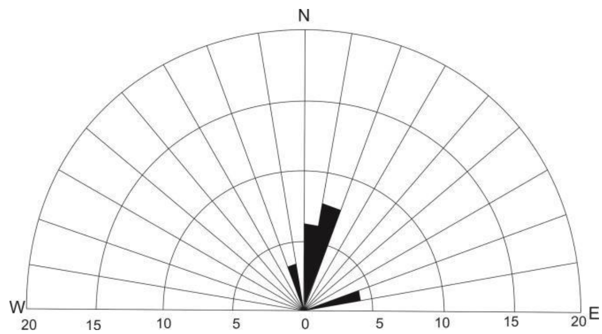


Station 7:- Shanawa Area

Toposheet No. 38 p/

Formation:	Dhok Pathan Formation	Area of Circle = $3.14m^2$
Class Interval:	10	
Unit:	Sandstone 1	Radius of Circle = 1m
Lithology:	Standstone	Joint = Three sets.

10 º -0	0-10 º	11 º -20 º	71º -80 º
N 10 º E	N 08º E	N20º E	N75º E
N 08 º E	N 10 º E	N15º E	N80º E
N 05 º E	N 10º W	N19º E	N75º E
	N 08 º E	N15º E	N80º E
	N 05 º E	N20º E	
	N 10 º E	N20º E	
		N15º E	



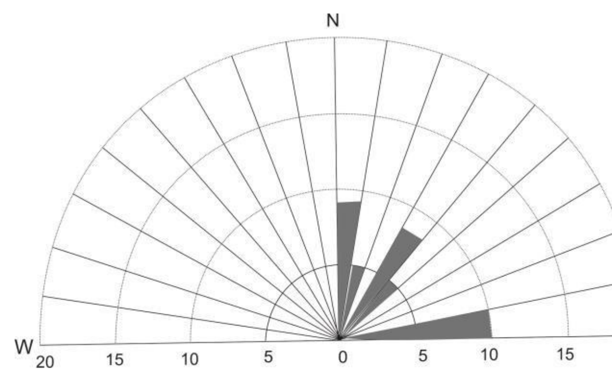
Station 8:- Branch Of Rama Thanga

Toposheet No. 38 p/

Formation:	Dhok Pathan Formation	
Class Interval:	10	Joint = Three sets.
Unit:	Sandstone 1	
Lithology:	Standstone	Methotd: Rectangular

Area of Rectangle: L=24, W= 09

10 º -0	11 º -20 º	21 º -30 º	41º -50 º	81º -90º
N 10 º E	N 15º E	N23º E	N40º E	N 80 º E
N 5 º E	N 16 º E	N25º E	N42º E	N 81 º E
N 5 º E	N 18 º W	N26º E	N45º E	N 85º E
N 5 º E	N 17 º E	N27º E	N46º E	N82 º E
N10 º E	N 11 º E	N27º E	N 50 º E	N85 º E
N 5 º E		N28º E		N 82 º E
N 10º E		N25º E		N 81º E
N10 º E				EW
N 5 º E				N 82 º E
				N 83 º E

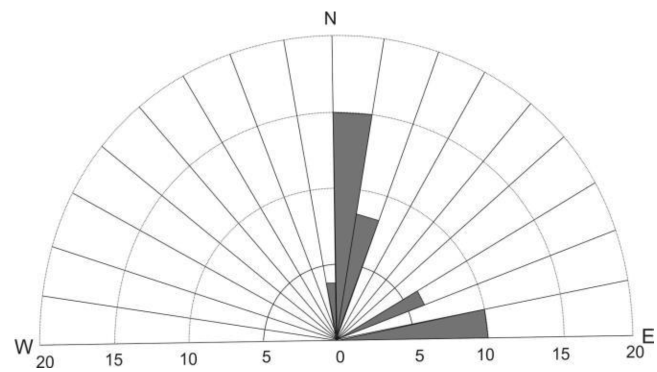


Station 9:- Branch of Rama Thanga

Toposheet No. 38 p/
Formation: Dhok Pathan
Class Interval: 10º
Unit: Sandstone 1 Joint = Three sets.
Lithology: Standstone Methotd: Rectangular

Area of Rectangle: L=13, W= 27

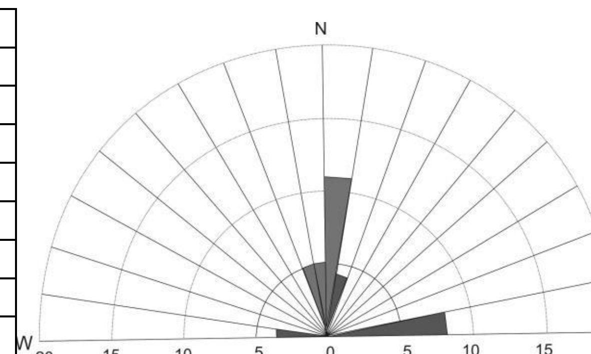
10 º -0	0 -10º	11º -20 º	61º -70 º	81º -90º
N 5 º W	N 10º E	N15º E	N65º E	N 85 º E
N 5 º W	N 05 º E	N14º E	N66º E	N 82 º E
N 5 º W	NS	N18º E	N64º E	N81 E
	NS	N15º E	N62º E	N89 º E
	NS	N15º E	N 65 º E	N85 º E
	N 10 º E	N15º E	N 60 º E	N 80 º E
	N 05 º E	N15º E		N 85º E
	NS	N16º E		N 80 º E
	N 05 º E			N 86 º E
	N 05 º E			EW
	N 06 º E			
	N 05 º E			
	N 09 º E			
	N 05 º E			
	N 09 º E			



Station 10:- Mara Thanga

Toposheet No. 38 p/1
Formation: Dhok Pathan
Class Interval: 10º
Unit: Sandstone 1 Joint = Three sets.
Lithology: Standstone Methotd: Rectangular
Area of Rectangle: L=07, W= 05

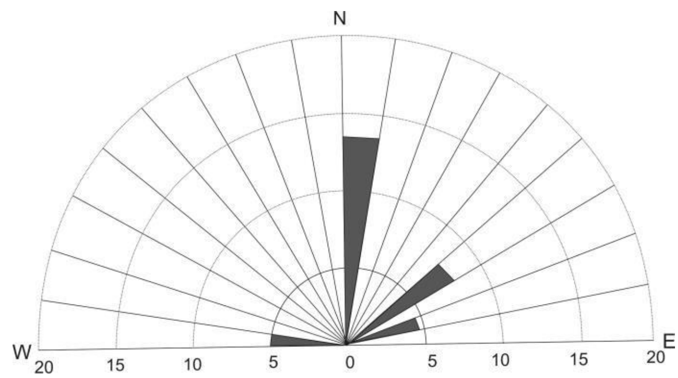
81º -90º	11º -20º	10 º -0	0 -10º	11º -	81º -90º
EW	N 20º W	N 10º	N05º E	N15º E	N 85 º
EW	N 19º W	N 09º	N05º E	N11º E	N82 º E
N 85 º	N 15º W	N 05º	N06º E	N12º E	N85 E
	N 11º W	N 05º	N05º E	N15º E	N85 º E
	N19 W	N10 W	N 08 º E		N82º E
			NS		N 82 º
			NS		N 83º E
			N 10 º E		N 86 º
			N 05 º E		
			N 05 º E		
			N 05 º E		



Station 11:-   Mara Thanga

Toposheet No. 38 p/1
Formation: Dhok Pathan
Class Interval: 10°
Unit: Sandstone 1   Joint = Three sets.
Lithology: Standstone   Methotd: Rectangular
Area of Rectangle: L=07, W= 05

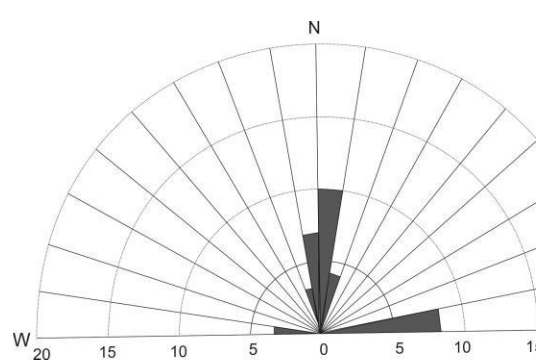
81° -90°	0-10	51-60	71-80
EW	NS	N60° E	N80° E
N 85° W	NS	N55° E	N80° E
N 87° W	NS	N60° E	N80° E
EW	N10° E	N55° E	N75° E
N 86° W	N10° E	N 60 ° E	N 75°E
	NS	N 60 ° E	
	N05° E	N 56 ° E	
	N09° E	N 60 ° E	
	N05° E		
	NS		
	NS		
	N10° E		
	N05° E		



Station 12:-   Mir Khata Tanga

Toposheet No. 38 p/1
Formation: Dhok Pathan
Class Interval: 10°
Unit: Sandstone 1   Joint = Three sets.
Lithology: Standstone   Methotd:
Rectangular
Area Of Rectangle: L=26, W= 12

81 -90	11-20	10-0	0-10	11-20	81-90
EW	N15° W	N05° W	N05° E	N 15 ° E	N 85 °E
EW	N11° W	N09° W	N05° E	N 11 ° E	N 82° E
N85°W	N19° W	N10° W	N06° E	N 12° E	N 85 °E
		N09° W	N05° E	N 15 ° E	N 85 °E
		N05° W	N08°E		N86 ° E
		N05° W	NS		N 82 °E
		N05° W	NS		N 83 °E
		N10° W	N 10°E		N 86 °E
			N 05°E		
			N 05°E		

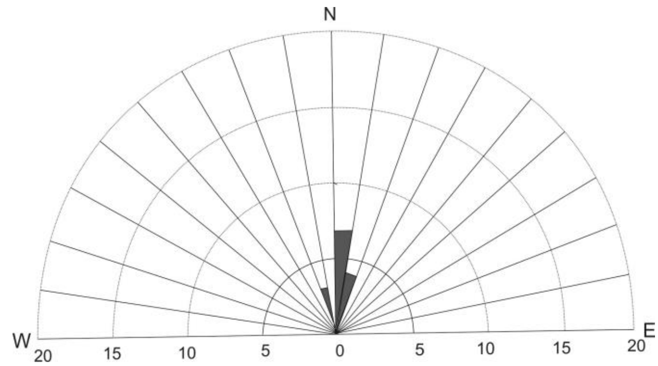


Station 13:-   Bothene Tanga

Toposheet No. 38 p/1
Formation: Dhok Pathan
Class Interval: 10^o
Unit: Sandstone 1
Lithology: Standstone
Area of Rectangle: L=35, W= 19

Joint = Three sets.
Methotd: Rectangular

11-20	0-10	11-20
N11º W	N8º E	N18º E
N20º W	N10º E	N20º E
N15º W	N2º E	N17º E
N20º W	NS	N15º E
	N6º EW	
	N10º E	
	N5º E	

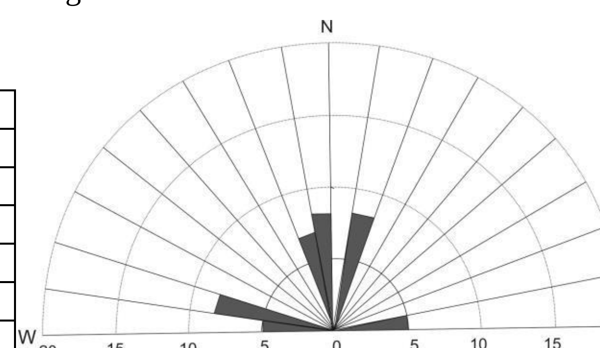


Station 14:-   Azghi Thanga

Toposheet No. 38 p/1
Formation: Dhok Pathan
Class Interval: 10^o
Unit: Sandstone 1
Lithology: Standstone
Area of Rectangle: L=30, W= 19

Joint = Three sets.
Methotd: Rectangular

81 -90	71-80	11-20	10-0	11-20	81-90
N80ºW	N75º W	N15º W	N10º W	N 01 º E	N 86 º E
N85º W	N78º W	N20º W	N5º W	N 20 º E	N 85º E
N80º W	N75º W	N15º W	N5º W	N 15º E	N 86 º E
N80ºW	N70º W	N11º W	N1º W	N 20 º E	N 85 º E
N85ºW	N80º W	N20º W	N10º W	N 15 º E	N85º E
	N70º W	N20º W	N5º W	N 15 º E	
	N70º W	N15º W	N10º W	N 16 º E	
	N70º W		N8º W	N15 º E	

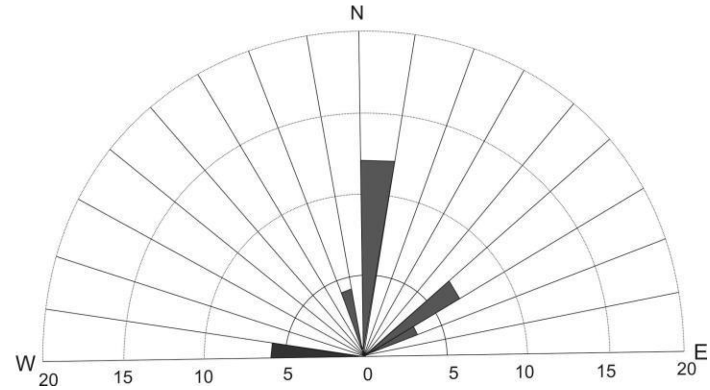


Station 15:-   Khollola Thanga

Toposheet No. 38 p/1
Formation: Dhok Pathan
Class Interval: 10^o
Unit: Sandstone 1
Lithology: Standstone
Area of Rectangle: L=25, W= 10

Joint = Three sets.
Method: Rectangular

81 -90	11-20	0-10	51-60	11-70
N85° W	N20° W	N10° E	N59° E	N 70 ° E
EW	N17° W	N10° E	N55° E	N 69 ° E
N88° W	N11° W	NS	N60° E	N 70° E
N87° W	N16° W	N08° E	N56° E	
EW		N09° E	N60° E	
N87° W		N06° E	N60° E	
		NS	N60° E	
		N5° E		
		NS		
		NS		
		N10° E		
		N05° E		



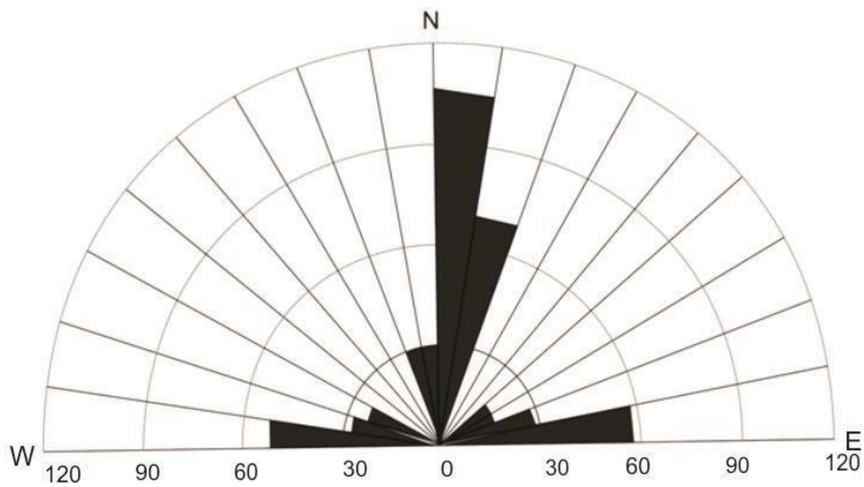


Diagram showing relative abundance of fractures/joints in Shanawa area calculated from fifteen stations.

6. Discussion and conclusions

Fractures sets in Shanawa area show distinct structural geometries. Most of the Shear zones of tabular form show nice geometrical arrangements of R1, R2, P and Y shear fractures. Sinestral sense of movement has been deducted from these reidel assemblages, studied within the shear zones (Marwer, 1989). These shear fractures are developed in moderately to hard cemented sandstones locally named as Shanawa sandstone about 130 m thick. In most places these joins cut across each other form a complex geometry of conjugate patterns. The analyses of these joints indicate three joints patterns one joint pattern which is developed along strike of the host sandstone is older and ranges from due North to N 20° E and the second joint pattern is from due North to N 20° W. Both the phases are associated with the development of compressional tectonics and movement of Bannu Thrust Sheet in the area. The third joint pattern is younger and ranges from EW- N70 W-EW which reflect the neo-tectonic and development of Makarwal Anticline in the area (Angelier, 1994). Tensional joints of orthogonal symmetry are well developed especially on the hard sandstone bands. These joints are systematic and may have formed due to the folding of strata i.e., related with the folding of Makarwal Anticline. The hybrid relationship of joints and conjugate fractures are nicely preserved in hard sandstone bands. In Shanawa area, where the strike of the strata is about NS, these joints display north south compression and east-west extension showing effect of compression from east. Thus, we interpret that the origin of shear zones in Shanawa area is related with the neo-tectonics of the area, while tensional joints and shear zones further suggest that the southern tip of Makarwal Anticline structurally developed under trans-tensional regime.

At least three episodes of deformation and uplift are identified in this area. Mainly known as Shanawa, Shava and Zhira uplifts associated with three phases of uplifts. Channel avulsion in Bannu Basin also indicates that the area is tectonically active.

The strike in Shanawa area on western flank of Makarwal Anticline is north-south. It shows younger joint pattern dipping toward east and crosscutting all older joint pattern on the eastern flank of the Makarwal Anticline. Its eastern flank is deeply eroded exposing older rocks and splays of Surghar Thrust dipping towards west. Thus, we interpret that the origin of the shear zones in the studied areas is dynamically related with the neo-tectonics of the Makarwal Anticline, while tensional joints may episodically have related with the formation and uplifting of Makarwal Anticline. The synchronous relationship of these joints and shear zones, further suggests that Makarwal Anticline may be developed as a result of inversion tectonics as positive flower structure under transtentional regime.

Authors' contribution

Nazir-ur-Rehman prepared geological map, collected fracture orientation data in the field at about more than 20 stations and plot it on the map in the form of rose diagram, measured thickness of various formations in the field, prepared the rose diagram and wrote the manuscript. Sajjad Ahmad helped in the interpretation of data, reviewed different versions of the manuscript and specially provide incredible help in construction and interpretation of rose diagram. Fayaz Ali, Iftikhar Alam and Amin Shah helped in preparation of rose diagrams and reviewing the manuscript.

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