Pakistan Journal of Hydrocarbon Research
Vol. 24, (June 2014),p.19-31, 12 Figs. 02 Tables.

Tectonic Evolution of Fractures in the Precambrian Manki and Dakhner Formations,Khairabad, Pakistan

Asghar Ali[1], Sohaib Ahmad[1], Tufail Ahmad[1] and Muhammad Rehan[1]

ABSTRACT

The Attock Cherat Range that forms the southern boundary of the Peshawar Basin evolved ~ 20 Ma by N-S directed convergent margin tectonism related with the Himalayan Orogeny along the northern margin of the Indian Plate. This orogeny led to the initiation of pervasive conjugate fractures in the Precambrian Manki and Dakhner formations. Systematic tectonic conjugate fractures are arranged in such a way that their acute bisector σ1 is parallel to the N-S horizontal bulk shortening. The acute bisector σ1 of the conjugate fracture of the Precambrian Manki Formation is parallel to the acute bisector of the pervasive conjugate fractures in the Precambrian Dakhner Formation. These conjugate fractures collectively indicate N-S shortening and southward thrusting that has affected the Precambrian Manki and Dakhner formations in the Attock Cherat Ranges.

The through going E-W trending fracture set-1 was exclusively observed within the Manki Formation. It is filled with crystallized quartz and aligned parallel to E-W striking beds of the Formation. Fracture set-1 predates conjugate fractures because the later have displaced fracture set-1 across the study area. The presence of well developed plumose marking within the Manki Formation shows brittle extensional fractures and evidently pre-dates all other fracture sets in the region. The quartz crystals in fracture set-1 are fractured, which are later healed by secondary calcite. The presence of well developed curved calcite fibers in conjugate fractures indicates a possible opening direction with smooth boundaries. The calcite crystals, which are not the main ingredient of the wall rocks, initiate from the narrow median suture and gradually grow towards fracture boundaries. Therefore, the conjugate fractures are characterized by antitaxial vein growth.

INTRODUCTION

Brittle structures in the upper crust produce due to brittle deformation (Patterson, 1978; Pollard and Aydin, 1988; Ranalli, 1995; Koehn et al., 2005). These structures in the form of fractures, faults and veins contain important information about multiple deformation events and stress orientation (Koehn et al., 2005). Fractures are surfaces along which material failure occur during brittle deformation of rocks and provide the detail of tectonic stresses during a deformation history (Ramsay and Chester 2004; Koehn et al., 2005).

Fractures are commonly observed in form of extension/dilation fractures (mode I) and shear fractures (mode II and mode III) in all type of rocks. In mode I fractures the relative motion is perpendicular to the maximum principle stress and fracture walls. An extensional fracture produces when dilation stresses become greater than the tensile strength of a rock (Segall, 1984). Solution filled fractures, which are called extension veins or gashes usually develop in the rocks orthogonal to the propagating direction (Ramsay and Huber, 1983).

Extensional fractures can be classified into two classes, i.e. systematic and non-systematic extensional fractures. Systematic extensional fractures occur in sets with parallel to sub parallel orientation to one another (Hodgson, 1961; Herman, 2005). The nonsystematic extension fractures occur in different orientation and have curvi-planar and irregular surfaces extending to a systematic fracture set (Groshong, 1988; Herman, 2005). Systematic vein and fracture sets over a large area reflect either entirely pre-uplifting origin or entirely caused by a stress field produce due to a significant tectonic event e.g. folding and thrusting (Engelder and Geiser, 1980; Garret and Lorenz, 1989; Gross et al., 1992). In compressional regime, extensional fractures or veins strike parallel to the fold axes, allowing strata to be stretched both along the axes and in the outer arc of the fold (Herman, 2005).

The study of veins is important for understanding various deformation events preserved in multiply deformed rocks (Bons and Montenari, 2005). The shape, general trend and composition of veins can be used to unravel the palaeo-strain (Bons and Montenari, 2005). Similarly the internal microstructures related with veins can enhance our understanding regarding tectonics of a region (Durney and Ramsay, 1973; Koehn and Passchier, 2000; Bons and Motenari, 2005). Veins are normally defined according to different textures of infilling fibers i.e. stretched crystal, elongate-blocky crystal and strongly stretched crystal with prominent curvature with the main constituents of the wall rock (Bons, 2000; 2001).

In some tectonic setting two sets of fractures form in compression environment at acute angle to the maximum principal compressive stress. These fractures are termed conjugate fractures (Figure 1). The intersection of these fractures is generally parallel to the axis of intermediate principle stress. The minimum compressive stress is the obtuse angle between the conjugate fractures. In the conjugate fractures the maximum compressive stress is perpendicular to the minimum compressive stress (Twiss and Moores, 1992). These fractures are often associated with fold and thrust belts. Establishing relationship of fractures pattern with regional faults and folds can provide ample information about stress and strain field during their origin (Wilkins et al., 2001; Finn et al 2003; Koehn et al., 2005). Spectacular exposure of conjugate fractures in the Precambrian Manki

[1] Department of Geology, University of Peshawar, Pakistan.

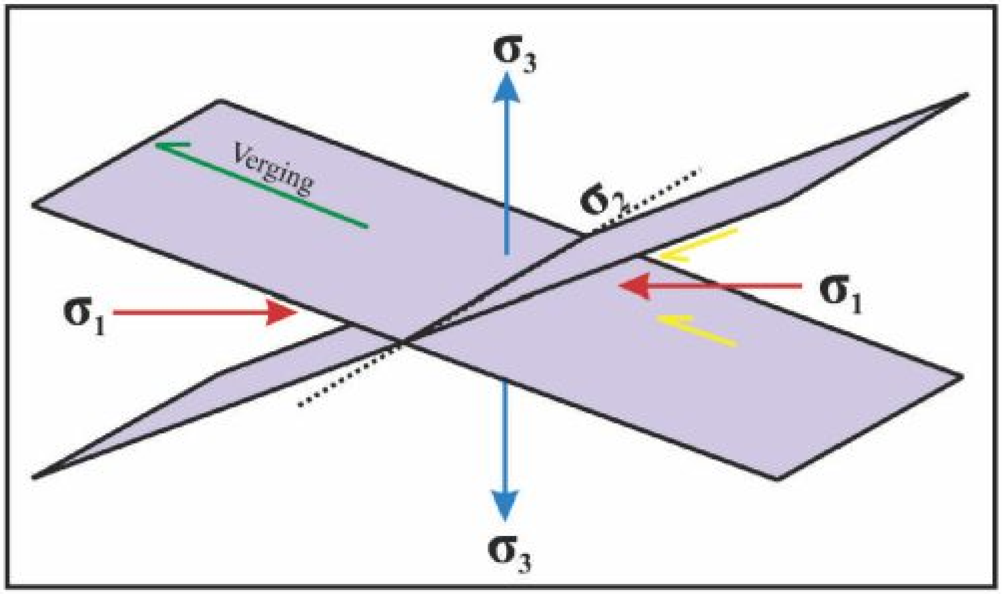


Figure 1 - Schematic diagram showing maximum, minimum and intermediate stress directions in relation to the conjugate fracture geometry.

and Dakhner formations provide an opportunity to study the diverse origin and kinematics of these fractures in association with regional faults and folds related with the Himalayan Orogeny. No single geological process for the formation of these conjugate fractures has been established yet.

GEOLOGICAL SETTING

Northern Pakistan has been divided into the Kohat and Potwar Plateaus with Cambrian to Neogene unmetamorphosed sedimentary rocks, a zone of unmetamorphosed sedimentary rocks, a zone of Himalayan foothills represented by transition from unmetamorphosed to high-grade metamorphic rocks and the Kohistan Island- Arc tectonic provinces (Figure 2; Pogue et al. 1999). The Main Boundary Thrust separates the Kohat and Potwar Plateaus from the Himalayan foothills and the Main Mantle Thrust separates the Himalayan Foothills from the Kohistan Island-Arc. The Himalayan foothills in the study area have been divided into the Panjal-Khairabad (Northern block), Nathia Gali-Hissartang (Central block) and Kalachitta-Margala (Southern block) blocks on the basis of the major faults that form the southern boundaries of these blocks (Figure 2; Pogue et al. 1999). The Northern and Southern blocks are separated from the Central block by the E-W trending and north wards dipping Khairabad and Hissartang Thrust faults respectively (Figures 2 and 3). These two faults in the Attock-Cherat Range run almost parallel to each other before merging into the Panjal Fault in the Hazara region towards east (Figure 2; Tahirkheli, 1970; Parvez, 1987). The Attock-Cherat Range consists of multiply deformed sedimentary and meta-sedimentary sequences. The rocks older than the Cenozoic are metamorphosed to the north of the Khairabad fault (Pogue et al., 1999). In general, the grade of metamorphism increases from south to north beyond the Khairabad Thrust Fault (Pogue et al., 1999). These three blocks in the Attock region are collectively called the Attock Cherat Range, which is bounded to the north by the Peshawar Basin, to the south by the Nizampur Basin and to its east by the Campbellpore Basin (Figure 2; Yeats and Hussain, 1987). The Precambrian to Paleozoic Attock-Cherat Range is exposed in an area of about 50 square miles in Attock on both sides of the Indus River (Tahirkheli, 1970). The Central block is predominantly underlain by the Precambrian Dakhner Formation. The Dakhner Formation extends NE into the Hazara Formation and overlain by the Jurassic, Cretaceous and Paleocene rocks (Yeats and Hussain, 1993). The Manki and Dakhner Formations make the basal Precambrian sequence of the Himalayan foothills (Pogue et al., 1999). Substantial regional uplift ranging from 2 to 8 km and N-S shortening occurred in the Attock Cherat Range during the Pliocene time (Burbak, 1983). During this time extensive folding and thrust faulting occurred in rocks surrounding the southern marginofthePeshawar Basin.

STRATIGRAPHY

Manki Formation

The Precambrian Manki Formation makes substantial part of the Northern Block of the Attock-Cherat Range. The Formation is mainly composed of highly cleaved slate and phyllite. It also contains intra-formational limestone and quartzite beds (Figure 3; Tahirkheli, 1970; Hussain et al.1989). The upper contact of the Manki Formation with the overlying Shahkot Formation is gradational while its lower contact is not exposed in the region. Hussain et al., (1989) has reported that the Manki Formation is ~950 m thick in the Northern Block.

Mineralogically it consists of muscovite, biotite, chlorite and quartz. The rocks display one set of well developed continuous cleavage. No fossil has been reported from the Manki Formation.

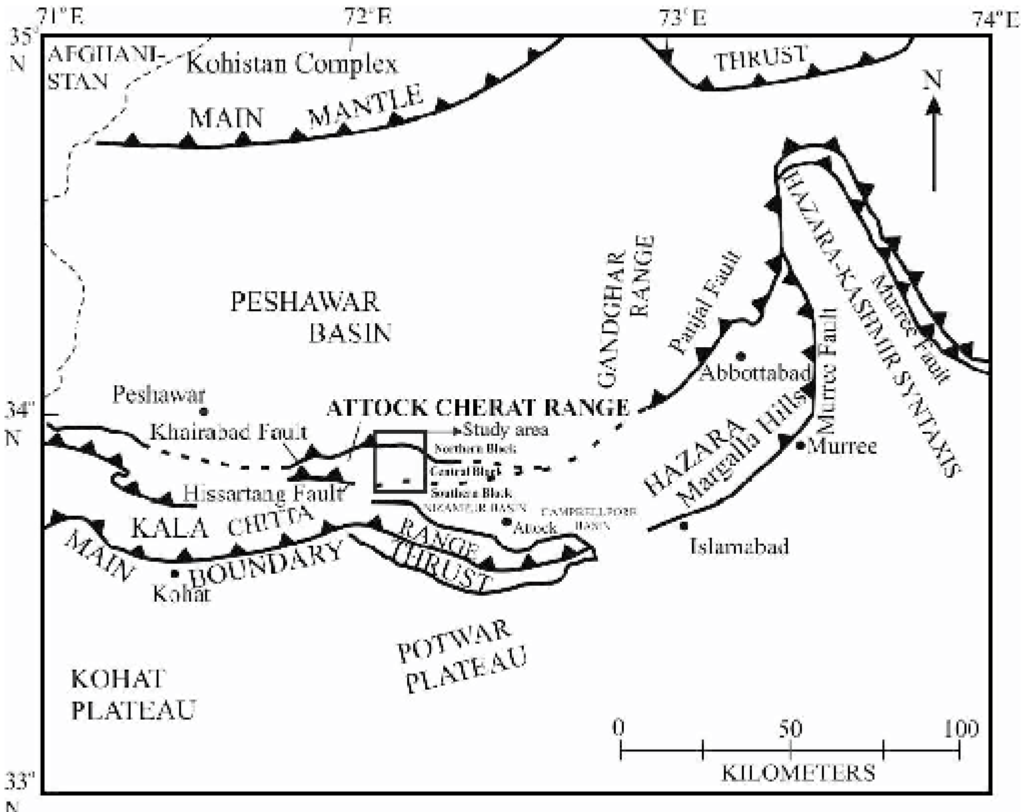


Figure 2- Map of Northern Pakistan showing physiographic subdivisions and major thrust faults. The thick dark lines indicate major faults. The dotted lines show subsurface faults concealed by the Quaternary deposits (modified after Yeats and Hussain, 1987).

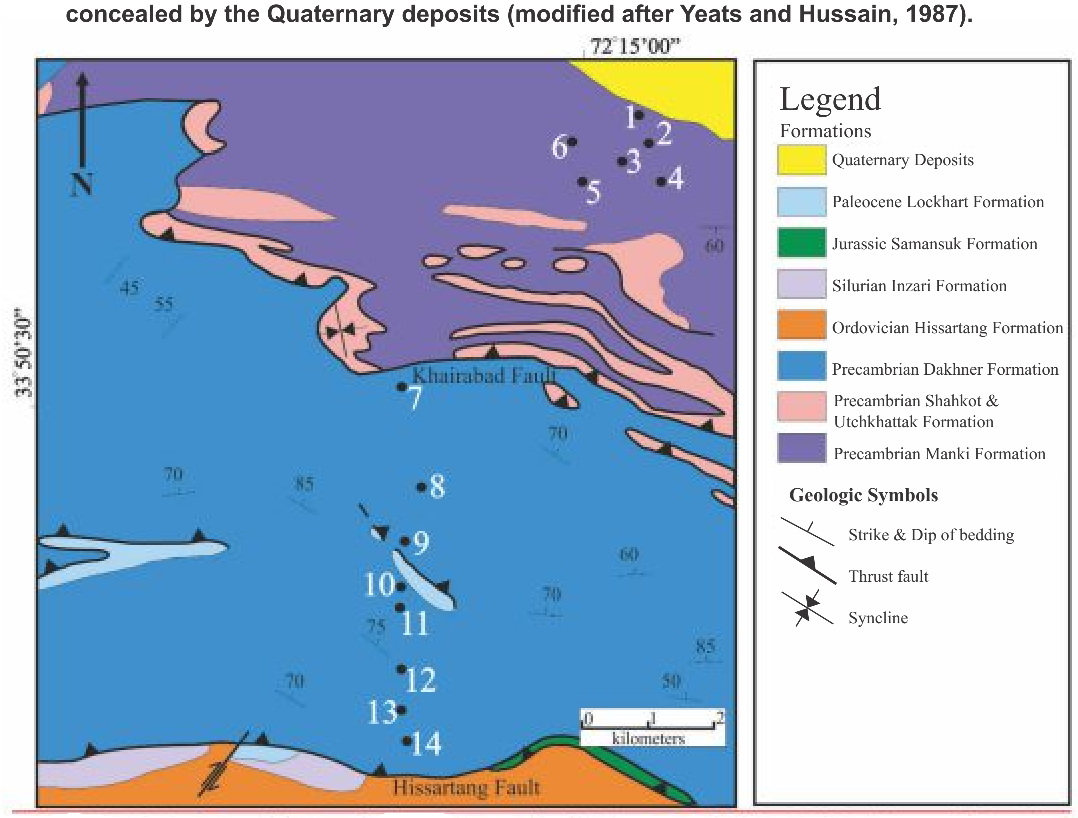


Figure 3 - Geological map of the Attock Cherat Range and adjoining areas of Khyber Pakhtunkhwa and Punjab. The black dots showing the station location (after Hussain et al., 1990).

Dakhner Formation

The central Block of the Attock-Cherat Range is occupied by the Precambrian Dakhner Formation. The Formation consists of weakly metamorphosed pelites, quartzite and limestone. The Formation is highly fractured and cleaved. The cleavages are parallel to bedding. Overall the Formation is thinly bedding with chlorite grade metamorphism (Hussain, 1984). The lower contact of the Formation is not exposed in the study area however its upper contact with the Utch-Khattak Limestone is unconformable. Hussain et al. (1989) have reported 1000 m thickness of the formation.

FIELD AND LABORATORY INVESTIGATIONS

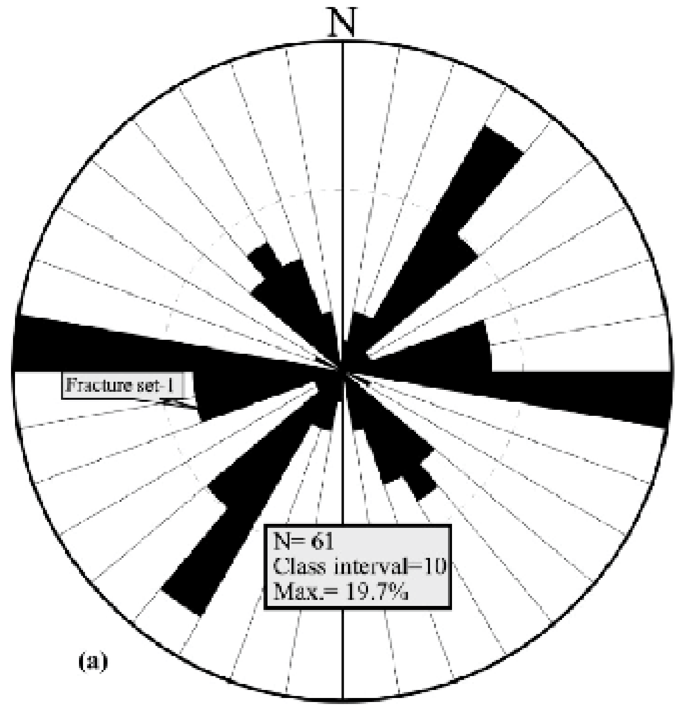
The field work was mainly focused on recording fracture and vein orientations. The crystal growth behavior and pattern in veins that contain much information about deformation were studied in oriented samples. These samples were collected very systematically from the Manki and Dakhner formations. We reoriented these samples in laboratory using the orientation table. Oriented thin sections were prepared from those samples, which were containing veins.

METHODOLOGY

Field observations and structural data were collected from the E-W trending Precambrian Manki and Dakhner formations of the Attock Cherat Range along the Indus River. Fractures and veins were collected in the Northern block, which exclusively consists of the Manki Formation. Due to lack of veins in the Dakhner Formation, data were only collected from conjugate fracture sets in the Center block of the Attock-Cherat Range (Figure 3). The orientation data were plotted on the rose diagrams (Figures 4a and 4b). The fracture data, which were recorded at the New Attock Bridge predominantly consist of mode I fractures, conjugate fractures and plumose marking. The plumose marking on extensional fracture walls are nicely preserved in these rocks.

PLUMOSE MARKING

Extensional fractures often exhibit nicely developed features on fracture walls that can provide important insight to interpret the fracture's origin. Feathery-shape features called plumose markings, which often develop during extensional tectonism, were observed in the Manki Formation. Morphologically they consist of hackle plumes, ribs and fringes (Figure 5a). Hackles are characterized by regular pattern and grooves that diverge from the central axis of the fracture surface and ribs. These originate from initial origin site of a fracture, plume axis and ribs. Ribs (hesitation lines), which are indicative of fracture front, aligned perpendicular to the hackles and local propagation direction with in the fracture surface. The presence of nicely developed plumose marking within the Manki Formation shows brittle extensional fractures. The origin of plumose marking pre-dates all other fractures observed in the area. The later fractures cross cut the plumose markings (Figure 5b). Prominent plumose marking with the above mentioned morphological features were not observed in the Dakhner Formation.



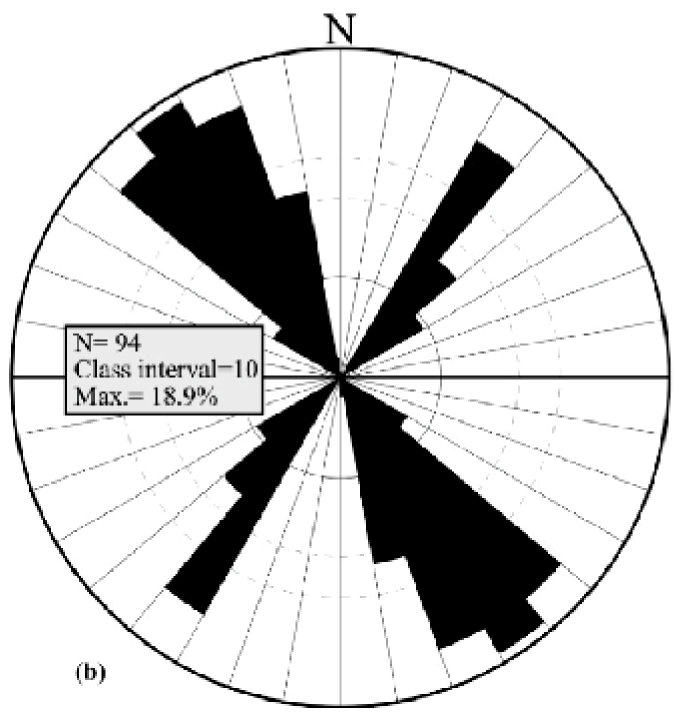


Figure 4- Rose diagram showing orientation of (a) fracture set-1 and conjugate fractures of the Manki Formation and (b) conjugate fractures of the Dakhner Formation. The orientation of the conjugate fractures in the both formations is similar

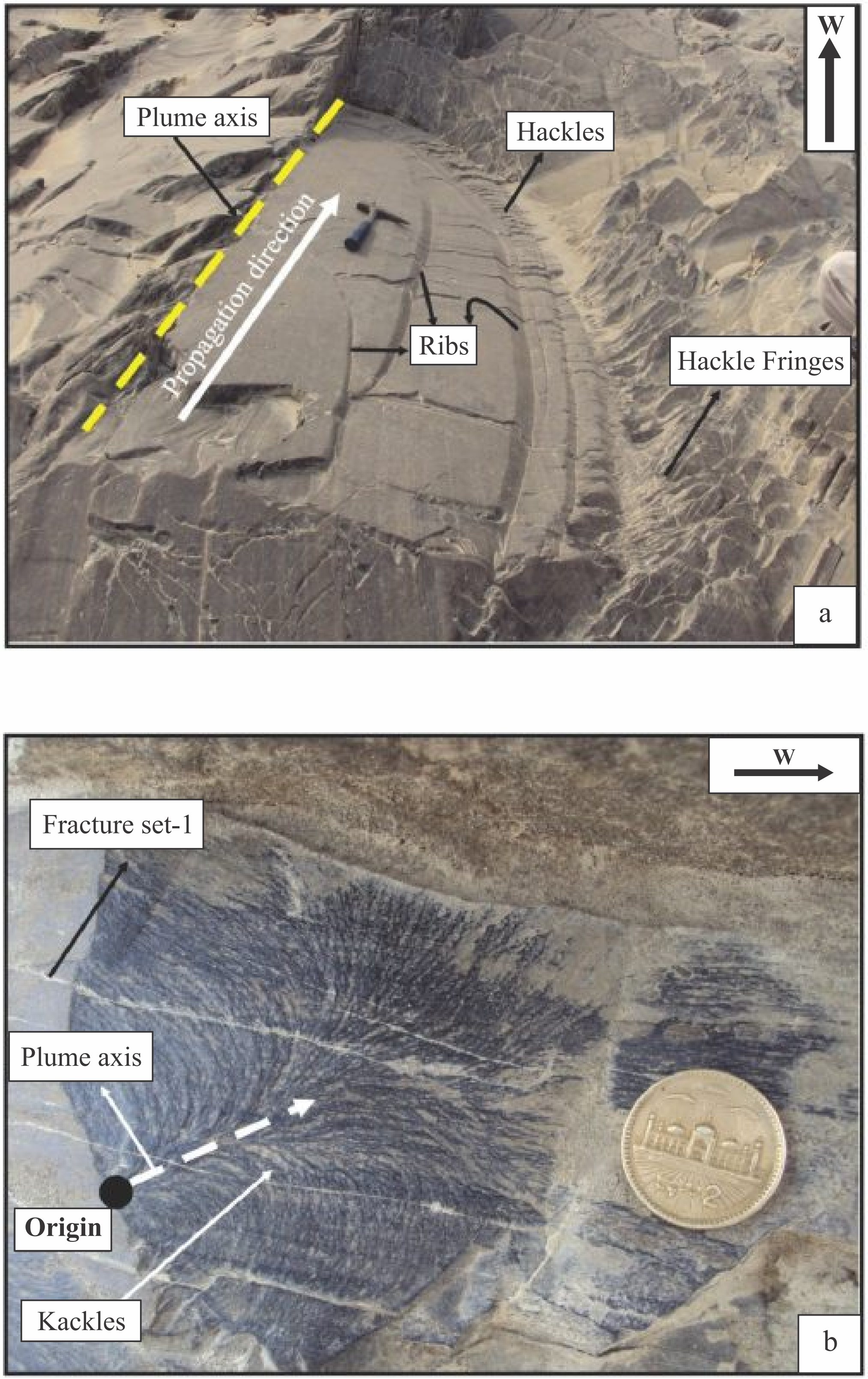


Figure 5 - Manki Formation (a) Oriented photograph showing half plumose marking, which is mainly comprises of plume axis, ribs, hackles and hackle fringes. White arrow showing the propagation direction of the fracture. (b) Oriented photograph showing the origin and direction of propagation of the plumose marking on the extensional fracture face, which pre-dates fracture set-1.

FRACTURE ANAYLSES IN THE MANKI FORMATION

Three systematic fracture sets were observed within the Manki Formation (Table 1; Figure 4a). The dominant fracture set-1 is aligned parallel to the E-W trending beds with a mean orientation of 86°. The conjugate fractures dislocate the pre-existing fracture set -1 (Figure 6). The younger fracture sets in the formation terminate against the conjugate fracture sets and form T-shaped geometry (Figure 7).

PETROGRAPHIC DESCRIPTION OF VEINS OF THE MANKI FORMATION

Veins

Four oriented samples were collected from the Manki Formation near the New Attock Bridge. Four oriented thin sections with different strikes were made from these samples to understand the characteristic structures related with the veins. Petrographic observations show that the dilation sites are filled by quartz and calcite mineralization. We observed muscovite in traces in these veins.

Quartz veins

Quartz filled veins are curvi-planar and oriented parallel to the strike of the beds. The quartz veins are highly deformed and cross cut by younger calcite filled fractures (Figure 8).

Internal structure of the quartz veins

The quartz veins of the Manki Formation are characterized by blocky equidimensional crystals of quartz. Quartz crystals are characterized by undulose extinction. Most of the equidimensional quartz crystals are fractured and later healed by secondary calcite (Figure 9).

Calcite veins

Conjugate fracture sets are predominantly filled with fibrous calcite and very little muscovite. Calcite filled veins are approximately oblique to the general trend of the Manki Formation (Figure 4a).

Internal structure of the calcite filled veins

Conjugate fractures of the Manki Formation, which are filled with calcite mineralization, contain nicely preserved median suture line. The calcite filled vein becomes younger on either side of the median suture line. The median suture line is marked by a strip of country rock constituents. Note the median suture line predate the calcite growth on each side towards the wall rock (Figure 10). These veins are characterized by fibrous calcite growth along the walls and blocky calcite crystal in the centre. Elongated fibrous calcite growth on each side of the median suture line is followed by shearing and gentle kinking. This geometry of the veins implies that these calcite veins are antitaxial in nature (Figure 10). In antitaxial veins crystal growth of mineral take place from the median suture line towards the fracture walls

Table 1- Trends of fracture set-1 and conjugate fracture sets measured within the Manki Formation.

NO.	Fracture set-1	Conjugate Fractures	
1	095°	040°	160°
2	090°	005°	140°
3	090°	020°	150°
4	110°	040°	140°
5	070°	010°	160°
6	080°	020°	150°
7	070°	030°	155°
8	070°	015°	145°
9	080°	035°	140°
10	080°	055°	140°
11	095°	035°	130°
12	080°	035°	135°
13	095°	035°	135°
14	075°	035°	135°
15	085°	035°	155°
16	065°	030°	-
17	095°	030°	-
18	095°	035°	-
19	095°	045°	-
20	095°	045°	-
21	095°	045°	-
22	095°	045°	-
23	095°	-	-
24	070°	-	-

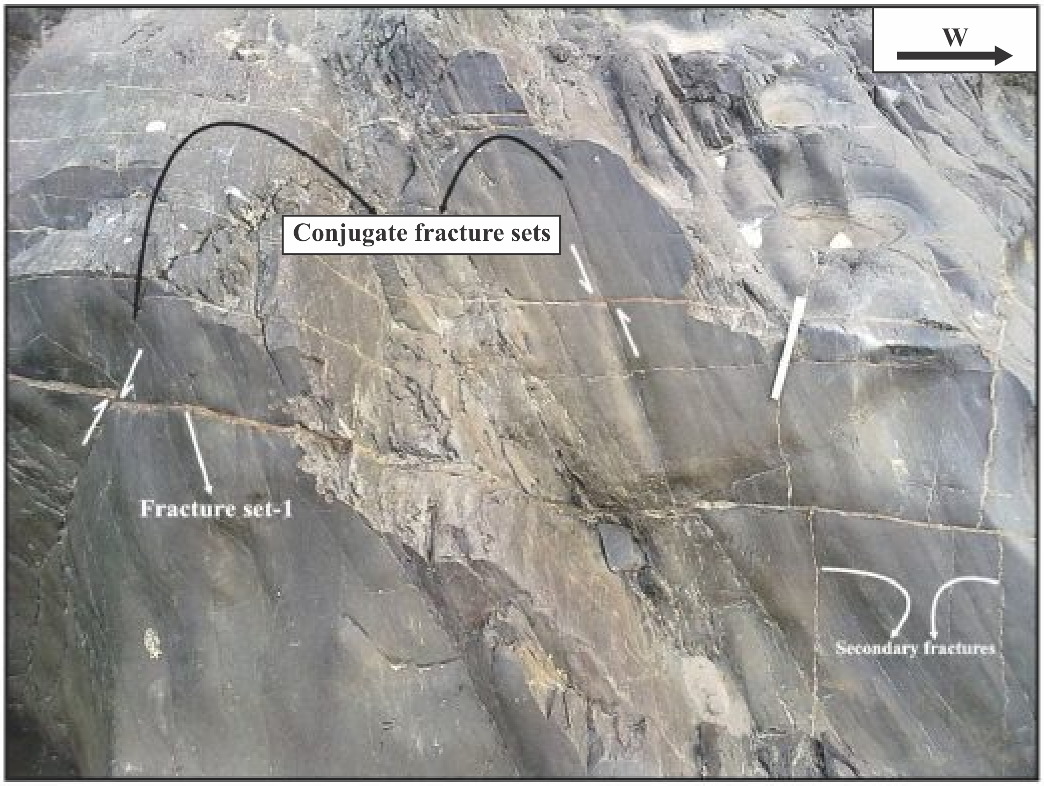


Figure 6 - Manki Formation Oriented photograph showing conjugate fractures. The fracture set-1 is displaced by the conjugate fractures. The secondary fractures truncates against the fracture set-1. Note the fracture set-1 pre-dates the conjugate fractures.

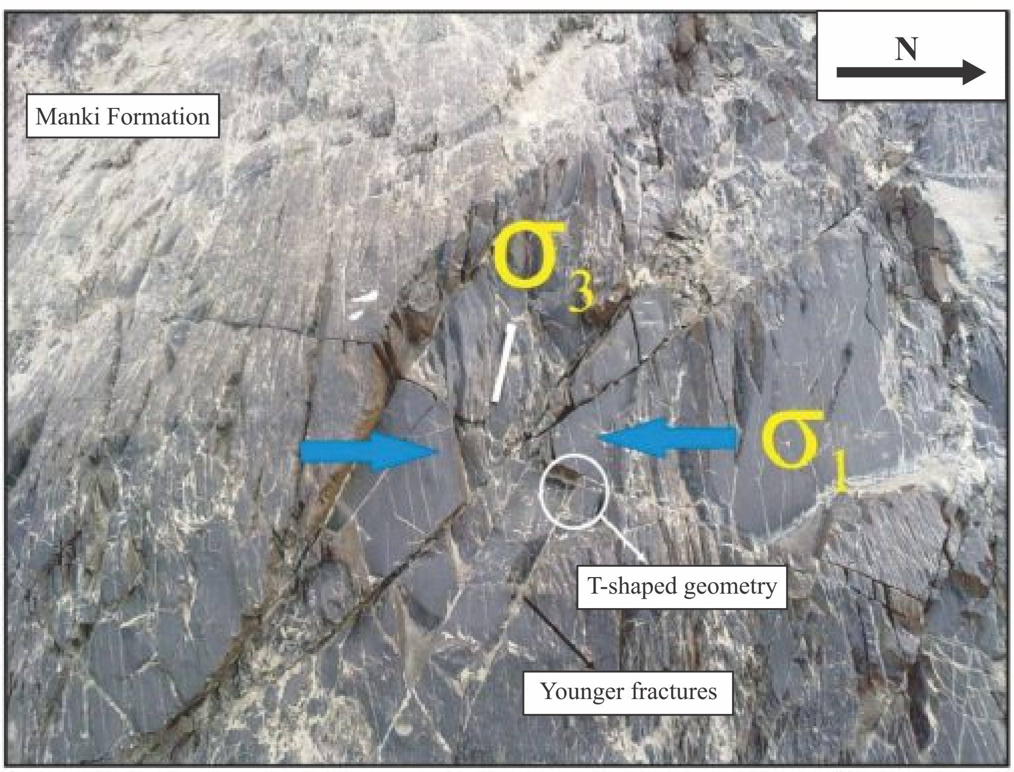


Figure 7 - Manki Formation Oriented photograph showing conjugate fractures. The σ1 and σ3 showing the directions of maximum shortening and extension respectively. The secondary fractures terminate against the well developed conjugate fractures.

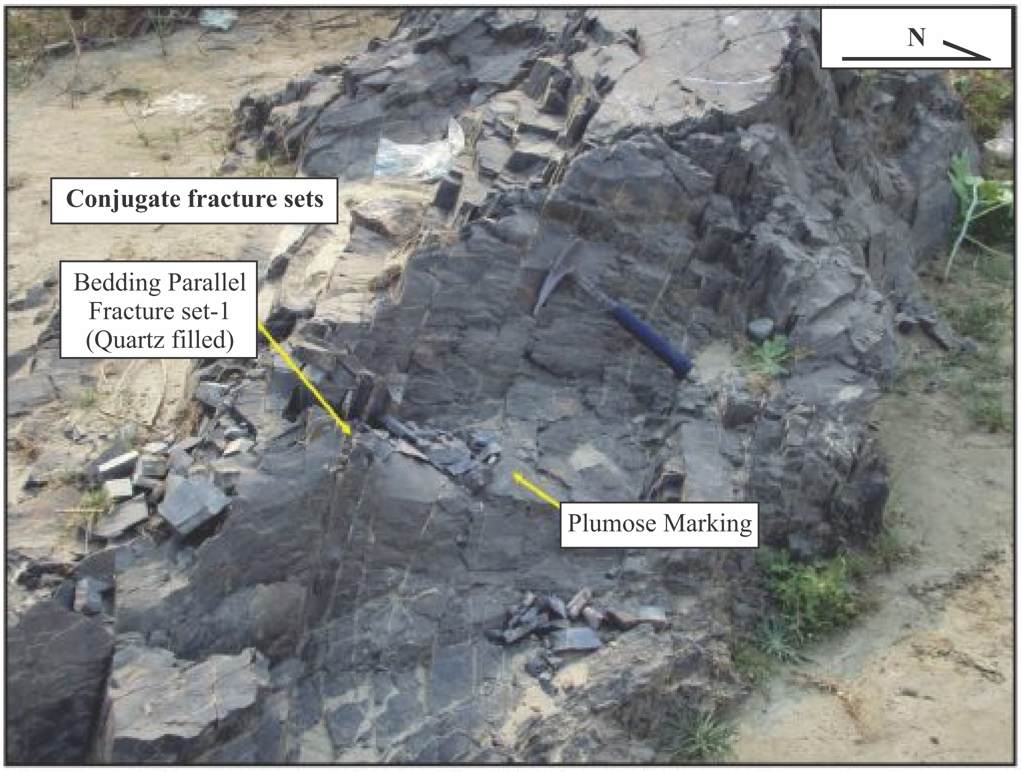


Figure 8- Oriented photograph showing parallel aligned quartz filled veins. The trends of the veins are parallel to the bedding of the Manki Formation.

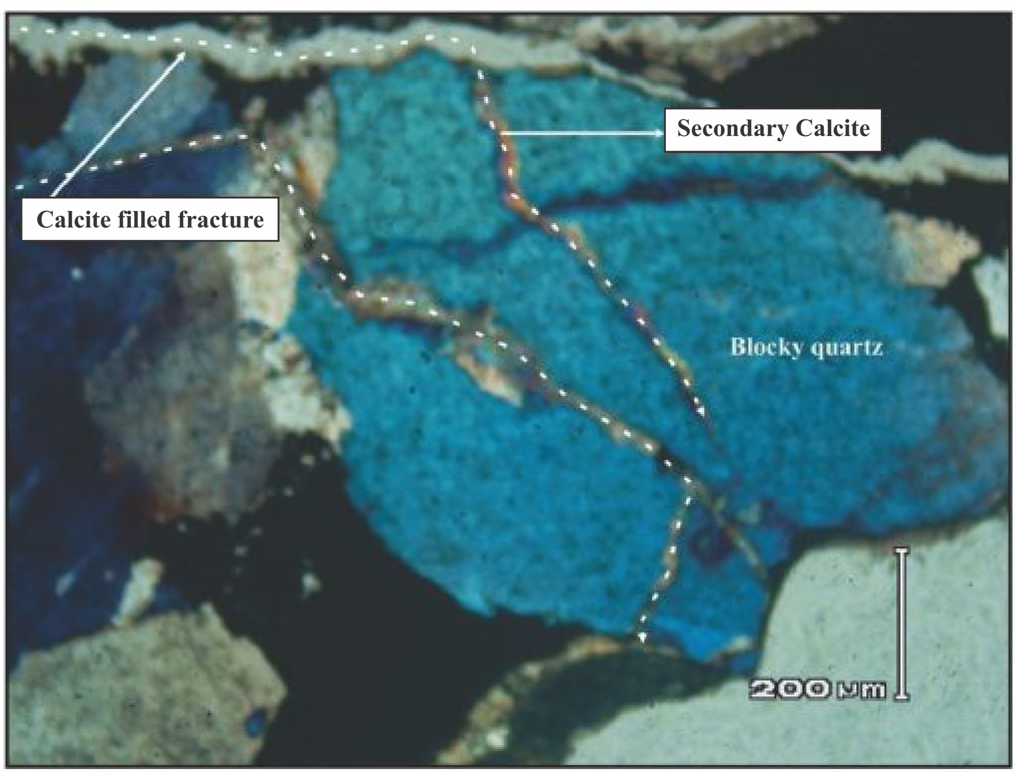


Figure 9 - Photomicrograph illustrating fractured quartz grain in the Manki Formation, which is filled by the secondary calcite mineralization. The dotted lines showing the fractures in quartz grain, which are filled by younger calcite vein in the matrix.

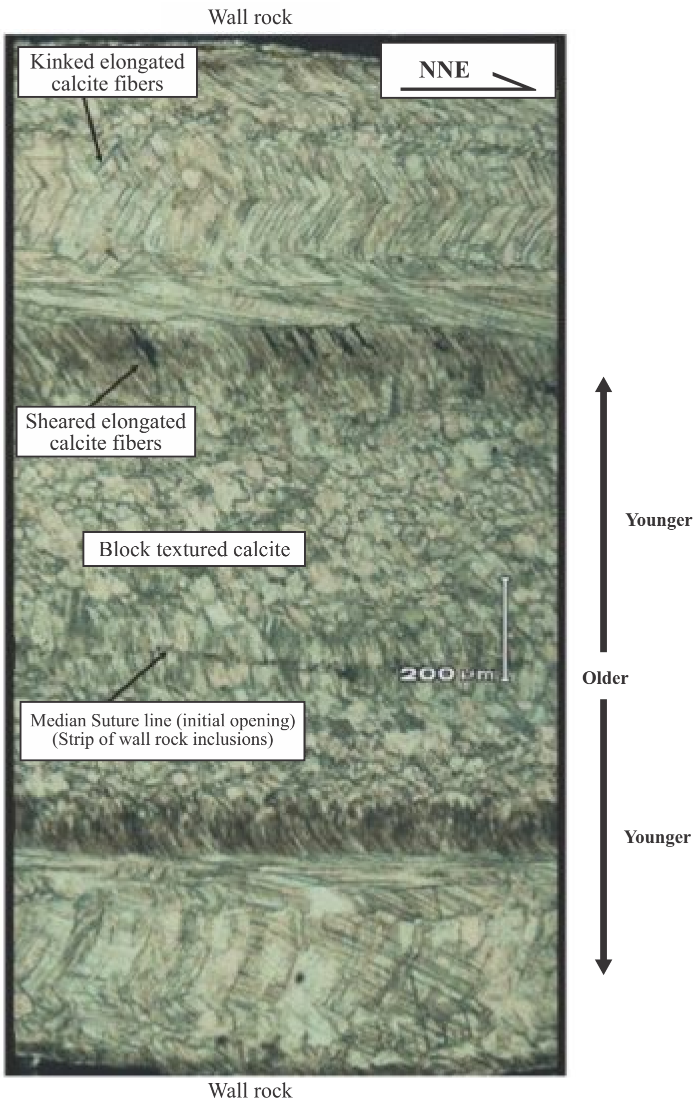


Figure 10- Oriented photomicrograph of an antitaxial calcite vein showing different phases of deformation, curved fibers near the walls and median suture line in the centre of the Manki Formation.

(Durney and Ramsay, 1973; Bons and Monterai, 2005). Note the antitaxial veins of the Manki Formation are filled by calcite, which is not a main constituent of the wall rocks. The calcite is concurrently added at both side of the suture line.

Fracture Analyses in Dakhner Formation

Fracture data were collected at eight stations from the weakly metamorphosed Precambrian Dakhner Formation, which is exposed between the Khairabad and Hissartang Thrust faults (Figures 3 and 4b). These faults make the northern and southern structural boundaries of the Formation respectively. Two pervasive fracture sets, one trending NW-SE and the other NE-SW and associated secondary fractures are present throughout the Dakhner Formation (Figure 11a). The secondary fractures that terminate against NW-SE and NE-SW conjugate fracture sets and numerously scattered throughout the Formation are interpreted as late stage fractures. The secondary fractures have curving geometries adjacent to these two fractures sets. NW-SE and NE-SW bed-confined conjugate fractures divide the Dakhner formation into fracture bounded blocks (Figure 11b). The NW-SE and NE-SW fractures mostly dip at average 58° with mean orientations 145o and 218o towards SW and NW respectively (Table 2). The acute angle between the mean orientation of the NW-SE and NE-SW trending conjugate fracture sets is ~60°. Analyses show a subvertical least principle stress σ3 and a subhorizontal maximum principle stress σ1. These fractures are commonly highly planar and consistent in orientation for a considerable length across the region. Quartz and calcite filled fractures were not observed across the Dakhner Formation. Similarly plumose patterns that reflect tensile origin were missing in the Formation,Implying compression related fractures in the region. These fractures have bed-normal axis of intersection σ2. The acute bisector σ1 strike roughly N-S, which are more clearly visible in cross sectional profiles (Figure 11).

INTERPRETATION

The E-W trending Precambrian Manki Formation displays three major fracture sets. The estimated average mean orientation of the Fracture set-1 and conjugate fractures is 86°, 32° and 144° respectively (Table, 1; Figure 4a).Conjugate fractures are oblique to the bedding and displace fracture set-1. The fracture set-1 is predominantly filled by blocky quartz showing undulose extinction (Figures 8 and 9). The conjugate fractures are characterized by calcite infilling. Calcite filled fractures carry information about the opening mode of these fractures. Fibrous calcite crystals near the wall surface of the veins are untwined while blocky calcite crystals in the centre are twinned. The twinned calcite grains indicate local tectonic compression across the region (cf. Herman, 2005). The highly curved and elongated fibers of calcite at both sides of the vein are formed by intense shearing. Calcite filled fractures show at least the following five deformation events (Figure 10).

(i) An early fracture with well defined median suture line and wall rock inclusions.
(ii) Blocky calcite crystal growth on both sides of the median suture line.
(iii) Elongated calcite fibers growth perpendicular to the wall rock and shearing.
(iv) Elongated calcite fibers growth parallel to the walls of vein.
(v) Elongated calcite fibers growth perpendicular to the wall rock and kinking.

The presence of the blocky calcite and calcite fibers in the vein lead to the interpretation that the first two deformation events occurred during extensional environment followed by elongated fibrous calcite growth, shearing and kinking (Figure 10). All the events become younger towards the wall of the vein.

The north-south shortening related to the Khairabad and Hissartang Thrust faults is largely accomplished by conjugate fractures development in the Manki and Dakhner formations. These fractures display kinematic relation to the south verging Khairabad and Hissartang Thrust faults (Figure 11). The strike of the acute bisector (σ1) is consistent with N-S

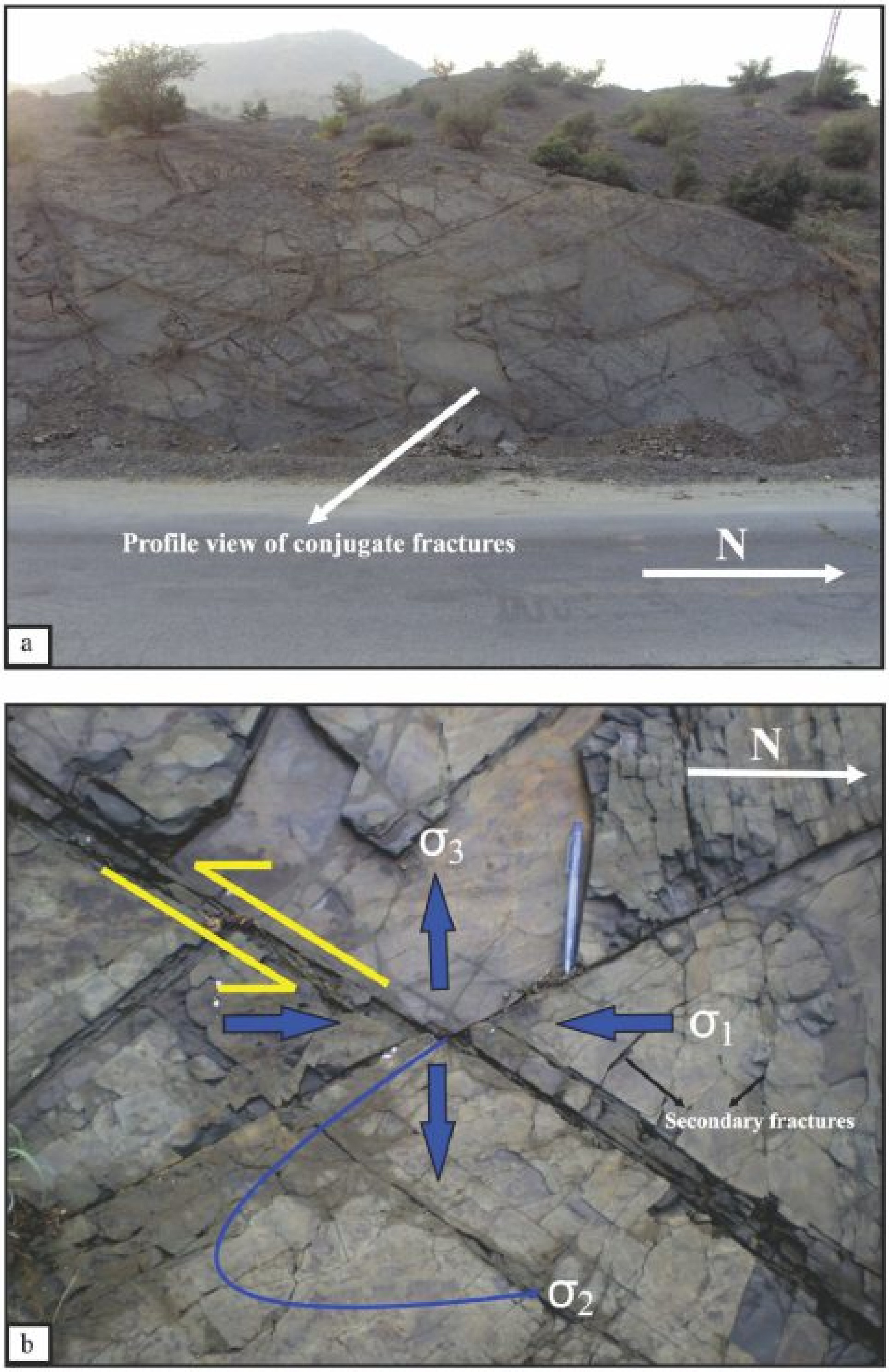


Figure 11 - (a) Oriented photograph illustrating the profile view of the conjugate fractures in the Dakhner Formation. (b) Oriented photograph of a developed conjugate fracture of the Dakhner Formation, whose maximum shortening and extension directions are similar to the conjugate fracture sets of the Manki Formation.

Table 2- Trends of the conjugate fractures measured within the Dakhner Formation.

No.	Conjugate Fractuers		No.	Conjugate Fractuers	
1	050°	140°	34		145°
2	040°	155°	35		150°
3	055°	160°	36	–	150°
4	030°	135°	37	–	145°
5	045°	135°	38	–	135°
6	035°	140°	39		155°
7	040°	140°	40	–	155°
8	045°	170°	41	–	155°
9	035°	165°	42	–	150°
10	035°	150°	43		150°
11	015°	145°	44		145°
12	035°	135°	45	–	120°
13	045°	140°	46	–	135°
14	055°	150°	47		145°
15	035°	160°	48		155°
16	030°	165°	49	–	165°
17	035°	130°	50	–	150°
18	030°	145°	51	–	140°
19	035°	160°	52		140°
20	030°	130°	53		165°
21	030°	130°	54	–	145°
22	030°	140°	55	–	130°
23	035°	150°	56	–	130°
24	035°	140°	57		130°
25	050°	142°	58	–	125°
26	050°	155°	59	–	140°
27	040°	155°	60	–	145°
28	040°	160°	61		135°
29	040°	160°	62		135°
30	–	120°	63	–	125°
31	–	135°	64	–	165°
32		135°	65		150°
33		135°	–	–	–

directed horizontal bulk shortening. The conjugate fractures of the Dakhner Formation are unfilled by calcite and quartz because it is more clay rich, ductile and less brittle. Note the same conjugate fractures are filled by the calcite solutions in the Manki Formation, which is more brittle and less ductile. Similarly the nicely developed plumose marking and fracture set-1 within the Manki Formation are also induced due to its brittle nature.

CONCLUSIONS

In chronological order the plumose markings pre-date the fracture set-1 and conjugate fracture sets. Fracture set-1 is characterized by blocky quartz infilling and is displaced by the conjugate fracture sets. The conjugate fractures are predominantly characterized by calcite infilling within the Manki Formation. The horizontal bulk shortening and shear strains in the region are induced by the south ward movement of the Khairabad and Hissartang thrust faults (Figure 12). The conjugate fractures sets are pervasively developed in the Precambrian Manki and Dakhner formations, which indicate that they are not restricted to localized deformations. The acute bisector σ1 of the conjugate fractures and their geometries across the area are highly compatible with the north-south shortening related with the Khairabad and Hissartang Thrust faults. A very close similarity between the south verging faults and principal compressive stress direction σ1 show that the conjugate fractures and the thrust fault have formed coevally in response to N-S shortening phase of tectonism related with the Attock Cherat Range.

ACKNOWLEDEMENT

We highly appreciate the fund and logistic support provided by the Department of Geology, University of Peshawar.

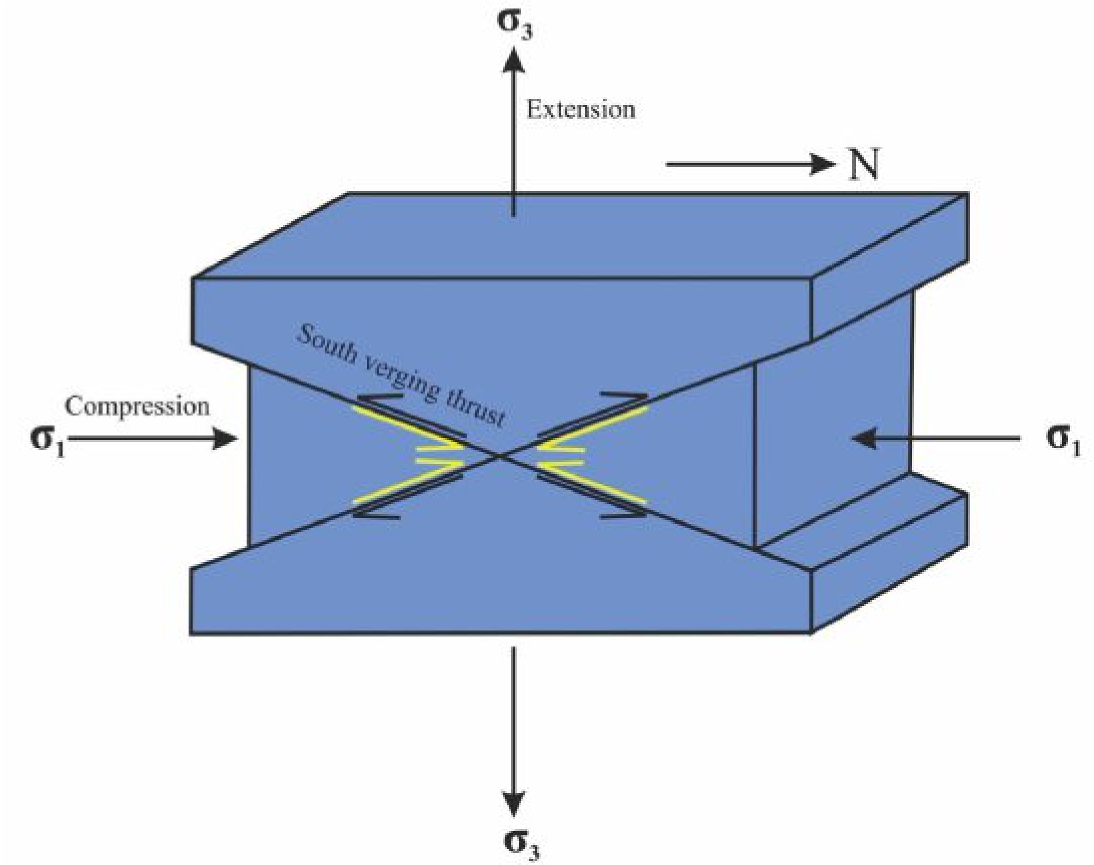


Figure 12- Schematic block diagram showing the overall mechanism, which has induced the pervasive conjugate fracture sets in the Manki and Dakhner formations and the south verging thrust faults in the region.

REFERENCES

Bons, P. D., 2000. The formation of veins and their microstructures. In: Jessel, M.W., Urai, J.L. (Eds.), Stress, Strain and Structure a Volume in Honour of W.D. Means. Journal of the Virtual Explorer 2.

Bons, P. D., 2001. Development of crystal morphology during unitaxial growth in a progressively widening vein: I. the numerical model. Journal of Structural Geology. Vol. 23, p. 865-872.

Bons, P.D. and Montenari, M., 2005. The formation of antitaxial calcite veins with well-develoed fibres, Oppaminda Creek, South Australia. Journal of Structural Geology. Vol. 27 p. 231-248.

Burbak D. W., 1983. The chronology of intermontane-basin development in the northwestern Himalyas and the evolution of the Northwest Syntaxis. Earth and Planetary Science Letters. Vol. 64, p. 77-92.

Durney, D.W. and Ramsay, J. G., 1973. Incremental strains measured by syntectonic crystal growths, in: De Jong, K.A., Scholten, K. (Eds.), Gravity and Tectonics. John Wiley and Sons, New York, p. 67-69.

Engelder, T. and Geiser, P. A., 1980. On the use of regional joint sets as trajectories of paleostress fields during the development of the Appalachian Plateau, New York. J. Geophysics Res. 85, p. 6319-6341.

Finn, M. D., Gross, M. R., Eyal Y. and Draper G., 2003. Kinematics of thoroughgoing fractures in jointed rocks. Tectonophysics Vol. 376, p. 151-166.

Garret, C. H. and Lorens, J. C., 1989. Fracturing along the Grand Hogback Garfield County, Colorado. New Mexico Geological Society Guidebook, 41st Field Evaluation. Vol. 4, p. 11-16.

Groshong, R. H., 1988. Low-temperature deformation mechanisms and their interpretation. Bull. Geological Society of America, Vol. 100, p. 1329-1360.

Gross, M. R., Engekler, T., and Poulson, S. R., 1992. Veins in the Lockport dolostone: evidence for an acadian fluid circulation system. Geology. Vol. 20, p. 1111-1128.

Herman, G. C., 2005, Joints and veins in the Newark basin, New Jersey, in regional tectonic perspective: I Gates, A. E., editor, Newark Basin View from the 21st Century, 22nd Annual Meeting of the Geological Association of New Jersey, College of New Jersey, Ewing, New Jersey, p. 75-116.

Hodgson, R. A., 1961, Regional study of jointing in Comb ridge-Navajo Mountain Area, Arizona and Utah, American Association of Petroleum Geologists Bulletin. Vol. 45, p.1-38.

Koehn, D., Arnold, J. and Passchier, C. W., 2005. Fracture and vein patterns as indicators of deformation history: a numerical study. Tectonophysics, Institute for Geosciences, Bechherweg 21, University of Mainz, 55099 Mainz, Germany. Geological Society, London, Special Publications. Vol. 243, p. 11-24.

Koehn, D. and Passchier, C. S., 2000. Shear sense indicators in striped bedding veins. Journal of Structural Geology. Vol. 22, p. 1141-1151.

Parvez, M. K., 1987. Geology of a part of Attock-Cherat and Kalachitta Ranges in the Vicinity of Nizampur, N.W.F.P., Pakistan. M. Phil thesis.

Passchier, C. W. and Trouw, R. A. J., 2005. A. J. Microtectonics, Vol.1, Second edition. Publisher; Springer;

Patterson, M. S. 1978. Experimental Rock Deformation-Brittle Field. Publisher; Springer; Second edition Verlag, Berlin.

Pogue, K. R., Hylland, M. D., Yeats, R. S., Khattak. W., and Hussain, A., 1999. Stratigraphic and structural framework of Himalayan foothills, northern Pakistan. Geological Society of America. Special paper. Vol. 328, p. 258-274.

Pollard, D. D. and Aydin, A., 1988. Theoretical displacements and stresses near fractures in rocks: with applications to faults, joints, dikes and solution surfaces. In: Atkinson, B. K. (ed) Fracture Mechanics of Rock. Academic Press, London, p. 277-348.

Ramsay, J. G. and Huber, M. I., 1983. The techniques of modern structural geology, 1: Strain Analysis. Academic Press, London, UK.

Ramsay, J. G. and Chester, F. M., 2004. Hybrid fracture and the transition from extension fracture to shear fracture. Nature. Vol. 428, p. 63-66.

Ranalli, G. 1995. Rheology of the Earth, Second edition. Chapman and Hall, London, UK. Publisher: Kluwer Academic.

Segall, P., 1984. Formation and growth of extensional fracture sets. Geol. Society of America, Vol. 95, no. 4, p. 454-462

Tahirkheli, R. A. K., 1970. The geology of Attock-Cherat Range, west Pakistan. Geol. Bull. Univ. of Peshawar, Vol. 5.

Twiss, R. J. and Moores, E. M., 1992. Structural Geology. Freeman, New York. p. 532.

Wilkins, J. S., Gross, R. M., Wacker, M., Eyal, Y. and Engelder, T. 2001. Faulted joints: Kinematics, displacement-length scaling relations and criteria for their identification. Journal of Structural Geology 23, p. 315-327.

Yeats, R.S. and Hussain, A., 1987. Timing of structural events in the Himalayan foot hills of NW Pakistan. Geological Society of America. Vol. 99, No. 2, p. 161-176.

Yeats, R. S. and Hussain, A., 1993. Geology of the Himalayan Foothills from the perspective of the Attock-Cherat Range. Himalaya Karakorum Tibet Workshop. Vol. 8, p. 56.