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Quartz C-axis fabric along Main Central Thrust (MCT), Garhwal Himalaya, India

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ABSTRACT

The granite-gneisses are thrust over the less metamorphosed quartzites along the Main Central Thrust (MCT) in Garhwal Himalaya. The quartz C-axes fabrics from the plastically deformed quartzites and granite-gneisses were studied with the help of universal stage in XZ sections. The measurements of quartz C-axes in quartzite exhibit single and cross girdles. The C-axes maxima are located at the peripheries and towards the Y-axis. The quartz C-axes maxima in granite-gneisses are characterised by diffuse cross girdles with unequally populated pattern. The concentration of the quartz C-axes maxima is recorded progressively towards Y-axis.

The single inclined girdles are generally exhibited by the quartz grains due to simple shear. The cross girdle patterns are due to conjugate direction of shear acting simultaneously under the influence of non-coaxial flattening (Bouchez and Pecher 1981). The fabric of C-axes, commonly encountered in the shear zone are characterised by the maxima forming cross girdles which are asymmetric to the MCT transport direction. The quartz C-axes fabrics in quartzite formed by glide on the basal <a> and rhomb <a> systems. The deformation movements were of sinistral type during the formation of the MCT.

INTRODUCTION

Plastically deformed quartzites commonly show distinct types of preferred orientation, textural and structural features which are mainly controlled by (1) the magnitude of finite strain, (2) the type of strain history, (3) the particular combination of slip systems active during deformation and (4) the role of dynamic recrystallisation. Lister et al. (1978), Lister and Paterson (1979), Lister and Hobbs (1980), Hobbs (1985), Law (1986), Law and Potts (1987), Jessell (1988), Law et al. (1990), Garbutt and Teyssier (1991) and Fueten (1992) remarked that the development of crystallographic fabrics in quartzite involves intracrystalline glide systems with symmetry of structural elements.

The Main Central Thrust (MCT of Heim and Gansser 1939) is the major tectonic feature in the Himalaya and separates the Higher Himalaya from Lesser Himalaya (Fig. 1). The investigated area of Garhwal Himalaya is located between the longitudes $78^0 35'$ to $78^0 45'$ E and latitudes $30^0 25'$ to $30^0 40'$ N and geologically, it consists of Pratapnagar quartzite and Central Crystalline rocks (Fig. 2).

The main objective of this paper is to discuss the quartz C-axis orientation in the footwall and hangingwall rocks of the MCT, to understand the process and nature of deformation.

GEOLOGY OF THE AREA

The study area is tectonically delineated by the MCT which is a tectonic plane between the Pratapnagar quartzites (footwall side) and the Central Crystallines (hangingwall side). The Pratapnagar quartzite is massive white and ferruginous. It may be remarked that the ferruginous quartzite which is exposed in the vicinity of the MCT is devoid of mylonitic effects. The ferruginous quartzite is characterised by pebbly horizon near Chhatera and Raunsal (Singh 1993, Saklani 1993). However, at a distance of about 2 to 3 km towards south of the MCT (i.e., near Ghansyali) the massive white quartzite is mylonitised (Fig. 2) and is characterised by intercalations of chlorite - sericite schist. The Central Crystalline rocks (side of the MCT) consists of granite - gneiss, granitoids, migmatites, quartzo- feldspathic schist, augen gneiss, porphyroblastic gneiss, kyanite -sillimanite gneiss and garnet - biotite schist. The metabasics are intrusive in these rocks.

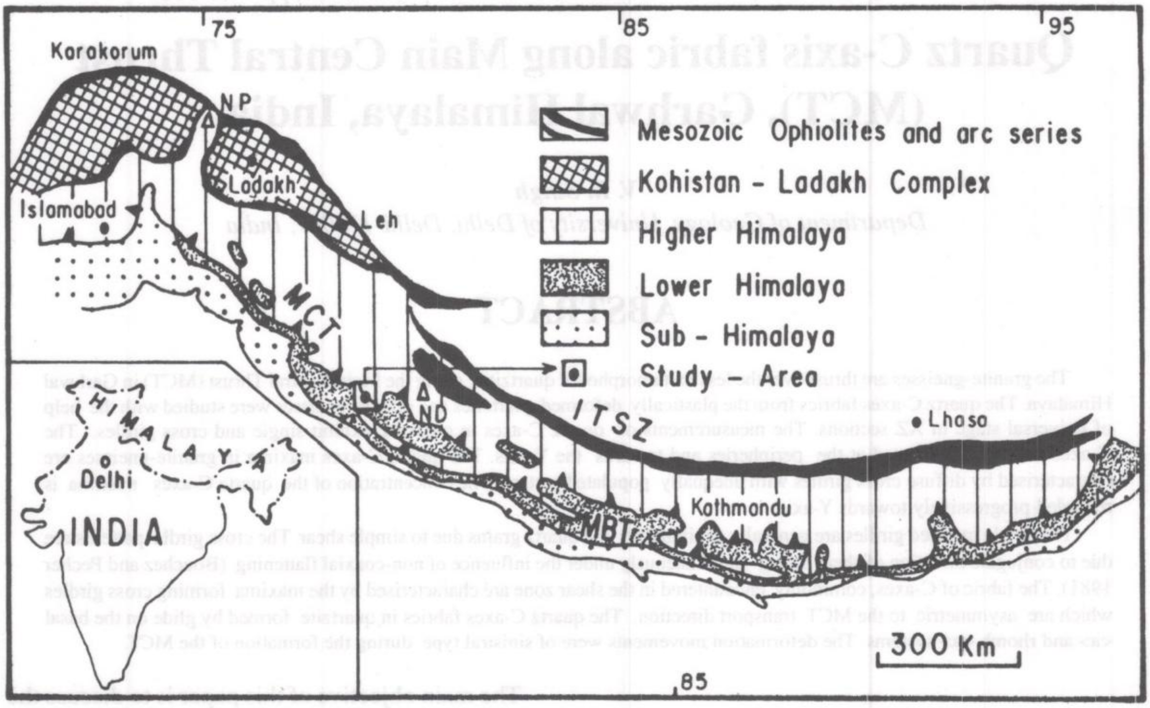


Fig. 1 General tectonic map of the Himalaya after Honegger et al. (1989). NP: Nanga Parbat, ND: Nanda Devi, ITSZ: Indus Tsangpo Suture Zone, MCT: Main Central Thrust, MBT: Main Boundary Thrust.

The granite gneisses and quartzofeldspathic schist are sheared and mylonitised along the MCT. The migmatites and gneisses comprise plagioclases, K-feldspars, perthite, muscovite, biotite, relics of alumino-silicate and quartz in different proportions (Singh 1993; Singh et al. 1993). The granitoid, gneisses occassionaly contain enclaves of the mafic and pelitic materials. Sometimes the pelitic enclaves show high degree of alteration and retrogression. These rocks show a decrease of the grade of metamorphism away from the MCT (Singh et al. 1995). The entire rock sequence of the area is of Precambrian age.

The detailed structural study of the Himalayan rocks in different areas of Garhwal were carried out by Gansser (1964), Vashi and Merh (1974), Valdiya (1980), and Saklani (1993) and others. It reveals that the Lesser and Higher Himalayan zone were affected by four phases of deformations viz. D_1, D_2, D_3 and D_4 which were responsible for F_1, F_2 and F_3 phases of folding in the Himalayan region. With reference to the area, the F_1 is represented by tight and isoclinal folds plunging ~20^0 toward E - W formed during D_1 deformation. The F_2 folds are of overturned type and plunge ~20^0 towards NW (D_2 deformation). The quartz c-axis fabric is related to D_2 deformation. The D_2 deformation was also responsible for major folding which in sequel was followed by thrusting (at the last stage of D_2 deformation) in Himalaya (Saklani et al. 1991, Singh 1993). The F_3 folds of D_3 deformation are of chevron type which plunge ~10^0 towards NE and SW or N - S. During D_3 deformation, new sliding occured in the MCT zone on the S_2 plane and retrograde metamorphic minerals formed. D_4 deformation is coaxial with D_3 deformation and produced cataclasis of the rocks and displacement of the lithological units of the area.

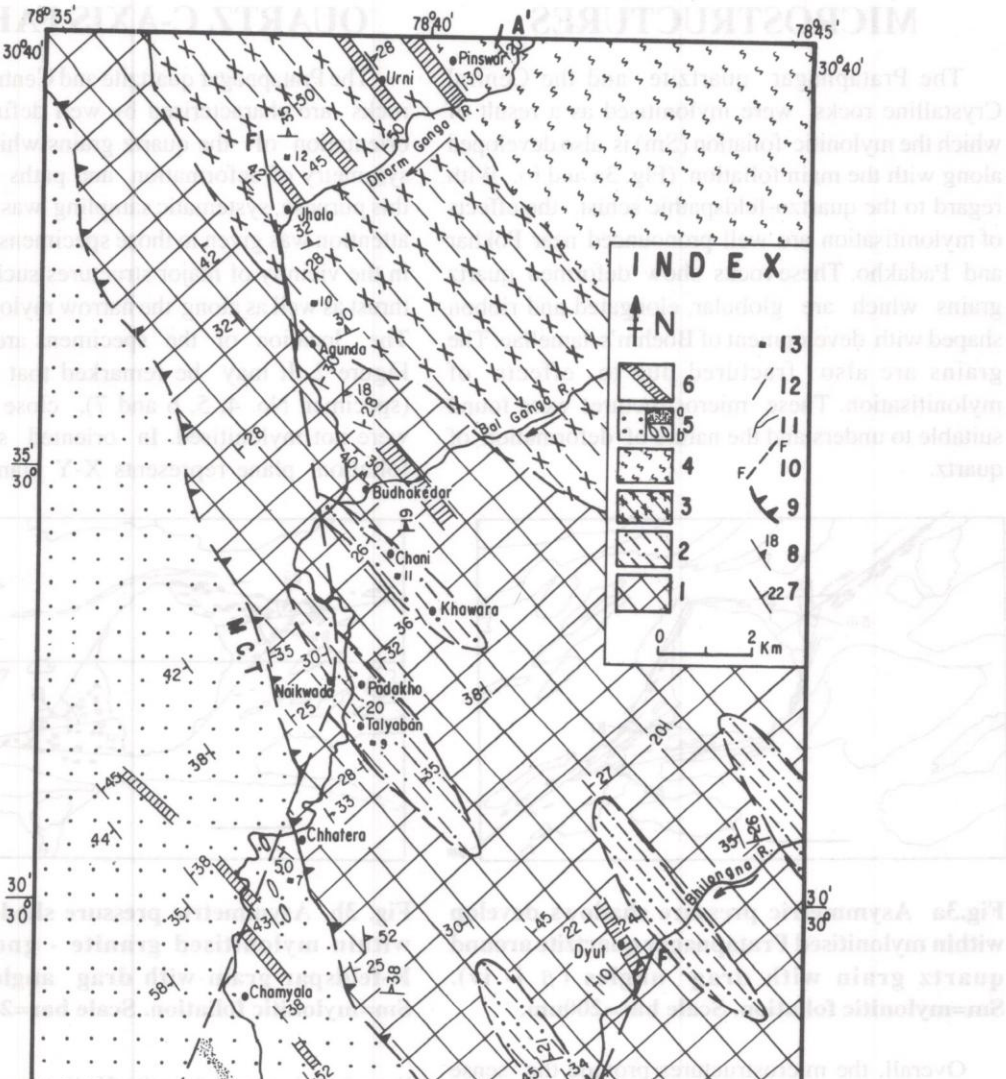


Fig. 2 Geology of northern part of Bhilangna valley, Garhwal Himalaya, India. 1: granite -gneiss and migmatites, 2: quartzo-feldspathic schist, 3: kyanite-sillimanite gneiss and schist, 4: garnet - biotite schist, 5: Pratapnagar quartzite, (a) mylonitised, (b) pebbly, 6: metabasics, 7: S_1 schistosity, 8: S_2 schistosity, 9: thrust, 10: fault, 11: river, 12: lithological boundary, 13: specimen location and A-A' for cross section.

MICROSTRUCTURES

The Pratapnagar quartzite and the Central Crystalline rocks were mylonitised as a result of which the mylonitic foliation (Sm) is also developed along with the main foliation (Fig. 3a and b). With regard to the quartzo-feldspathic schist, the effects of mylonitisation are well pronounced near Pokhar and Padakho. These rocks show deformed quartz grains which are globular, elongated and ribbon shaped with development of Boehm's lamellae. The grains are also fractured due to effects of mylonitisation. These microstructures were found suitable to understand the nature of deformation of quartz.

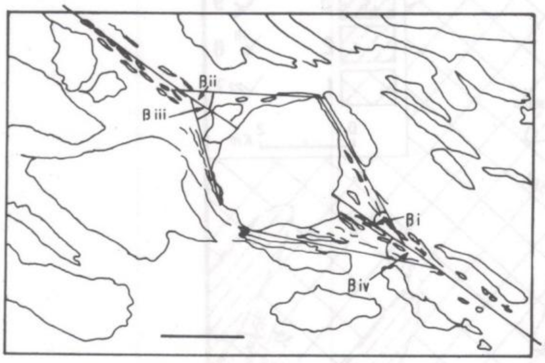


Fig.3a Asymmetric pressure shadows develop within mylonitised Pratapnagar quartzite around quartz grain with drag angles (β i- iv). Sm=mylonitic foliation. Scale bar=200um.

Overall, the microstructures provide the sense of shear as sinistral type in the area which has been deduced from drag angles (β) of porphyroblasts following the method proposed by Takagi and Ito (1988). In the mylonitised quartzite (Fig. 3a) the drag angles (βi = 26^0, βii = 30^0, βiii = 40^0 and βiv = 23^0) were measured. In the quartzofeldspathic schist the drag angles were βi = 49^0, βii = 16^0, βiii = 42^0 and βiv = 13^0 (Fig. 3b). In both rocks the drag angles in upper right- and lower left - hand side of a porphyroblast is larger than the upper left- and lower right -hand side and thus, a sinistral type of shearing can be deduced.

QUARTZ C-AXIS FABRICS

The Pratapnagar quartzite and Central Crystalline rocks are characterised by well defined preferred orientation of the quartz grains which reflect the symmetry of deformation and paths of strain. For this purpose, systematic sampling was done and due attention was given to those specimens which occur in the vicinity of major structures such as fault and thrust as well as along the narrow mylonitised zones. The location of the specimens are indicated in Figure 2. It may be remarked that the quartzite (specimen No. 4, 5, 6 and 7), close to the MCT, were not mylonitised. In oriented samples the foliation plane represents X-Y plane while the

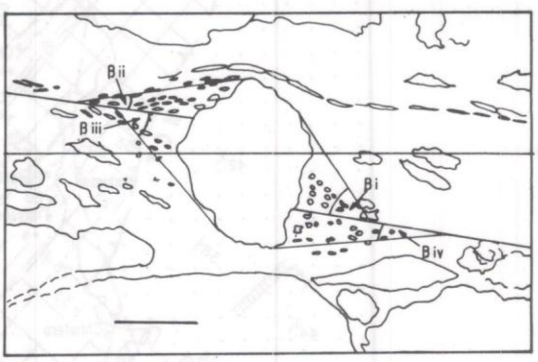


Fig. 3b Asymmetric pressure shadows develop within mylonitised granite - gneiss around K-feldspar grain with drag angles (β i- iv). Sm=mylonitic foliation. Scale bar=200um.

lineation is parallel to the X direction. The Z axis lies perpendicular to the foliation plane. For c-axis analysis, the thin sections were prepared along X-Z plane.

The quartz c-axis were measured on the oriented specimens of quartzite (No. 1 to 7) and Central Crystalline rocks (No.8 to 12) along X-Z sections were measured following the method as described by Turner and Weiss (1963). In each of the oriented thin sections, about 200 to 300 c-axes of quartz grains were measured. The data of all the specimens have been plotted on lower hemisphere of equal area net. In all the stereograms, the X axis is horizontal and the pole of the foliation is vertical in X-Z plane (Fig. 4 to 10).

The quartzite specimens exhibit single girdle (specimen 1b), single -inclined girdle (specimen 2,3,5) and cross- girdle (specimen 1a,4,6,7) of the c-axis maxima characterised by unequally populated pattern. In majority of the specimens cross -girdles are present. However, specimen No. 1b and 2 show well developed single and single - inclined girdles. The maxima in specimen No. 1a, 1b, 2 and 6 show concentration from peripheries to inclined position. In specimen No. 1a, 4, 6 and 7, the cross girdle patterns are present with unequally populated quartz c-axes and the maxima are in inclined position (Fig. 4 to10). The concentration of maxima exhibits monoclinic symmetry.

The quartz c-axis fabric of the Central Crystalline rocks are characterised by cross girdles with unequally populated pattern. The concentration of the maxima is recorded progressively towards Y-axis (specimen No. 8 to 12 and Fig. 7 to 10) and weak peripheries maxima. The symmetry pattern of the Central Crystalline rock is triclinic.

In fact, grain boundary migration, recrystallisation and intracrystalline glide systems during the strain history play an important role in deformation. The preferred orientation of quartz c-axes shows a close relationship with rotation component of the deformation. The fabric of c-axes, commonly encountered in the shear zone are characterised by the maxima forming cross girdles which are asymmetric to the tectonic transport direction (Lister 1977; Lister and Price 1978; Burg and Laurent 1978; Brunel 1980; Bouchez 1977 and Bouchez and Pecher 1981). In shear zones, the c-axis fabrics, textures and grain shapes can develop due to late stage of deformation and the girdle maxima depend on the initial orientation inherited from previous stages of deformation.

DISCUSSION

As a result of thrusting, the quartz grains were intensively flattened, elongated and became ribbon shaped. The ribbon shaped quartz grains also contain pressure shadows around it. The D_2 deformation is characterised by non-coaxial deformation associated with rotation (Singh 1993). The obliquity, the angle between the average girdle and the normal to X-Y (Z axis), is high.

The single inclined girdles are generally exhibited by the quartz grains due to simple shear. The cross girdle patterns have been attributed to conjugate direction of shear acting simultaneously under the influence of non-coaxial flattening (Bouchez and Pecher 1981). The author has attempted to find out the sense of shearing in the quartzite with the help of asymmetric pressure shadows of quartz. Based on the drag angle (β) it has been inferred that the movement was of sinistral type (Fig. 3a). The author is of the opinion that during the formation of the MCT the deformation movements were of manily N to S from top. Diffuse girdles of c-axis within Central Crystalline rocks may be due to post tectonic recrystallisation, but does not seem to strongly affect the initial lattice preferred orientations.

The c-axes were rotated towards the Y axis, (=rhomb slip of Bouchez and Pecher, 1981). The c-axis maxima concentration at periphery and 45^0 to lineation show a basal <a> glide (Bouchez and Pecher, 1981; Price, 1985 and Schmid and Casey, 1986). This type of fabric is suggested by Lister and Dornsiepen (1982) as a balance between slip on the basal <a> and prism <c> systems. The c-axis fabric concentration show somewhere in between periphery and centre described as rhomb <a> glide (Bouchez and Pecher, 1981) while the concentration of c-axis fabric at centre as prism <a> glide (Bouchez and Pecher 1981; Mancktelow 1987 and Fueten et al. 1991). The quartz grains which can keep their stored strain energy to a minimum by the use of a single glide system, oriented approximately parallel to the plane and direction of maximum resolved shear stress. Inclined and centered maxima in the position found in the Garhwal samples are indicative of medium to higher temperature rhombohedral and prismatic <a> slip (Bouchez and Pecher 1981 Hobbs 1985, Aller and Bastida 1993). The different slip systems active in quartz across the shear zone agree with the temperature changes

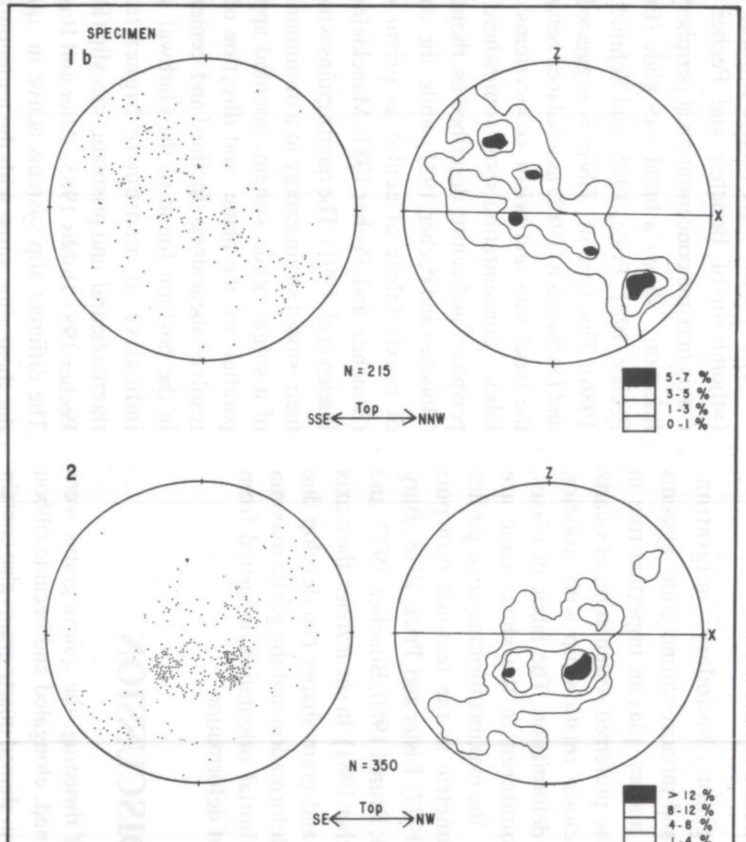


Fig. 4

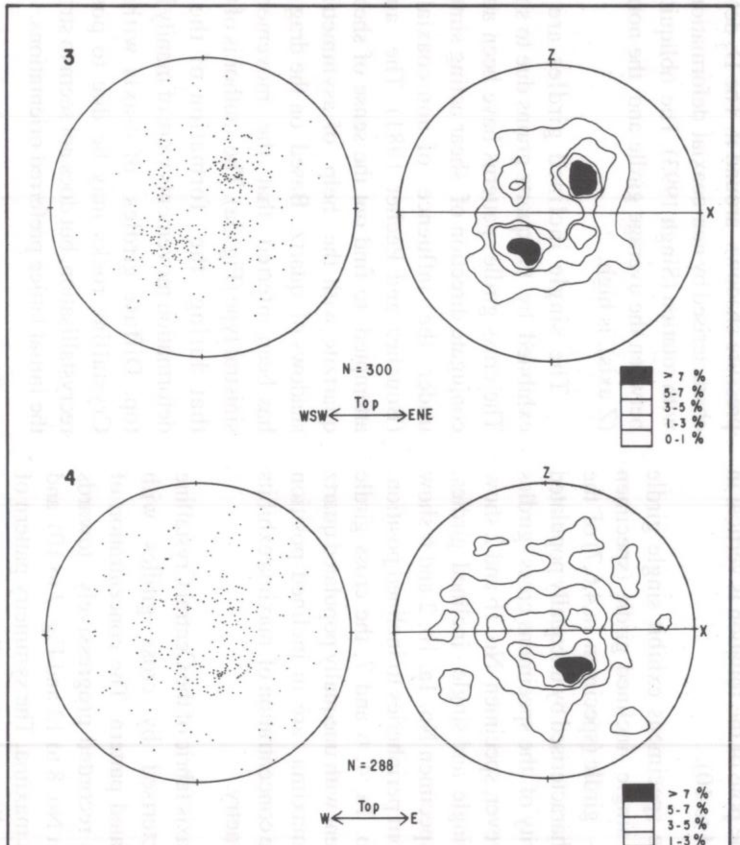
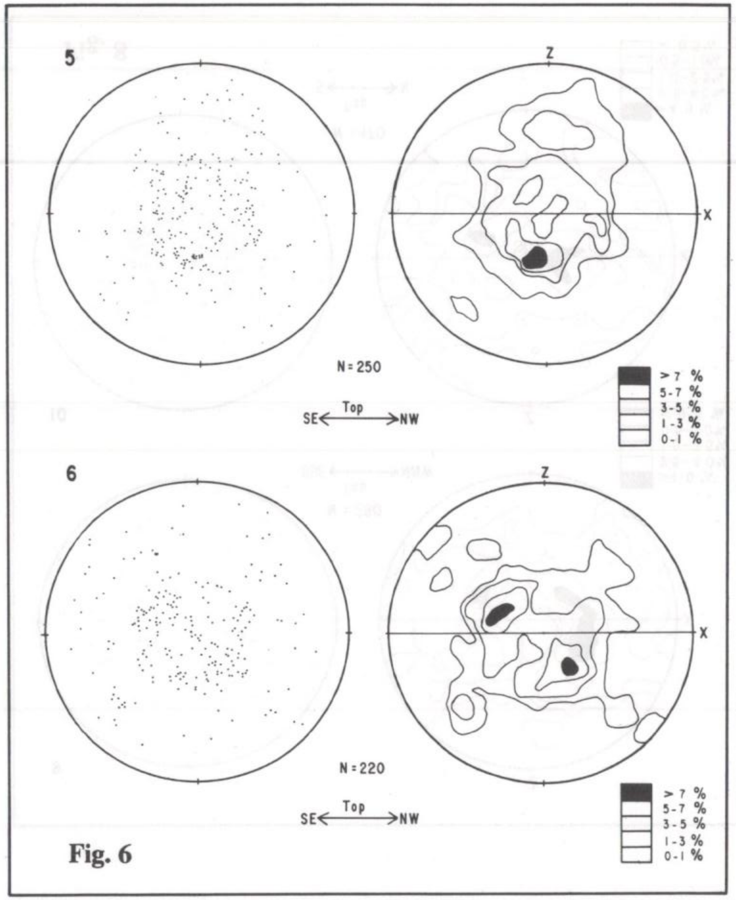


Fig. 5

Fig. 4 and 5 Quartz C-axis orientations. X-Z section; lineation is horizontal and trends are given with top position. (N =number of measured quartz grains). Left figure shows plotting of c-axes and right figure shows its contour %. Contours of % per 1% area are given right.



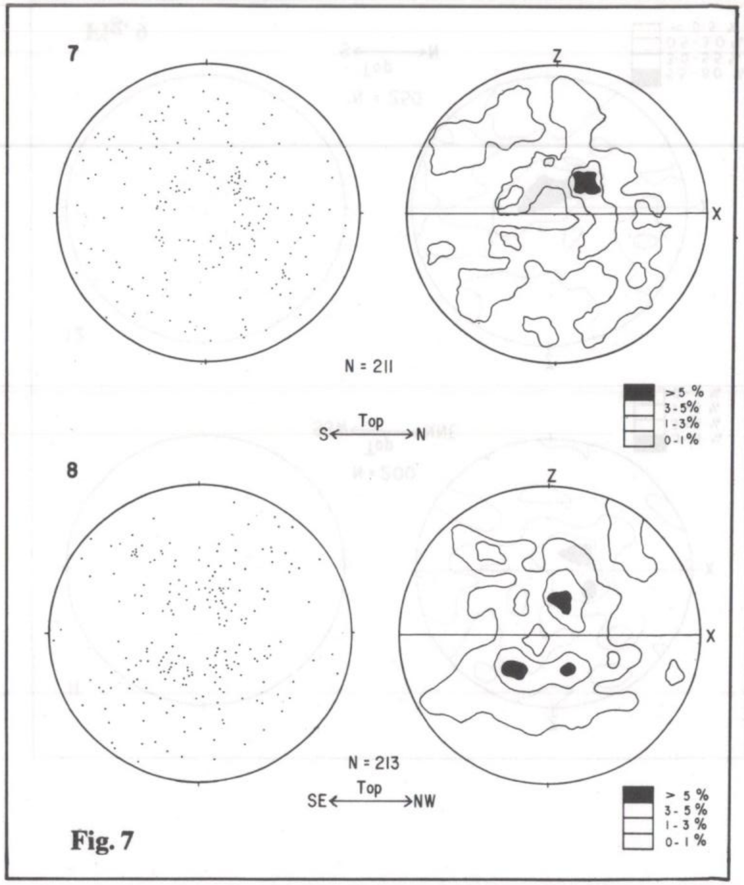


Fig. 6 and 7 Quartz C-axis orientations. X-Z section; lineation is horizontal and trends are given with top position. (N =number of measured quartz grains). Left figure shows plotting of c-axes and right figure shows its contour %. Contours of % per 1% area are given right.

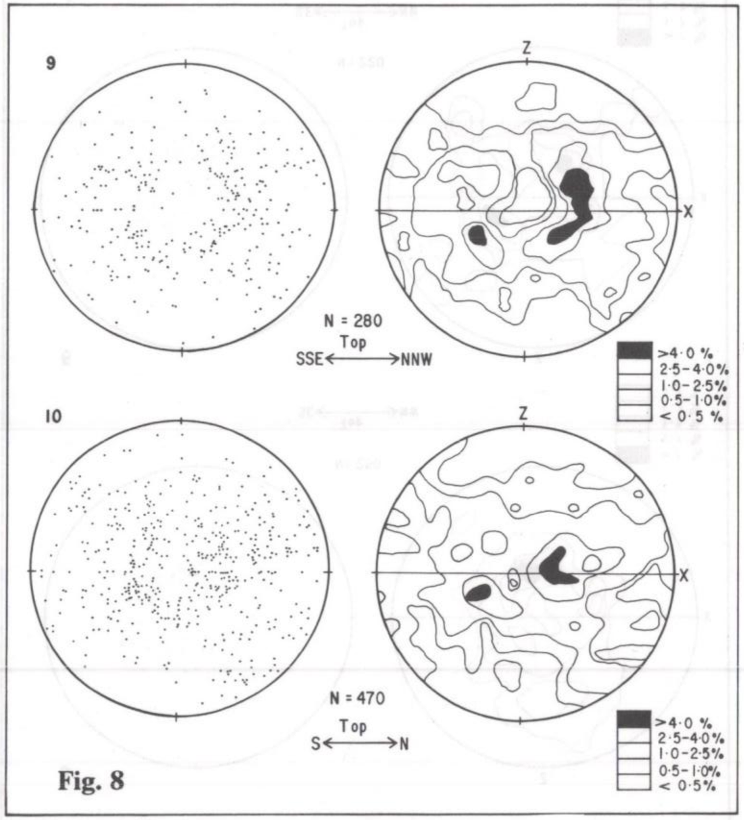


Fig. 8

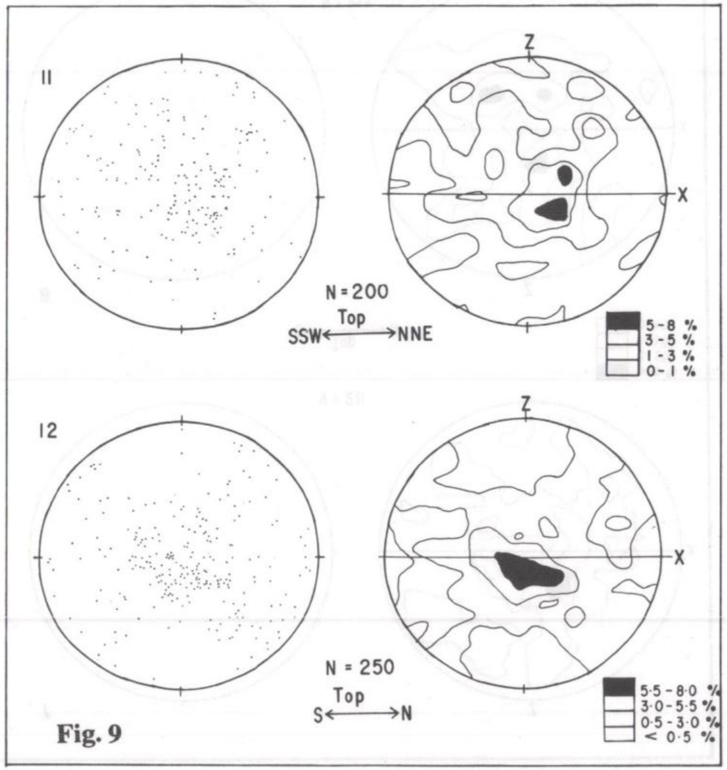


Fig. 9

Fig. 8 and 9 Quartz C-axis orientations. X-Z section; lineation is horizontal and trends are given with top position. (N =number of measured quartz grains). Left figure shows plotting of c-axes and right figure shows its contour %. Contours of % per 1% area are given right.

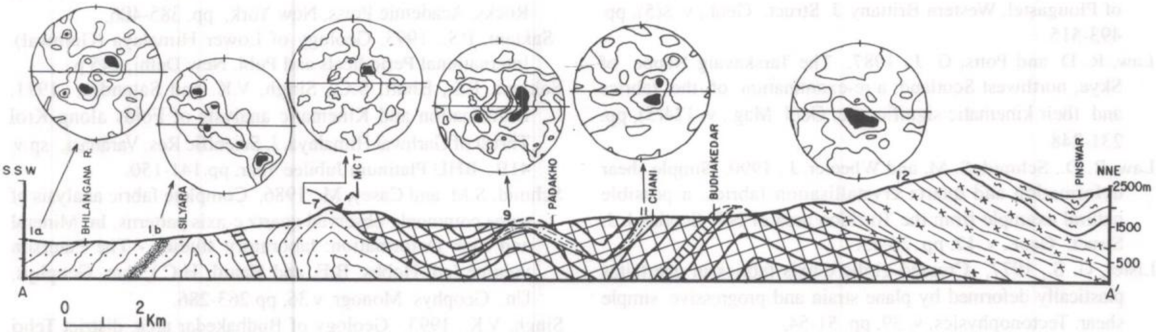


Fig.10 Geological cross section along the line A-A'(Fig.2) with c-axis orientation. Symbols as in Fig. 2.

recorded by the metamorphic minerals (Fig. 10). Therefore, the main gliding planes were basal <a>, rhomb <a> and prism <a> in rocks of the study area.

CONCLUSIONS

The quartz was affected by plastic deformation along the basal and prismatic planes in a basal direction (Bouchez 1977 and Lister and Williams 1979). In the Pratapnagar quartzite, the deformation of c-axis took place along basal <a> and rhombic <a> planes but it was manily along the rhombic <a> planes with monoclinic symmetry especially reflected by the specimens belonging to the mylonitised zones. The gliding mechanism in the Central Crystalline rocks was rhombic <a> and prismatic <a>. Due to high temperature deformation within Central Crystalline rocks the quartz grains glide mainly along the prismatic <a> planes.

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REFERENCES

Aller, J. and Bastida, F., 1993, Anatomy of the Mondonedo Nappe basal shear zone (NW Spain). J. Struct. Geol., v.15, pp.1405-1419.

Bouchez, J. L., 1977, Plastic deformation of quartzites at low temperature in an area of natural strain gradient. Tectonophysics, v. 39, pp. 25-50.

Bouchez, J. L. and Pecher, A., 1981, The Himalayan Main Central Thrust Pile and its quartz-rich tectonites in Central Nepal. Tectonophysics, v. 78, pp. 23-50.

Brunel, M., 1980, Quartz fabrics in shear-zone mylonite: evidence for a major imprint due to late strain increments. Tectonophysics, v. 64, pp. 33-44.

Burg, J. P. and Laurent, P., 1978, Strain analysis of a shear zone in a granodiorite. Tectonophysics, v. 47, pp.15-43.

Fueten, F., 1992, Tectonic interpretation of systematic variations in quartz c-axis fabrics across the Thompson Belt. J. Struct. Geol., v.14, pp. 775-789.

Fueten, F., Robin, P.-Y.F. and Stephens, R., 1991, A model for the development of a domainal quartz C-axis fabric in a coarse grained gneiss. J. Struct. Geol., v.13, pp.1111-1124.

Gansser, A., 1964, Geology of the Himalaya. Wiley Interscience, London. 289 p.

Garbutt, J. M. and Teyssier, C., 1991, Prism <c> slip in the quartzites of the Oakhurst Mylonite Belt, California. J. Struct. Geol., v. 13, pp. 657-666.

Heim, A. and Gansser, A., 1939, Central Himalaya, geological observations of the Swiss expedition 1936. Mem. Soc. Helv. Sci. Nat., v. 73, pp. 245.

Hobbs, B. E., 1985, The geological significance of microfabric analysis. In: Wenk, H.R. (ed.) Preferred Orientation in Deformed Metals and Rocks: An Introduction to Modern Texture Analysis, Academic Press, New York, pp. 463-485.

Honegger, K., Le Fort, P., Mascle, G. and Zimmermann, J.-L., 1989, The blueschists along the Indus Suture Zone in Ladakh, NW Himalaya. J. Meta. Geol., v. 7, pp. 57-72.

Jessell, M. W., 1988, Simulation of fabric development in recrystallisation aggregates-II, Example Model runs. J. Struct. Geol., v. 10, pp. 779-793.

Law, R. D., 1986, Relationships between strain and quartz f73 crystallographic fabrics in the Roche Maurice quartzites of Plougastel, Western Brittany. J. Struct. Geol., v. 8(5), pp. 493-515.

Law, R. D. and Potts, G. J., 1987, The Tarskavaig Nappe of Skye, northwest Scotland: a re-examination of the fabrics and their kinematic significance. Geol. Mag., v. 124(3), pp. 231-248.

Law, R. D., Schmid, S. M. and Wheeler, J., 1990, Simple shear deformation and quartz crystallisation fabrics: a possible natural example from the Torridon area of NW Scotland. J. Struct. Geol., v. 12, pp. 29-45.

Lister, G. S., 1977, Crossed girdle c-axis fabrics in quartzites plastically deformed by plane strain and progressive simple shear. Tectonophysics, v. 39, pp. 51-54.

Lister, G. S. and Dornsienpen, U. F., 1982, Fabric transitions in the Saxony granulite terrain. J. Struct. Geol., v. 4, pp. 81-92.

Lister, G. S. and Hobbs B. E., 1980, The simulation of fabric development during plastic deformation and its application to quartzite: the influence of deformation history. J. Struct. Geol., v. 2, pp. 355-370.

Lister, G. S. and Paterson, M. S., 1979, The simulation of fabric development during plastic deformation and its application to quartzites: fabric transitions. J. Struct. Geol., v. 1, pp. 99-116.

Lister, G. S., Paterson, M. S. and Hobbs, B. E., 1978, The simulation of fabric development in plastic deformation and its application to quartzites: the model. Tectonophysics, v. 45, pp.107-158.

Lister, G. S. and Price, G. P., 1978, Fabric development in a quartz feldspar mylonite. Tectonophysics, v. 49, pp. 37-78.

Lister, G. S. and Williams, P. F., 1979, Fabric development in shear zones: theoretical controls and observed phenomenon. J. Struct. Geol., v. 1, pp. 283-297.

Mancktelow, N. S., 1987, A typical texture in quartz veins from the Simplon Fault Zone. J. Struct. Geol., v. 9, pp. 995-1006.

Price, G. P., 1985, Preferred orientations in quartzites. In: Wenk, H. R. (ed.) Prefferred Orientation in Deformed Metals and Rocks, Academic Press, New York, pp. 385-406.

Saklani, P.S., 1993, Geology of Lower Himalaya (Garhwal). International Periodicals and Publ. New Delhi, 245 p.

Saklani, P.S., Bhatt, S.C., Singh, V.K. and Satendra, 1991, Deformation and Kinematic analysis of Folds along Krol Thrust of Garhwal Himalaya. J. Scientfic Res. Varanasi, sp.v. 41B: BHU Platinum Jubilee Year, pp.141-150.

Schmid, S.M. and Casey, M., 1986, Complete fabric analysis of some commonly observed quartz c-axis patterns. In: Mineral and rock Deformation: laboratory studies - The Paterson volume (ed. Hobbs, B.E. and Heard, H.C.), Am. Geophys. Un. Geophys. Monogr. v.36, pp.263-286.

Singh, V.K., 1993, Geology of Budhakedar area, district Tehri Garhwal, Lesser Himalaya, U.P. Unpublished Ph.D. thesis, University of Delhi, pp. 135.

Singh, V.K., Singh, S.P. and Saklani, P.S., 1993, Alumino- silicate (kyanite-sillimanite-andalusite) - bearing assemblage from schist of Budhakedar Granite, Dharm Ganga Valley, Lesser Garhwal Himalaya. Seminar on Himalayan Geology and Geophysics (abstracts), Silver Jubilee Year, Wadia Institute of Himalayan Geology, Dehradun.

Singh, V.K., Singh, S.P. and Saklani, P.S., 1995, Metamorphic and Geodynamic Evolution of Central Crystallines of Garhwal Himalaya, India. N.Jb. Geol. Palaont. Mh. (in Press).

Takagi, H. and Ito, M., 1988, The use of asymmetric pressure shadows in mylonites to determine the sense of shear. J. Struct. Geol., v.10, pp.347-360.

Turner, F.J. and Weiss, L.E., 1963, Structural analysis of Metamorphic Tectonites. McGraw Hill Book Co., New York, 545p.

Valdiya, K.S., 1980, Geology of Kumaun Lesser Himalaya. Wadia Institute of Himalayan Geology, Dehradun, 219p.

Vashi, N.M. and Merh, S.S., 1974, Fold history of the Almora Synform. Him. Geol., v.4, pp.247-258.