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Superimposed folding, finite strain and magnetic lineation in the Mussoorie Syncline, Lesser Himalaya: implications for regional thrusting and the Indian Plate motion

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Abstract : Field, finite strain, and anisotropy of magnetic susceptibility (AMS) studies were performed in the Mussoorie Syncline, Garhwal Lesser Himalaya. Random orientation and low axial ratios of strain ellipses, even in the vicinity of the Main Boundary Thrust (MBT) and the klippe detachment thrust, indicate an overall weak deformation and low magnitude of simple shear along the thrusts. The orientations of the strain ellipses and associated magnetic lineations are controlled by the early and superposed fold hinge lines. The study, in concurrence with most of the earlier field based investigations, highlights the importance of folding and emphasizes its dominant role in the development of stretching mineral lineation. It is inferred that the relationship between stretching mineral lineation and Indian plate motion is one of the several over simplifications incorporated in the theory of plate tectonics.

INTRODUCTION

Strain studies in fold- and –thrust belts are useful in understanding the nature of deformation and structural evolution (Ramsay and Huber, 1987). However, such studies are sparse in the Lesser Himalaya because of lack of suitable strain markers. The available studies (e.g. Gairola and Srivastava, 1983; Gairola and Hatwal, 1991) are mostly confined to cross-sections across major thrusts and regional folds. Hence a three dimensional picture does not emerge in order to build up a structural framework of the deformed region. The present strain analysis was carried out along and across the Main Boundary Thrust (MBT), and Mussoorie Syncline including the Satengal klippe to comprehend the deformation pattern of the area. The study is important because the area is weakly deformed, it has undergone superimposed deformation, lie close to the Main Boundary Thrust and incorporates klippen structures.

GEOLOGY OF THE AREA

A geological map of the area compiled from the earlier work (Auden, 1937; Jain. 1972; Shankar and Ganesan, 1973; Valdiya, 1980), present fieldwork, and satellite data (IRS LISS II/A2 path 28 Row 46 date of coverage 7/5/89) is shown in Figure 1. The geological succession and gross lithology are shown in Table 1.

The Mussoorie Syncline is a doubly plunging syncline, which extends in NW-SE direction. It lies between the Main Boundary Thrust (MBT) in the south and North Almora Thrust (NAT) in the north. It comprises mainly of rocks of the Chandpur, Nagthat, Blaini, Krol, and Tal formations

A small reentrant structure as a result of junction of frontal and oblique ramp structures lies south of the Mussoorie Syncline. The parallelism of the thrust and the geological formations, especially near the oblique ramp, suggests that the MBT was formed as normal fault oblique ramp during the tensional regime in the region (Dubey, 1997). The oblique ramp is a zone, which gradually tapers towards the trailing ramp in the northerly direction and merges with the MBT frontal ramp. The tapering is visible on the imagery, and the junction is marked by intense crushing of rocks.

The rocks have suffered two phases of folding episodes (Fig. 2). The early folds are simultaneous with the development of major thrusts of the area. These folds show a wide variation in geometry from open to isoclinal, occasionally recumbent. The trend of the fold hinge lines varies from NW-SE to E-W with gentle plunge on either side. The superposed folds were formed after locking of the major thrusts (Dubey and Bhat, 1986). These folds are mostly upright or asymmetric with varying trends from NE-SW to N-S and gentle plunge on either side.

East of the oblique ramp, the early fold hinge lines are oriented in the NW-SE direction. When traced in a

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Table 1. Lithotectonic succession of the rocks of the Mussoorie Syncline (modified after Auden, 1937; Jain, 1972).

Formation	Gross Lithology	~Thicknesss in meters
Chandpur Formation	Low grade, grayish- green phyllite	?
Mandhali Formation	Blue, grayish fawn arenaceous limestone, yellowish to white, gritty and slaty quartzite Phyllite.	?
———— Kathu-ki-chail Thrust ————		
Subathu Formation	Ferrugineous purple to dark gray shale with lateritic/ limonitic nodules.	200
~~ unconformity ~~~~~~		
Tal Formation	Orthoquartzite and calc-arenite with pebbly Quartzite, brownish yellow siliceous limestone, Dirty white to yellowish quartzite, greenish- gray shale, dark black phosphoritic and cherty layers	1552
Krol Formation	Dark bluish- gray dolomitic limestone, fine grained carbonaceous limestone, limestone and shale alteration	2070
Blaini Formation	Slate and muddy quartzite, conglomerate, graywacke and limestone	517
Nagthat Formation	Orthoquartzites (locally pebbliferous) with subordinate shale	546
Chandpur Formation	Olive green and gray phyllite with subordinate slate	1782
Mandhali Formation	Blue, grayish -fawn arenaceous limestone, yellowish to white gritty and slaty quartzite. Phyllite.	>345
———— MBT (Krol Thrust) ————		
	Siwalik/Dagshai/Simla slates	

northwesterly direction, the hinge lines gradually curve towards west and acquire a position roughly parallel to the frontal ramp of the MBT. Hence the curvature of the fold hinge lines may be attributed to the interference between folding and thrusting (cf. fig. 9 in Dubey, 1997).

Minor faults are prominent in the southern (near MBT) and central part of the area. The continuity or displacement of foliations across the faults indicates that these faults have formed at different periods. The earliest synsedimentary faults have been observed south of Dewalsari (Fig. 1) in the Blaini Formation. Their characteristic feature is that they displace the bedding but do not displace the early foliation indicating that they were formed during post-rift subsidence and sedimentation (Dubey, 1992). These faults have probably formed during the first available record (which is of at least Late Archaean age) of the rift phase in the Himalaya (Bhat and Le Fort, 1992). The youngest faults displace the foliation formed during the superposed folding.

A number of lineaments and strike slip faults were deduced from the imagery and incorporated in the structural map (Fig. 2).

The area has the following advantages.

(i) A large number of traverses in different directions are possible.

(ii) Continuous outcrops of Nagthat and Tal quartzites are available for strain studies.

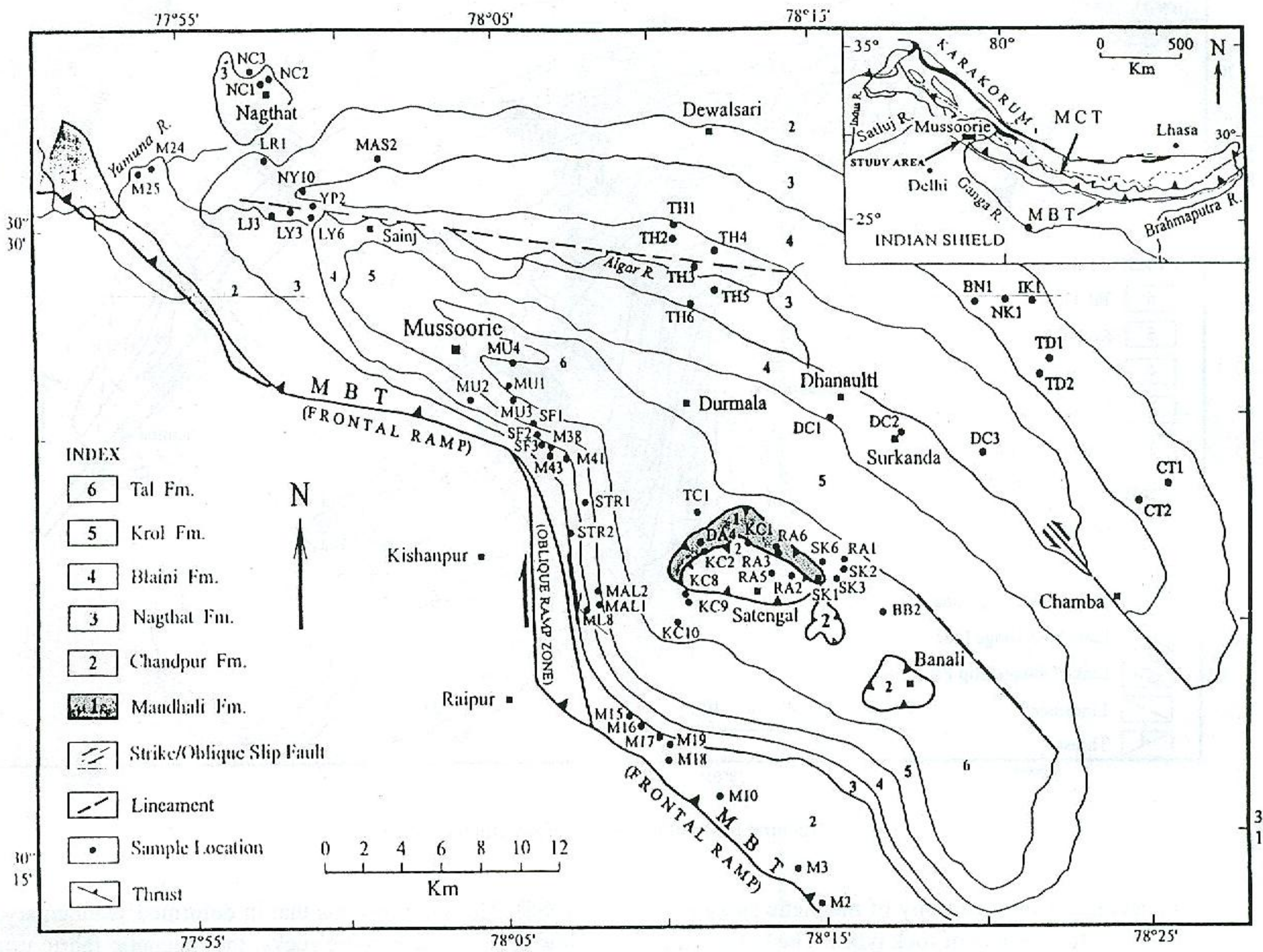

Fig. 1. Geological map of the Mussoorie Syncline, Lesser Himalaya (modified after Auden, 1937; Valdiya, 1980) showing location of the samples.

(iii) Klippen structures exist in the core of the Mussoorie Syncline.

(iv) Easy accessibility.

METHOD

The following methods were used to determine the shape of the strain ellipses.

(i) Centre to centre technique (Fry, 1979)

(ii) Surfor Wheel method (Panozzo, 1987), and

(iii) Anisotropy of magnetic susceptibility (Tarling and Hrouda, 1993).

The first two methods require the grains of the deformed rocks to be closely packed and can be applied to compact quartzites of the Lesser Himalayan formations. Eighty oriented samples of quartzite rocks from the Nagthat and Tal formations (Table 1) (Fig. 1) were used for strain determination by the Fry Technique. In addition, 72 out of these samples were analyzed by using the Inverse Surfor Wheel Technique. Thin sections were made along two orthogonal planes parallel to the strike and dip, since the rock does not possess prominent planar or linear fabrics. In each section (XZ, YZ) of individual samples, 75 to 150 markers were used for the measurements. The microscopic study of deformed quartz grains does not show elliptical shape of the individual grains. A feeble undulatory extinction of quartz grains is the only conventional microscopic evidence of deformation.

It is to be noted that orientations of the principal strain axes can not be determined in absence of deformed planar and linear structures in weakly deformed areas. Hence in order to substantiate the results, strain analysis was also carried out using the anisotropy of magnetic susceptibility (AMS) method.

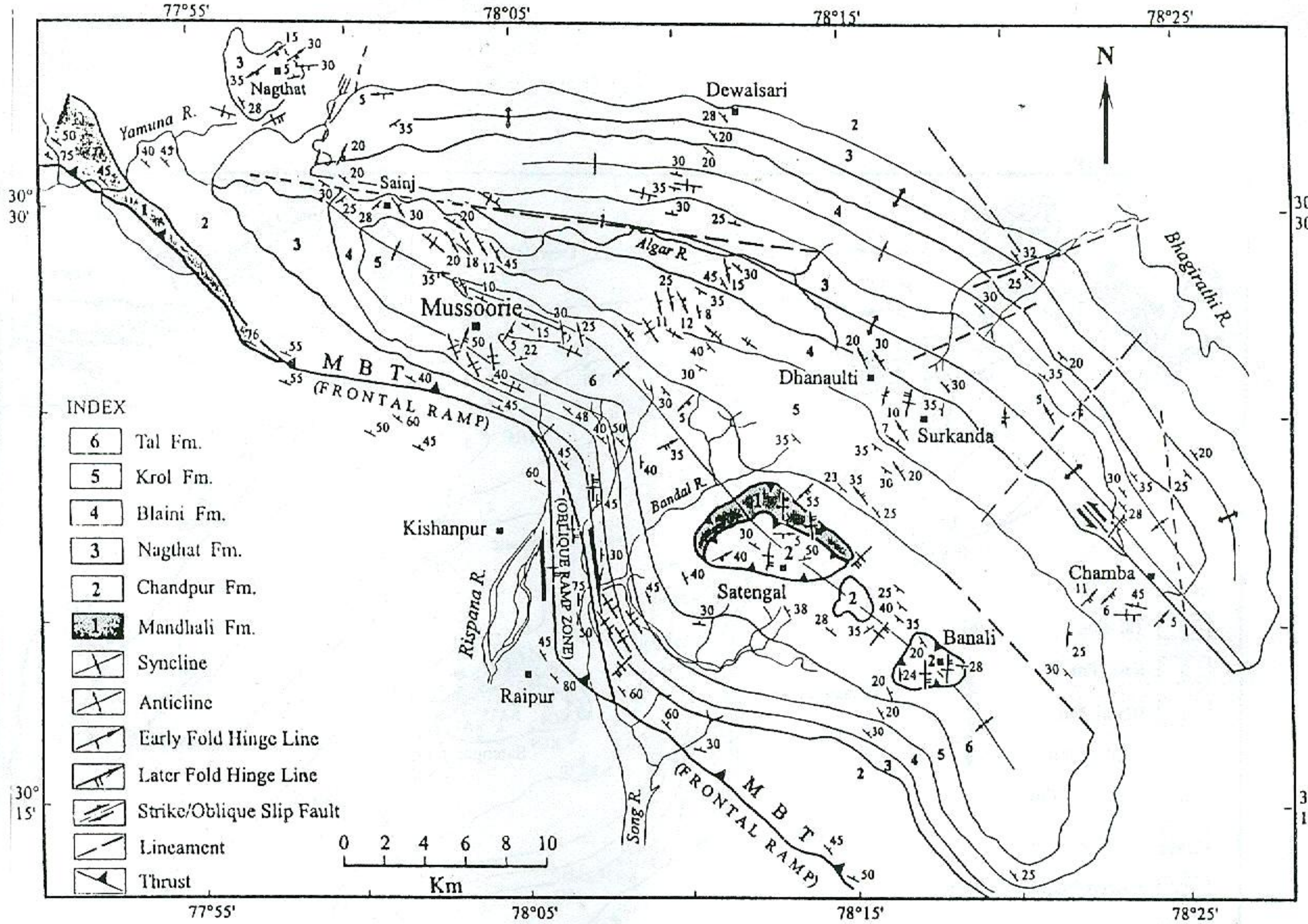

Fig. 2. Structural map of the Mussoorie Syncline, Lesser Himalaya.

The technique of anisotropy of magnetic susceptibility can be applied to a variety of rock types. The basic principle involves determination of the magnetization strength that a sample acquires when a known magnetic field is applied along different directions. The difference in the magnetic strength can be interpreted in terms of net shape of the grains and degree of their crystalline alignment. The technique does not require specific strain markers in the rock. A greater speed and precision of the method help in its application on a much wider range of geological problems than most of the conventional methods (e.g. Kligfield *et al.*, 1981; Rathore and Henry, 1982; Hrouda, 1991; Rochette *et al.*, 1992). The method can determine strain even where the deformation is <20%. The strain magnitude and direction can be determined in the form of susceptibility ellipsoids with their orientations. The authenticity of the AMS and its precision over the conventional methods have been tested with the help of field investigations (Borradaile and Alford, 1987, 1988), laboratory models (Owens, 1974; Hrouda, 1987; Rochette, 1988; Henry and Hrouda, 1989; Hrouda and Lanza, 1989), and empirical models (Henry, 1982; Hrouda, 1982; Borradaile, 1988; Rathore, 1988). The study reveals that in deformed sedimentary and low grade metamorphic rocks, the magnetic fabric usually represents a superposition of the deformation magnetic fabric on the initial sedimentary fabric (Hrouda, 1979; Borradaile and Tarling, 1981, 1984).

The present studies were performed on the Magnetic Susceptibility Meter KLY-2 made by Geofyzika, Brno, Czechoslovakia. The Susceptibilitybridge (KAPPABRIDGE KLY-2) works on autobalancing principle and a special circuit is used for automatic zeroing and compensation of the thermal drift of the measuring coil.

Initial studies were carried out in the magnetic susceptibility meter MS-2, made by Bartington Instruments, U. K. The instrument uses a sharply tuned oscillator circuit to detect the change in frequency of AC waveform resulting from insertion of a sample in the field. The change in frequency of the alternating current is directly proportional to the magnetic susceptibility of the sample. A peak alternating strength of 3 X 10E4 tesla (3 oersted) is applied in the discriminator oscillator circuit with a provision of low (0.465 kHz) and high (4.65 kHz) frequency. This facilitates calculation of the frequency dependency of susceptibility, an important indicator for magnetic granulometring (Collinson, 1983).

Field sampling and laboratory preparation

Oriented samples ~15cm X 10cm X 5cm were collected from 48 sites (Fig.1) and later drilled in laboratory. The structural and directional information were transferred on each core and cylindrical specimens of 2.5 cm diameter and 2.2 cm length were prepared.

The lithology of the study area varies from argillites (slate, phyllite) to metaquartzites. Therefore more than two specimens of representative sites of different lithology were selected for the rock magnetic studies (IRM and SIRM). A stepwise IRM field was applied in 16 steps by an impulse magnetizer (IM-10-30, ASC, USA) to generate the field up to 2600mT. The samples were then demagnetized by thermal demagnetizer at incremental steps of 150, 250, 350, 400, 500, 550, 600, 700, 750°C.

Measurement of the AMS

The cores were first washed by dilute sulfuric acid to remove any machine contamination. These were subjected to a detailed thermal and alternating field demagnetization using Schonstifedt's DSM-2, TSD-2 Molspin's AFD to study the intensity decay and change in magnetic susceptibility with temperature. The initial measurements of magnetic susceptibility were then conducted in a low field using a Magnetic Susceptibility –MS2 Bartington. The detailed AMS studies were carried out using KLY-2. Each sample was measured in 15 directions with reference to the fiducial north mark (Jelinek, 1977). The magnitude of the low field susceptibility and the field orientation data were then used to derive the magnitude and orientation of the AMS ellipsoid. The anisotropy of magnetic susceptibility analysis was carried out for 152 samples and computed by the ANISO 11 Program (Jelinek, 1977). Statistical mean values for corresponding sites were calculated using Fischer (1953) statistics for directional data.

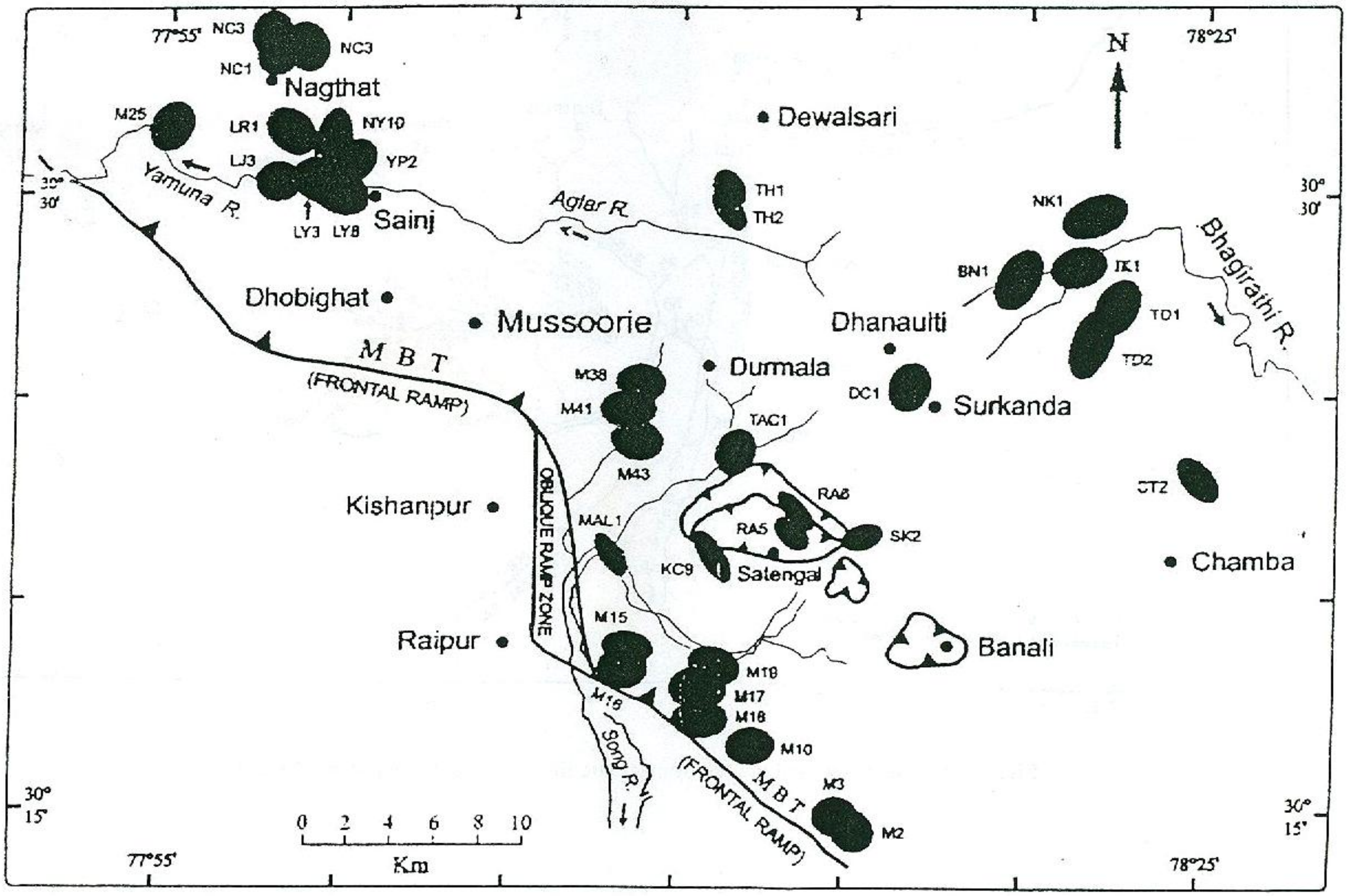

Fig. 3. The distribution of strain ellipses (XZ plane) in the Mussoorie Syncline. Projection horizontal.

The anisotropy in the study area is mainly controlled by heavy ore minerals such as magnetite, pyrrhotite and hematite in the more sandy rocks and by paramagnetic minerals such as chlorite and biotite in the slaty- phyllitic rocks (Jayangondaperumal, 1998).

RESULTS OF STRAIN ANALYSIS

The shapes and orientations of the strain ellipses derived by the conventional methods are shown in Figure 3. The axial ratios indicate a weak deformation even in the vicinity of the MBT and the klippen detachment thrust. The result is significant for Himalayan tectonics because the MBT is regarded as one of the fundamental thrusts of the Himalaya and the klippen detachment thrust is considered to have undergone a displacement of about 80km. Apart from the weak axial ratios, the longer axes of the ellipses have an oblique relationship with the thrusts. In the NW of the area (i.e. around Nagthat village) the orientation pattern appears to be governed by the early and superposed fold hinge lines and their interference effects (cf. Dubey and Paul, 1993). In the southern part, there are no planar or linear structures associated with the MBT. The bedding, bedding cleavage and the ellipses are oblique to the trend of the MBT. In the NE, the ellipses are oriented in the NE-SW direction parallel to the hinge lines of the superposed folds. In the central part of the area, the trend of the Mussoorie syncline shows a prominent curvature as a result of interference between simultaneously developing folds and oblique thrust ramp of the MBT (cf. fig. 9 in Dubey, 1997). Following the trend of the syncline, the ellipses are also arranged oblique to the oblique ramp and parallel to the trace of the axial surface. East of the trailing frontal ramp of the MBT, the ellipses are arranged in E-W direction parallel to the trend of the frontal ramp and hinge lines of the early folds.

Similar observations were made in the orientation pattern of the magnetic lineations (i.e. K_{max} axes) (Fig. 4). The

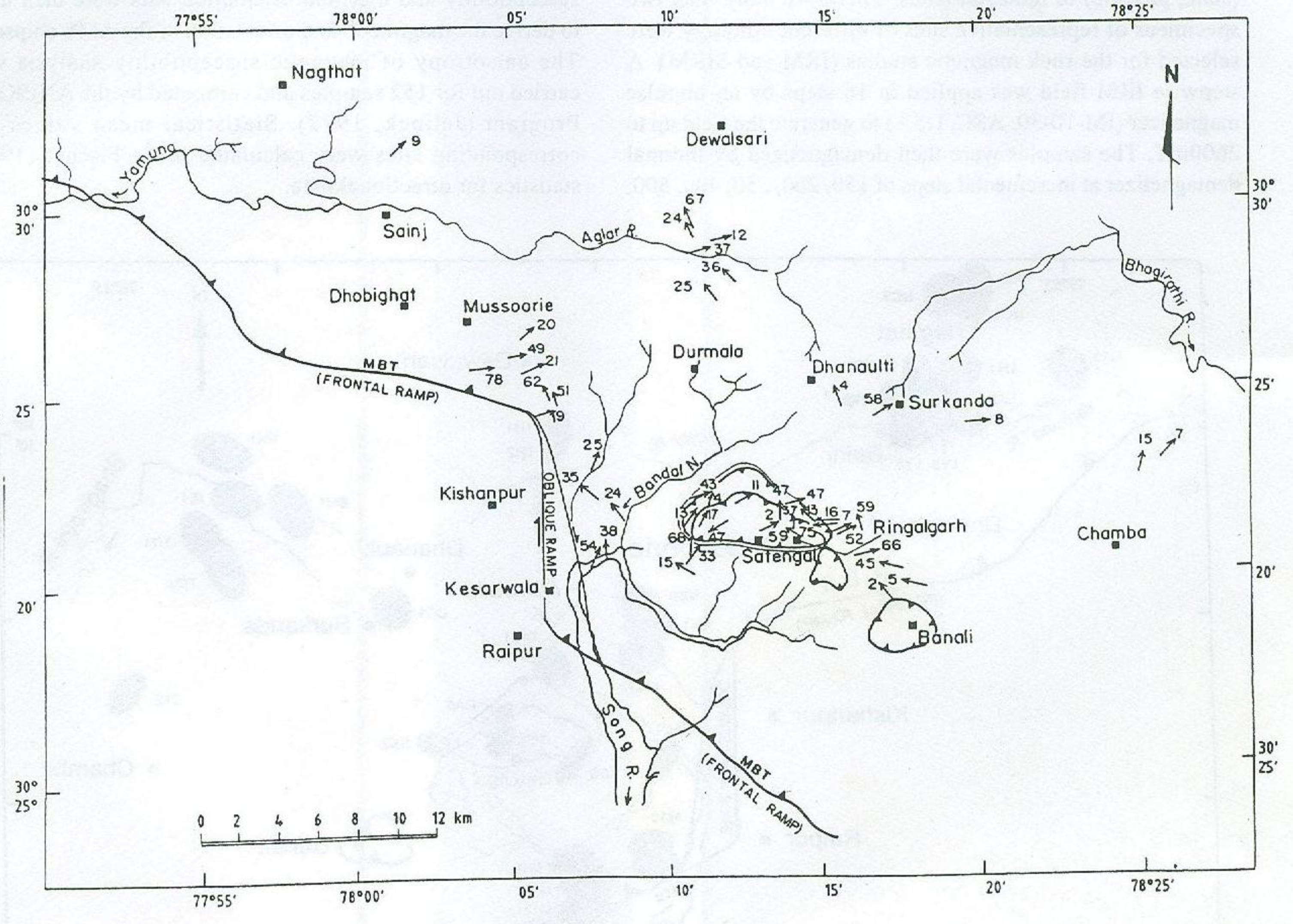

Fig. 4. The orientation and plunge of magnetic lineations in the Mussoorie Syncline.

lineations show random orientation and variable plunge from 2^0 to 78^0. The lineations are oblique to the trailing frontal ramp and the klippen detachment thrust.

In view of these observations it is concluded that the finite strain and magnetic lineation are controlled by the early and superposed folding and not by thrusting.

DISCUSSION

Since folding and thrusting are the most fundamental concepts of Structural Geology, their aspects have been studied in great details. The combined effects of these processes are evident in various orogenies. However, individual effects of folding and thrusting are assessed with personal bias. Some of the structural geologists provide a greater favor to importance of folding where as the others recognize thrusting as the dominating process. The last two decades have seen a tremendous rise in understanding of thrust tectonics and widening of its scope while folding was considered a lesser subsidiary process (e.g. Shackleton and Ries, 1984). As a result, minor folds were largely ignored in restoration of deformed sections, and formation of prominent lineations and foliations was attributed to thrusting. In Himalayan Geology, Brunel (1986) provided a good example of bias towards thrusting because a large number of earlier papers, highlighting the importance of folding, were either ignored or misquoted in order to create an impression that the mineral lineation is normal to the trend of the Main Central Thrust (MCT). A survey of the literature (some of the prominent ones are quoted below) clearly reveals that the concept of normal relationship between thrusting and stretching mineral lineation is not based on ground truth.

In the Himachal Himalaya strong development of mineral lineation "oblique to the generally accepted northeast to southwest overthrusting" was reported by Powell and Conaghan (fig.2, 1973). The fairly constant trend of the lineation is normal to the fold "crestal trace". The mineral lineation was interpreted as formed during movement along the axial surface of the isoclinal folds at late stage of the first deformation out of the total three deformations. Thakur and Tandon (1976) have reported the trend of the mineral and pebble lineations in the Chamba region of the Himachal Himalaya as nearly perpendicular to the regional fold axis. The lineation was attributed to folding and it was mentioned critically that "the simple shear as the sole mechanism can not be accounted for the formation of linear structure in the area". Later Singh and Thakur (1989) have attributed the lineation to have formed as a result of stretching of the fold limbs during late stages of folding. In the adjoining region of Dalhousie, the mineral lineation is parallel to the axis of the greatest extension of the strain ellipsoid and occurs on the axial plane foliation (Thakur, 1975). It was categorically stated (Thakur, 1975) that, "the lineation, showing preferred growth of minerals was not formed as a result of the thrust movement, and it is also incorrect to deduce the direction of thrust movement using mineral lineation".

The structural map of the Kulu valley (Thoni, 1977) shows a widely scattered lineation pattern without any preferred orientation. In the Simla Himachal Himalaya, the trend of the mineral lineation is parallel to the hinge lines of the early folds (mostly E-W), not normal to the Main Central Thrust (MCT).

Further east in the Garhwal Himalaya, two lineations that are normal and parallel to the fold axes were described by Gaur *et al.* (1977). None of these two is related to thrusting.

The lineation map of the Kumaun Himalaya (fig. 4a in Vashi and Merh, 1974) clearly shows that the lineations are oriented at angles of $40\text{-}60^0$ to the thrusts (North Almora Thrust and South Almora Thrust), and the orientations are independent of the thrust curvature on the map. Based on petrofabric analysis, Soman and Powar (1974) have correlated the lineation with folding and not with the regional thrusting. In a later publication (Yeddekar and Powar, 1986), two mineral lineations parallel to the strike and dip of the beds were reported from the North Almora Thrust Zone of the Kumaun Lesser Himalaya. Karanth and Shah (1977) have also described three lineation patterns in the granitic rocks of the Kumaun Himalaya as a result of three folding movements.

In the Nepal Himalaya, the mineral lineation varies in trend from NW-SE through N-S to NE-SW and even E-W in the central part with plunge on either side (Colchen *et al.*, 1980).

In the structural map of the Bhutan Himalaya (Gansser, 1983, p. 144-145), the fold axes and the major lineations have been assigned the same symbol indicating their close association. The lineation in the adjoining region of Sikkim Himalaya is related to flattening of the F_2 folds during late stages of deformation (Sinha Roy, 1977). In the Darjeeling Himalaya, the mineral lineation is associated with the first phase of folding (Sen, 1973) trending mostly in the E-W and the NE-SW directions. Similarly, Lahiri (1973) has also shown a variable trend of the lineation in the NE-SW directions. For the variable trend of the mineral lineation in the Arunachal Himalaya (formerly known as NEFA), Verma and Tandon (1976) have categorically stated that, "the variable orientation of these structures is a rule rather than an exception".

The above discussion clearly reveals that the mineral lineation throughout the Himalaya is related to folding and is largely unaffected by thrusting. Rare occurrence of sheath folds also points towards the absence of large simple shear along the prominent Himalayan thrusts.

Acceptance of the fact that folding is the dominating factor has the following important implications for Himalayan tectonics.

(i) The deformed sections can not be restored by ignoring the layer parallel shortening and minor folds.

(ii) Lubricating horizons (e.g., salt, gypsum, graphite etc) at the thrust surfaces are rare in the Himalaya hence the deformation should have been accommodated in a wider zone. Absence of such zones and small strains in the vicinity of the thrusts indicate smaller amount of horizontal translation than what was previously assumed.

(iii) The plate movement can not be predicted by lineation pattern.

CONCLUSIONS

Partly developed planar and linear structures in a weakly deformed area possess an inherent limitation in revealing the orientation of the principal strain axes. Hence the AMS method should be regarded as superior over the conventional methods because it can provide the orientations of the principal axes. In addition, the method is susceptible to small increments of deformation so that it can reveal the variations in the magnitude and intensity of the early and superposed deformations even where the deformations are weak.

The magnetic lineation in the study area is controlled by folding and not by thrusting. This may be because of greater lateral shortening and smaller simple shear along the thrusts. The conclusion appears to be valid for the entire Himalaya and therefore it is concluded that the stretching mineral lineation from the Himalaya does not reflect the direction of the Indian Plate movement. The earlier attempts to establish a relationship between lineation and plate motion (Shackleton and Ries, 1984; Brunel, 1986) are based on oversimplification and are not justified.

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References

AUDEN, J.B., 1937. Structure of the Himalaya in Garhwal. *Rec. Geol. Surv. India*, 71 (4), 407-433.

BHAT M.I. AND LE FORT, P., 1992. Sm-Nd Age and Petrogenesis of Rampur metavolcanic rocks, NW Himalayas: Late Archaean relics in the Himalayan belt. *Precambrian Res.*, **56**, 191-210.

BORRADAILE, G.J., 1988. Magnetic susceptibility, petrofabrics and strain. *Tectonophysics*, **156**, 1-20.

BORRADAILE, G.J. AND ALFORD, C., 1987. Relationship between magnetic susceptibility and strain in laboratory experiments. *Tectonophysics*, **133**, 121-135.

BORRADAILE, G.J. AND ALFORD C., 1988. Experimental shear zones and magnetic fabrics. *Jour. Structural Geol.*, **10**, 895-904.

BORRADAILE, G.J. AND TARLING, D.H., 1981. The influence of deformation mechanism in magnetic fabrics of weakly deformed rocks. *Tectonophysics*, **77**, 151-168.

BORRADAILE G.J. AND TARLING, D.H., 1984. Strain partitioning and magnetic fabrics in particulate flow. *Can. Jour. Earth Sci.*, **21**, 694-697.

BRUNEL, M., 1986. Ductile thrusting in the Himalayas: shear zone criteria and stretching lineations. *Tectonics*, **5**, 247-265.

COLCHEN, M., LE FORT, P. AND PECHER, A., 1980. Geological map. Annapurna-Manaslu-Ganesh-Himalaya de Nepal, Greco Himalaya-Karakorum. C.N.R.S. 130 012. *Cent. Natl. de la Rech. Sci., Meudon-Bellevue.*

COLLINSON, D.W., 1983. *Methods in Rock Magnetism and Paleomagnetism.* Chapman & Hall, 503 pp.

DUBEY, A.K., 1992. Fault bifurcation: evidence for reversal of fault displacement. *Jour. Him. Geol.*, **3**, 1-5.

DUBEY, A.K., 1997. Simultaneous development of noncylindrical folds, frontal ramps, and transfer faults in a compressional regime: Experimental investigations of Himalayan examples. *Tectonics*, **16**, 336-346.

DUBEY, A.K. AND BHAT, M.I., 1986. The role of reactivation of pre-rift basement listric faults in the structural evolution of the Himalaya: an experimental study. *Current Trends in Geology*, **9**, 265-290.

DUBEY, A.K. AND PAUL, S. K., 1993. Map patterns produced by thrusting and subsequent superposed folding: model experiments and example from the NE Kumaun Himalayas. *Eclogae geol. Helv.*, **86**, 839-852.

FISHER, R.A., 1953. Dispersion on a sphere. *Proc. Royal Soc. London*, **A217**, 295-305.

FRY, N., 1979. Random point distributions and strain measurement in rocks. *Tectonophysics*, **60**, 89-105.

GANSSER, A., 1983. Geology of the Bhutan Himalaya, *Birhauser Denks. Schweiz. Nat. Gessells.*, **96**, 181.

GAIROLA, V.K. AND SRIVASTAVA, H.B., 1983. Strain analysis in the conglomerates deformed due to shearing from Garhwal Group rocks of Marora, district Pauri Garhwal, U.P. *In:* SAKLANI, P.S. (ed.), *Himalayan shears*, Today & Tomorrow, New Delhi, 67-76.

GAIROLA, V.K. AND HATWAL, D., 1991. Strain analysis of deformed pebbly horizon from the Garhwal Group, Pharsaun, District, U.P. *Jour. Geol. Soc. India*. **37**, 457-468.

GAUR, G.C.S., DAVE, V.K.S. AND MITHAL, R.S., 1977. Stratigraphy and tectonics of the carbonate suite of Chamoli, Garhwal Himalaya. *Him. Geol.*, **7**, 416-455.

HENRY, B., 1982. Relations entre l'anistoropie de susceptibilite des mineraux ferrimagnetiques et la deformation finie des pelites permiennes des Alpes-Maritimes. *C.R. Acad. Sci. Paris, Ser. II*, **295**, 273-276.

HENRY, B. AND HROUDA, F., 1989. Analyse de deformation finie des roches par determination de leur anistoropie de susceptibilite magnetiques. *C.R. Acad. Sci. Paris, Ser. II*, **308**, 731-737.

HROUDA, F., 1979. The strain interpretation of magnetic anisotropy in rocks of the Nizky Jesenik Mountains (Czechoslovakia). *Sb. Geol. Ved. uz. Geofyz.*, **16**, 27-62.

HROUDA, F., 1982. Magnetic anisotropy of rocks and its application in geology and geophysics. *Geophys. Surveys*, **5**, 37-82.

HROUDA, F., 1987. Mathematical model relationship between the paramagnetic anisotropy and strain in slates. *Tectonophysics*, **142**, 323-327.

HROUDA, F., 1991. Models of magnetic anisotropy variations in sedimentary thrust sheets. *Tectonophysics*, **185**, 203-210.

HROUDA, F. AND LANZA, R., 1989. Magnetic fabric in the Biella and Traversella stocks (Periadriatic Line): implications for the emplacement mode. *Phys. Earth Planet. Ints.*, **56**, 337-348.

JAIN, A. K., 1972. Structure of Bidhalna-Pharat windows and Garhwal Thrust Unit, Garhwal, U.P. *Him. Geol.*, **2**, 188-205.

JAYANGONDAPERUMAL, R., 1998. *Structural evolution of Mussoorie Syncline, Lesser Himalaya*, U.P., Ph. D. Thesis (unpublished), H.N.B. Garhwal University, Srinagar (Garhwal), 175pp.

JELINEK, V., 1977. The statistical theory of measuring anisotropy of magnetic susceptibility of rocks and its application. *Brno, Geofyzika*, 1-88.

KARANTH, R.V. AND SHAH, A.N., 1977. An interpretation of the origin and tectonic setting of the granitic rocks of Almora in Kumaun Himalaya. *Him. Geol.*, 7, 398-415.

KLIGFIELD, R., OWENS, W.H. AND LOWRIE, W., 1981. Magnetic susceptibility anisotropy, strain and progressive deformation in Permian sediments from the Maritime Alps (France). *Earth Planet. Sci. Letters*, **55**, 181-189.

LAHIRI, S., 1973. Some observations on structure and metamorphism of the rocks of Kurseong-Tindharia region, Darjeeling district, West Bengal. *Him. Geol.*, **3**, 365-371.

OWENS, W. H., 1974. Mathematical model studies on factors affecting the magnetic anisotropy of deformed rocks. *Tectonophysics*, **24**, 115-131.

PANOZZO, R., 1987. Two dimensional strain determination by the inverse surfor wheel. *Jour. Structural Geol.*, **I**, 115-119.

POWELL, C.MC.A. AND CONAGHAN, P.J., 1973. Polyphase deformation in phanerozoic rocks of the Central Himalayas gneiss, Northwest India. *Jour. Geology*, **81**, 127-143.

RAMSAY, J.G. AND HUBER, M.I., 1987. *The Techniques of Modern Structural Geology.* **volume 2** : Folds and Fractures, Academic Press, 309-700.

RATHORE, J.S., 1988. Strain to anisotropy correlation corrected for the Digico calibration error. *Phys. Earth Planet. Ints.*, **51**, 355-360.

RATHORE, J.S. AND HENRY, B. 1982. Comparison of strain and magnetic fabrics in Dalradian rocks from the south-west Highlands of Scotland. *Jour. Structural Geol.* **4**, 373-384.

ROCHETTE, P. 1988. Inverse magnetic fabric in carbonate bearing rocks. *Earth Planet. Sci. Lett.*, **90**, 229-237.

ROCHETTE, P., JACKSON. M. J. AND AUBOURG, C., 1992. Rock magnetism and the interpretation of anisotropy of magnetic susceptibility. *Rev. Geophys.* **30**, 209-226.

SEN, A., 1973. Structural features of the rocks in Sukhiapolebri Bijanbari region, Darjeeling district, West Bengal. *Him. Geol.*, **3**, 356-364.

SHACKLETON, R.M. AND RIES, A., 1984. The relation between regionally consistant stretching lineations and plate motions. *Jour. Structural Geol.* **6**, 111-117.

SHANKER, R. AND GANESAN, T.M., 1973. A note on the Garhwal Nappe. *Him. Geol.*, **3**, 72-82.

SINGH K. AND THAKUR V.C., 1989. Strain analysis in a part of the Chamba Syncline using deformed quartz pebbles in Chamba region of North-western Himalaya. *Jour. Geol. Soc. India*, **33**, 140-149.

SINHA ROY, S., 1977. Relation between coplanar folds of variable orientation, stretching lineation and thrust in the Daling and associated rocks from the inner tectonic belt of Sikkim Himalayas. *Jour. Geol. Soc. India*, **18**, 153-169.

SOMAN, G.R. AND POWAR, K.B., 1974. Genesis of small scale folds in the metasediments of Manila area, Almora District, Uttar Pradesh. *Him. Geol.*, **4**, 619-629.

TARLING, D.H. AND HROUDA, F., 1993. *The Magnetic Anisotropy of Rocks*. Chapman & Hall, 217 pp.

THAKUR, V.C., 1975. Some genetic significance of the development of foliation and lineation in the Dalhousie granite body and surrounding metasedimentary formations of Chamba area of Himachal Pradesh. *In:* VERMA, P. K. *et al.* (eds.), Recent Researches in Geology, Hindustan Publishing Corporation, 2, 41-52.

THAKUR, V.C. AND TANDON, S. K., 1976. Significance of pebble and mineral lineation in the Chamba Syncline of Punjab Himalaya, H. P., India. *Geol. Mag.*, **113**, 141-149.

THONI, M., 1977. Geology, structural evolution and metamorphic zoning in the Kulu valley (Himachal Himalayas, India) with special reference to the reverse metamorphism. *Mitt. Gesch. Bergbaustud. Ostern.*, **24**, 125-187.

VALDIYA, K.S., 1980. *Geology of the Kumaun Lesser Himalaya.* Wadia Institute of Himalayan Geology, Dehra Dun, 291pp.

VASHI, N.M. AND MERH, S.S., 1974. Fold history of the Almora Synform. *Him. Geol.*, 4, 246-258.

VERMA, P.K. AND TANDON, S.K., 1976. Geologic observations in a part of the Kameng district, A.P. (Nefa). *Him. Geol.*, **6**, 259-286.

YEDEKAR, D.B. AND POWAR, K.B., 1986.A study of the North Almora Thrust Zone in the Chaukhutia – Dwarhat – Someshwar area, Kumaun Lesser Himalaya. *Current Trends in Geology*, **9**, 41-69.