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Mesostructures and deformational history of the Central Crystallines: an example from Garhwal Himalaya, India

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ABSTRACT

Structural analysis reveals that the Central Crystallines in the Garhwal region were subjected to four phases of deformations (D_1 to D_4). The D_1 deformational phase is highly obliterated and usually found as F_1 intrafolial (rootless) tight isoclinal folds in migmatites and gneisses. The D_2 deformational phase produced strong pervasive S_2 schistosity and asymmetric and open fold (F_2) plunging 20-30° towards ENE-WSW. The L_2 lineation plunge 5-10° towards east-west is well developed in medium grade metamorphic rocks. The D_3 deformations were responsible for F_3 folds reflected in large scale anticlinal and synclinal, overturned and recumbent folds, which have 10-40° plunges towards NW. The late D_3 deformational stresses were responsible for shearing along the middle limbs of F_3 folds and they ultimately initiated thrusting. The NNE-SSW plunging mineral or stretching lineation (L_3), S_3 crenulation cleavage and S-C fabrics were developed during the dominant ductile shearing related to the late D_3 deformation. The D_4 phase characterised by brittle-ductile deformation (minor kinks, puckers, transverse/transcurrent faults, and S-C' fabrics) and extensive cataclasis along thrust- and fault-zones reflects the last episode of deformation. The structural and geochronological data indicate that D_1 and D_2 deformation episodes may be related to the Precambrian time while D_3 and D_4 are exclusively of the Tertiary age.

INTRODUCTION

A major part of the Lesser and Higher Himalaya represents a reactivated northern edge of the Precambrian Indian shield (Valdiya, 1980 and Gansser, 1993). The initial collision between India and Eurasia took place about 50 Ma ago marked by the formation of the Indus Tsangpo Suture Zone. A 1500-2000 km crustal shortening occurred during the Tertiary time within the Indian plate. Due to this, the Indian crust was affected by extensive deformation with imbrications at different levels marked by the Tethys Thrust, Main Central Thrust, Main Boundary Thrust and Main Frontal Thrust.

The Main Central Thrust (MCT) is a tectonic discontinuity between the Central Crystalline rocks of the Higher Himalaya and low grade metasedimentary rocks of the Lesser Himalaya (Heim and Gansser, 1939). The Siwaliks were deposited as the fluvial molasse sediments since the Miocene. They are characterised by N-S transverse faults and longitudinal thrusts. The Tethys rocks were deposited on the northern passive margin of India from Late Precambrian to Eocene times, in which NW or SE plunging fold and N-S transverse faults were developed during the Tertiary deformations (Fuchs, 1992 and Gansser, 1993). But the Lesser Himalaya comprising the Precambrian to Paleozoic sedimentary cover of the Indian basement with intrusions of the Early Paleozoic granitoids and Higher Himalaya comprising Crystallines and intrusions of multiple granitoids have different deformational history.

The investigated area (Fig. 1) is a part of the Higher Himalayan Crystallines, which is bound by low grade sedimentary rocks of the Garhwal Group in south and Gangotri leucogranite with the Tethys sediments in north. The Central Crystalline rocks containing small-scale structures of different phases are well exposed in the Bhagirathi valley of the Garhwal Himalaya. The reactivated earlier structures of the Precambrian Lesser and Higher

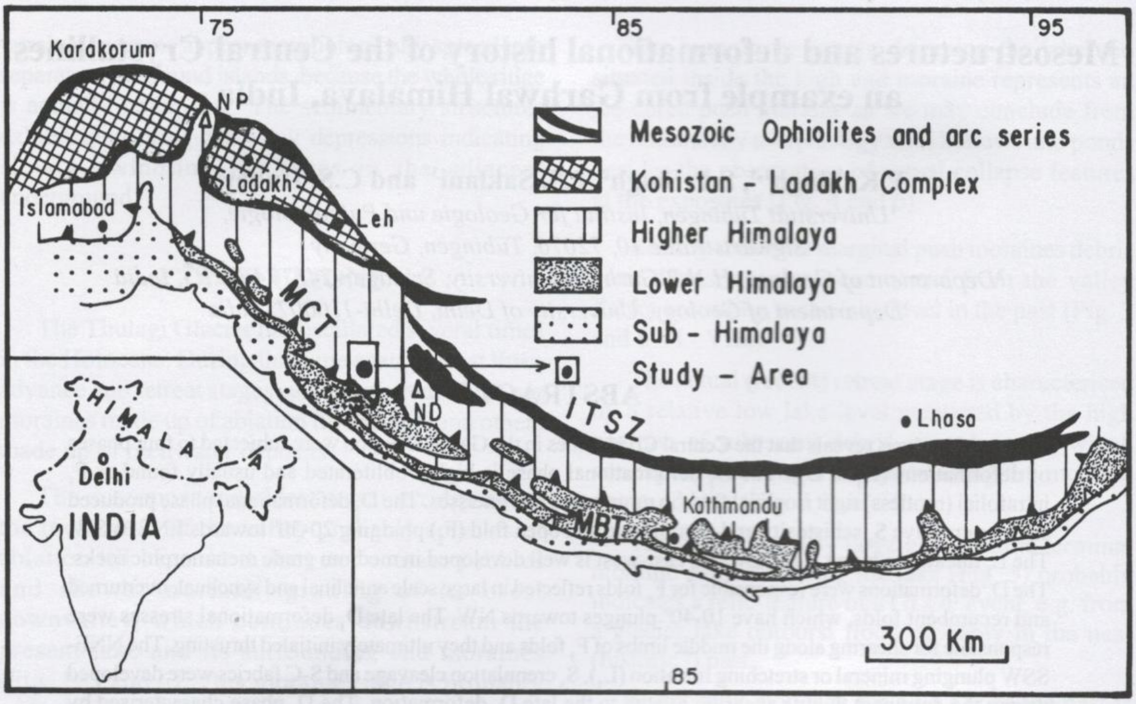

Fig. 1: General tectonic map of the Himalaya after Gansser (1964). Legend: NP = Nanga Parbat, ND = Nanda Devi, ITSZ = Indus Tsangpo Suture Zone, MCT = Main Central Thrust, and MBT = Main Boundary Thrust.

Himalayan rocks are important because they are overprinted by multiple phases of the Tertiary deformations. The main objective of this paper is to discuss the different episodes of deformation with the help of meso- and micro-structures.

GEOLOGY OF THE AREA

The investigated Central Crystalline zone of the Garhwal Himalaya comprises granite-gneisses, migmatites and sequences of regional metamorphics (Fig. 2). It is divided lithologically into three groups from north to south, i.e. the Vaikrita, Munsiari (=Jutogh) and Bhatwari (=Budhakedar/Chail/ Ramgarh) groups (Valdiya, 1980). Geologically, the area is delineated by MCT-I (Vaikrita Thrust), MCT-II (Munsiari =Jutogh Thrust) and MCT-III (Bhatwari =Budhakedar =Ramgarh Thrust) (Fig. 2 and 3). The tectonic setting of the area is given in Table 1. The MCT-I brought medium to high grade biotite-granite and gneiss, augen gneiss, sillimanite-gneiss, kyanite-garnet schist, biotite schist and quartzite (Vaikrita Group) to rest over the porphyroblastic gneiss, augen-gneiss, calcsilicates, and sheared phyllonite of the Jutogh Group (Fig. 3). This lithotectonic unit along the MCT-II is superposed over the granite-gneiss and migmatite and associated gneisses and schists (Bhatwari/Chail Group; Budhakedar and Pinswar Formation of Singh, 1993). The Bhatwari/ Chail Group (MCT-III zone) is tectonically separated towards south by the massive white quartzite of the Garhwal Group (Fig. 3). This tectonic boundary has been designated as MCT-III. The crystalline rocks also contain fine to thick mylonites, retrograded quartzofeldspathic schist and superposed metamorphic rocks at several places (Singh et al., 1996).

The Main Central Thrust (MCT) has been described as the MCT-I and -II by Arita et al. (1982) in Nepal while in the opinion of Valdiya (1980), the real MCT is the Vaikrita Thrust and the Munsiari and Chail thrusts are developed parallel to the real MCT. However, the MCT can be a complicated zone of imbrication (Gansser, 1993). This has made the numeration of the MCT to be very controversial. In the opinion of the authors, the thrusting processes started from the north east and the earliest thrusting took place along the Indus Suture Zone.

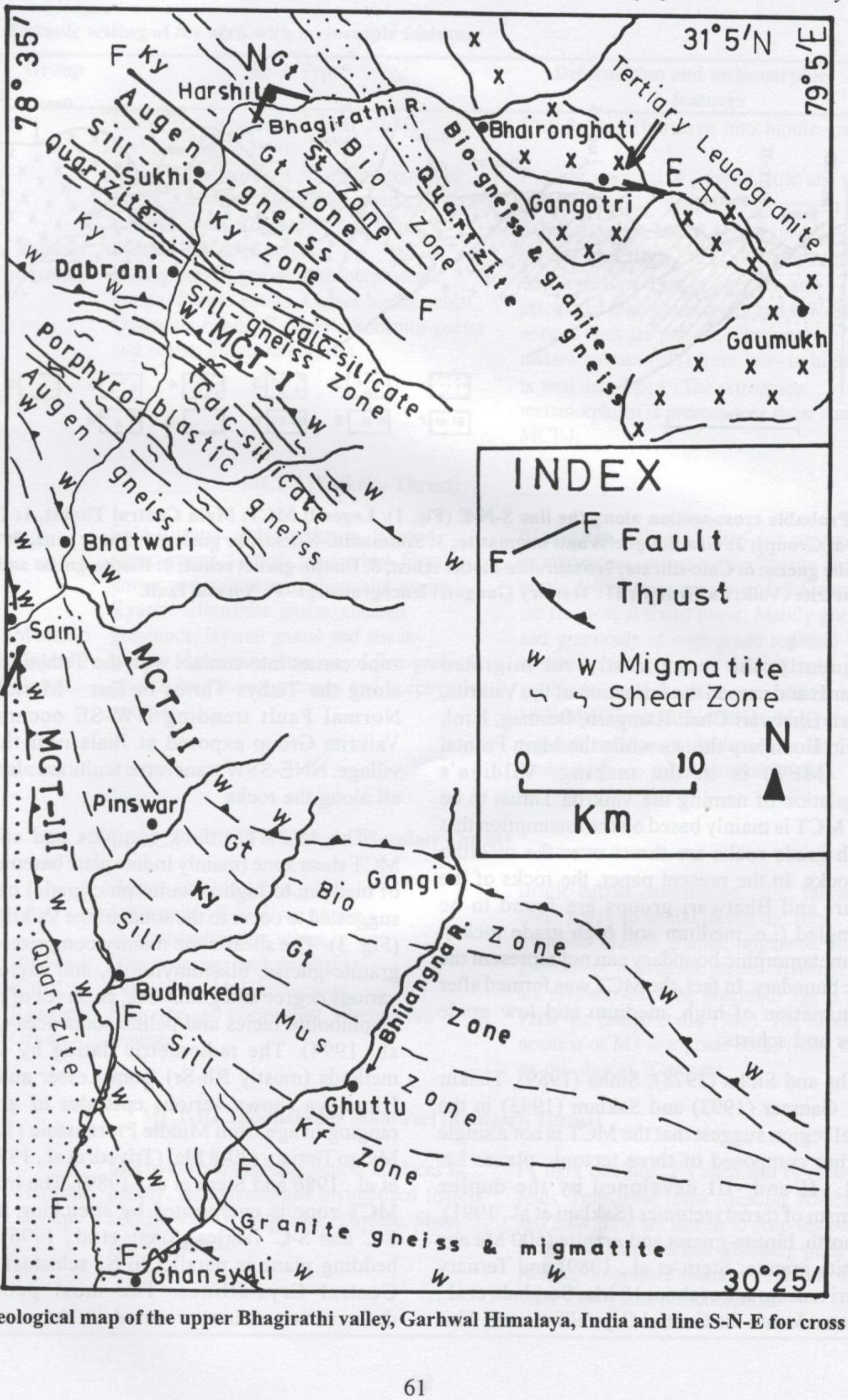

Fig. 2: Geological map of the upper Bhagirathi valley, Garhwal Himalaya, India and line S-N-E for cross section in Fig. 3.

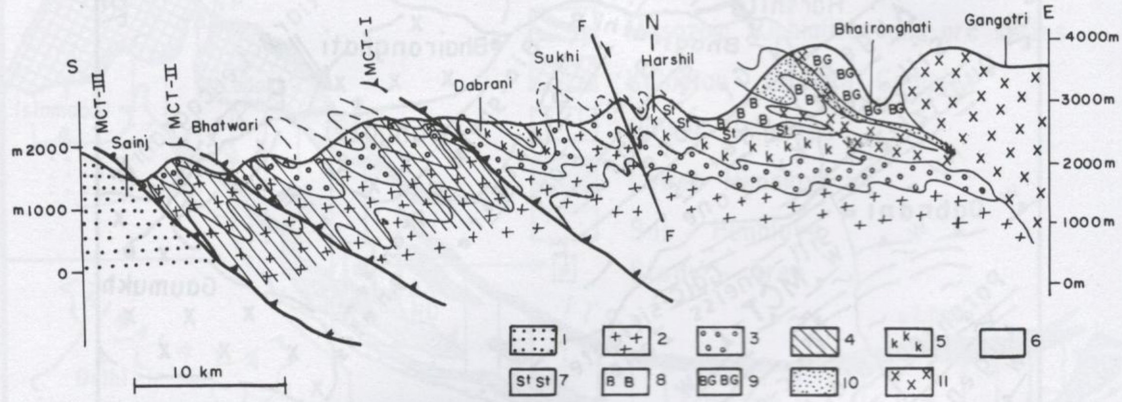

Fig. 3: Probable cross-section along the line S-N-E (Fig. 1). Legend: MCT: Main Central Thrust, 1: Quartzite (Garhwal Group); 2: Granite-gneiss and migmatite; 3: Sillimanite-K-feldspar gneiss; 4: Shear zone; 5: Kyanite-sillimanite gneiss; 6: Calc-silicate; 7: Staurolite-biotite schist; 8: Biotite-garnet schist; 9: Biotite-gneiss and granite; 10: Quartzite (Vaikrita Group); 11: Tertiary Gangotri leucogranite; F-F: Normal fault.

Subsequently, the tectonic stresses migrated southwards and caused the formation of the Vaikrita, Munsiari, Bhatwari/Chail/Ramgarh, Berinag, Krol, and Main Boundary thrusts while the Main Frontal Thrust (MFT) is in the making. Valdiya's contemplation of naming the Vaikrita Thrust to be the real MCT is mainly based on the assumption that the high grade rocks are thrust over the medium grade rocks. In the present paper, the rocks of the Munsiari and Bhatwari groups are found to be intermingled (i.e. medium and high grade rocks). So, the metamorphic boundary can not represent the tectonic boundary. In fact, the MCT was formed after the exhumation of high, medium and low grade gneisses and schists.

Fuchs and Sinha (1978), Sinha (1989), Thakur (1992), Gansser (1993) and Saklani (1993) in the Garhwal region suggest that the MCT is not a single thrust, but composed of three tectonic planes i.e. MCT-I, -II and -III developed by the duplex mechanism of thrust tectonics (Saklani et al., 1991). In the north, biotite-gneiss and granite (500 Ma age for biotite-granite; Stern et al., 1989) and Tertiary Gangotri leucogranite (about 18 Ma; Sorkhabi et al., 1996) intrude into the Central Crystalline zone. This zone comes into contact with the Tethys sediments along the Tethys Thrust or Dar - Martoli Fault. Normal Fault trending NW-SE occurs in the Vaikrita Group exposed at Jhala near the Sukhi village. NNE-SSW transverse faults are also present all along the rocks.

The 15-20 km thick complex and composite MCT shear zone (mainly Indian plate basement rocks of medium to high metamorphic grade) have been suggested to occur to the south of the Vaikrita Thrust (Fig. 3). The shear zone mainly comprises sheared granite-gneiss, blastomylonite, and mylonites of various degree and granitoids, enclaves of prograde amphibolite facies and pelitic sequences (Singh et al., 1994). The radiometric dating by different methods (mostly Rb-Sr) from Lesser and Higher Himalaya shows various episodes of granitoids ranging in age from Middle Proterozoic (1850 ± 50 Ma) to Tertiary (20-8 Ma) (Trivedi et al., 1984; Singh et al., 1986 and Stern et al., 1989). The imbricated MCT zone is overprinted by stretching lineation, S-C and S-C' fabrics (Singh et al., 1996). The S_1 bedding plane is parallel to S_2 schistosity in the Central Crystallines. The most penetrative deformation structure noted in the rocks is S_2

Table 1: Tectonic setting of the area with mesoscopic features.

Zone	Group	Rock Type	Deformation and metamorphic features
C E N T R A L	Vaikrita Group	Gangotri leucogranite (about 20 Ma; Sorkahbi et al., 1996).	Undeformed (intrusive into biotite-granite).
		Biotite-granite (about 500 Ma; Stern et al., 1989), Quartzite, Micaceous quartz, Chlorite-schist, Garnet-Chlorite-Biotite schist, Staurolite-Biotite schist. Banded augen-gneiss with porphyrotic gneiss. Biotite-gneiss, Garnet-biotite schist, Quartzitic bands, Kyanite-sillimanite gneiss and schist, Sillimanite gneiss.	F_1 tight isoclinal, F_2 asymmetric and open folds. L_1 and L_2 lineations are present in garnet-biotite schist. S-C structures are present near the thrust. Ductile to brittle-ductile deformation in gneisses and associated high-grade rocks and NW-SE normal fault are present. Regional metamorphism (M_1) from low- to high-grade is well developed. The retrograde metamorphism is present near shear zone of MCT-I.
		MCT-I (Vaikrita Thrust)	
C R Y S T A L L I N E	Munsiari (Jutogh) Group	Calc-silicates with phyllonite, Banded augen-gneiss, Garnet- mica schist, Granite - gneiss and migmatite, Sillimanite gneiss, Kyanite-sillimanite gneiss, sheared granitoids, layered gneiss and streaky gneiss. Mylonites, intrusive of fine-grained granite into augen-gneisses and porphyritic-gneisses.	F1 rootless, tight isoclinal folds are present in migmatites and gneisses. Ductile and brittle deformation are present. S-C fabrics are frequent at thrust plane. Mainly gneisses and granitoids of high-grade regional metamorphism (M_1) are sheared and mylonitised. The age of granitoids is about 1800 Ma (Singh et al., 1986). M_2 prograde regional metamorphism from low- to medium- grade is overprinted on (M).
		MCT-II (Jutogh /Munsiari Thrust)	
Z O N E	Bhatwari (Chail = Ramgarh) Group	Garnet - biotite schist, Sillimanite- K-feldspar gneiss, Quartzofeldspathic schist, Granite-gneiss and migmatite, Granitoids, Mylonite-gneiss, Mylonite and mica schist, Porphyritic - gneisses.	Brittle-ductile deformation, S-C' fabrics and shear zones up to 500 meters are very frequent. Mainly granite, migmatite and gneisses of high-grade metamorphism (M_1) are mylonitised. The granitoids age is about 1200 Ma (Singh et al., 1986). The super - position of M3 low-grade rocks (mica schist) on this duplex is present.
		MCT-III (Budhakedar /Bhatwari /Ramgarh Thrust)	
Lesser Hima-layan Zone	Garhwal Group	Massive white quartzite which, at places is pebbly, ferruginous and mylonitised (quartz sericite schist). Limestone, Phyllite, Slate, and Volcanics.	F_1 tight isoclinal, F_2 open and F_3 recumbent folds. Transverse faults (trending NNE / NE and SSW/SW) are similar to deep-seated faults in the Ganga basin and adjoining parts of Aravali orographic features (Valdiya, 1980). Very Low-grade metamorphism.

schistosity, which has been developed parallel to the axial plane of F_2 isoclinal folding. At places, sedimentary feature like cross bedding, ripple marks are found in quartzite exposed near Jangla, 6 km east of Harshil (Fig. 2).

MESO- AND MICRO-STRUCTURES

The major structural features, MCT-I, -II, -III zones in Garhwal Himalaya are considered as strong shear zones developed under ductile to brittle-ductile conditions. These thrust planes are parallel to foliations and show moderate dip of 30° towards NE in Bhagirathi River section (Fig. 2 and 3). The MCT-II and -III shear zones have many mylonitised bands, S-C and S-C' fabrics and they are characterised by low to moderate NE and SW plunging lineations. The kinematic indicators have been observed in both field and oriented thin sections in XZ plane suggest sinistral shear sense of movement along the MCT zone. The observed lineations show southward tectonic transportation of the ductile MCT plane. The petrofabric studies reveal that the non-coaxial ductile shearing from the MCT-III zone was of high order (Singh, 1993 and 1995). The sinistral type of movement is also indicated by orientation of asymmetric pressure shadows (APS) around porphyroblasts and mica fish present in rocks of the MCT-III zone. The major shear zones at the basal part of the Central Crystallines consisting mainly of a stack of sub-horizontal nappes are of two stages: (1) ductile shears under amphibolite facies metamorphic condition (MCT-I and -II zone), and (2) brittle-ductile shears under greenschist facies conditions (MCT-III zone). The earlier deformations are poorly preserved because of recrystallisation due to a late phase of high temperature deformation.

The earlier folds (F_1 and F_2) are remnant in high to medium grade rocks developed during the D_1 and D_2 deformations. The limbs of these folds are thin and hinge areas are generally thick. The F_1 flow folds and tight isoclinal folds occur in migmatite (Munsiari Group of rocks) near Bhatwari along the Bhagirathi River with variable plunges towards NNE. The gneisses and migmatites have bands of quartzitic layers in which the rootless and asymmetric isoclinal folds are present at mesoscopic and microscopic scales from the rocks of the Vaikrita and Munsiari groups. The F_2 asymmetric and open folds and S_2 schistosity were well developed in quartzite near Jangla, 7 km east of Harshil during D_2 deformation (Fig. 4a). The thin sections of biotite-garnet schist show S_1 bedding foliation of D_1 deformation (Fig. 4b) from the rocks of the Vaikrita Group. The two set of lineations are present in biotite-garnet schist near Dharali, 4 km east of Harshil (Fig. 4c). The first set of lineation (L_1) plunge 25° towards north (D_1 deformation) and L_2 plunges 5° towards west with variation in direction. The L_2 lineation coincides with trend of F_2 folds developed during D_2 deformation. The microstructural studies of the Central Crystallines show that the prograde metamorphic minerals were developed during the D_1 and D_2 deformations. These metamorphic isograds were folded during the D_3 deformation.

The F_3 folds are overturned, recumbent and large scale anticline and syncline and were affected by shearing and thrusting at the end of D_3 deformation. The earlier folds found in shear zones are asymmetric, very tight which developed sheath folds (Fig. 4d). The ductile deformations of the shear zone were characterised by S-C fabrics and NNE-SSW plunging tectonic mineral lineation. The pre-existing structures were modified (Fig. 4e). New sliding also occurred along the S_2 plane in the MCT zone and retrograded metamorphic minerals were formed along C-surfaces during D_3 (Fig. 4f). The S_3 crenulation cleavage was of late movements of D_3 and minor kinks (F_4) of D_4 deformation from basal part of crystalline rocks are present on microscopic scale exposed near Sainj and Budhakedar (Fig. 4g). The D_4 deformation produced large scale open folds, minor folds, cataclasis and faulting of the different lithological units under brittle conditions. The floor thrust (MCT-III) was associated with brittle-ductile condition existent during the last stage of shear zone deformational history (D_4). The microscopic structures from the Main Central Thrust zone also show extensive cataclasis and shearing during the last phase of deformation (Fig. 4h). The roof thrust (MCT-I) developed in ductile conditions were also affected by cataclasis and fracturing. The relationship between deformation, mesostructures and development of metamorphic minerals is summarised in Table 2.

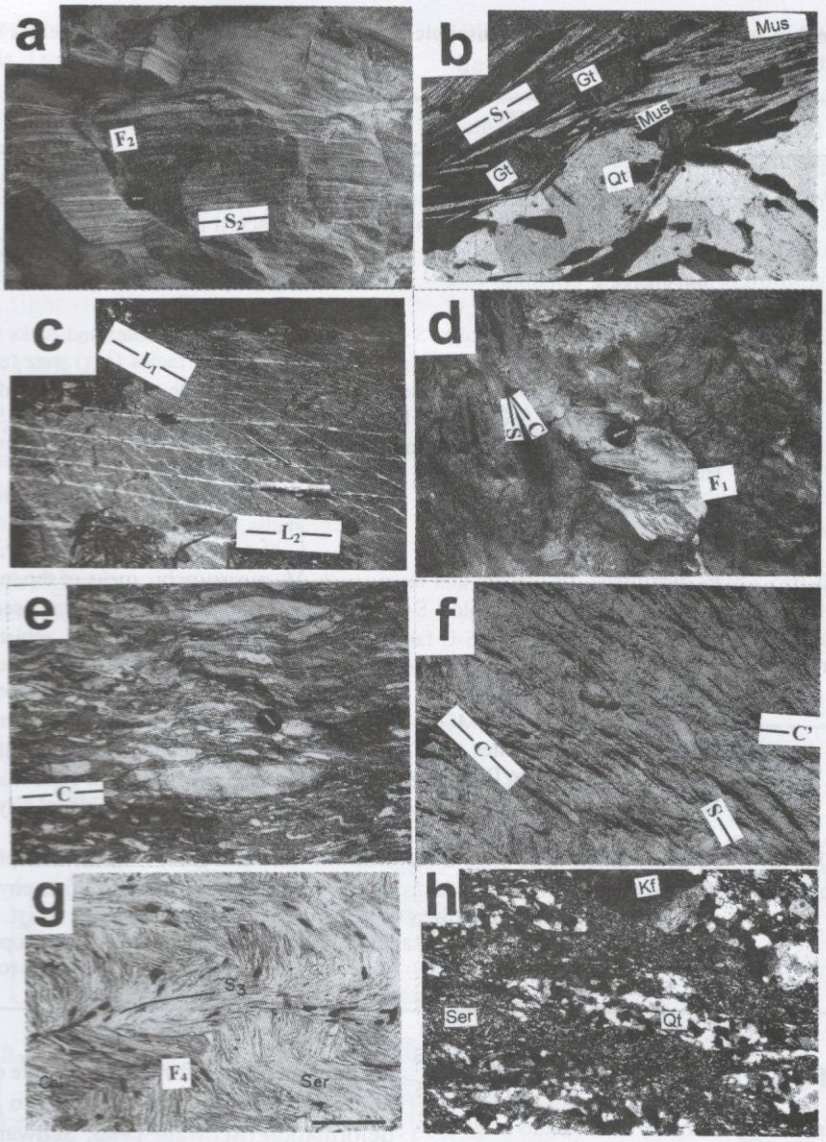

Fig. 4: (a) F_2 asymmetric fold with S_2 schistosity are well exposed in quartzite near Jangla, 7 km east of Harshil were developed during D_2 deformation, (b) Biotite, garnet (Gt), muscovite (Mus) and quartz (Qt) minerals were formed during D_1 deformation showing S_1 bedding foliation in thin section from biotite-garnet schist, (c) The two set of lineations are well exposed in biotite-garnet schist near Dharali, 4km east of Harshil. L_1 lineation (pen) plunge 25o towards North and L_2 lineation (marker) plunge 5o, E-W were developed during D_1 and D_2 deformations respectively, (d) The development of sheath geometries of earlier folds (F_1) are present in shear zone of migmatite and gneiss from Bhatwari (MCT-II zone) formed during D_3 deformation.ew C-surfaces under ductile condition during D_3 deformation, (f) The development of S-C and C' structures from gneiss of MCT-III zone exposed near Sainj formed during D_3 and D_4 deformations, (g) S_3 crenulation cleavage and minor kinks (F_4) developed on microscopic scale from retrograded chlorite (Chl) - sericite (Ser) rocks of MCT-III zone during late D_3 and D_4 deformations respectively. (Scale bar = 200 ley, Garhwal Himalaya. The sketches out the important structures noticed in the different episodes of deformation. The geochronology of the Lesser and Higher Himalaya from adjoining region is taken from published data by different workers.

Table 2 Relationship between deformation, mesoscopic structures and metamorphic minerals of the Central Crystallines of the Garhwal Himalaya.

Deformation	Mesoscopic structures	Metamorphic minerals
D_1 (? about 2400-1800 Ma; see Trivedi et al., 1984)	F_1 tight isoclinal (intrafolial) folds, rootless folds are present in gneisses and migmatites. S_1 (Si= internal schistosity) plane present in garnet from gneisses.	M_1 metamorphic minerals (chlorite, biotite, garnet) were formed. Gt-Bio schist and Chl-Bio schist rocks were developed. S_1 bedding plane and L_1 lineation are present in these rocks.
D_2 (? about 1200-500 Ma; 700-500 Ma have major orogeny : see Sinha, 1989)	F_2 asymmetric and open folds. S_2 penetrative schistosity (present in all type of rocks of Higher and Lesser Himalaya), without S-C fabrics. L_2 mineral lineations are frequent in Lesser Himalayan rocks.	Gneisses, migmatites and rocks of the upper amphibolite facies (M_1) were formed. Biotite-granite were formed and exposed. Ky-Gt-Mus schist, Ky-Sill gneiss, Sill-Kfs gneiss, Bio-Sill-Crd gneiss, Cpx-Gt-Plag - Calc gneiss. F_2 folds and L_2 lineations are present in gneiss, schist and quartzite.
D_3 (? about 60-16 Ma; about 20 Ma age for Main Central Thrust : see Sorkhabi et al., 1996)	F_3 overturned, recumbent and large anticlinal and synclinal folds. S_3 crenulation cleavage and S-C fabrics, Simple shear deformation (top to south shear i.e. sinistral), L_3 mineral stretching lineation (syn-MCT movement) and mylonites were developed during late D_3deformation. Major duplexes were developed.	M_2 metamorphic rocks of the lower amphibolite facies superimposed on M_1. Bio-Chl schist, Chl-Mus schist, Gt-Chl-Bio schist, St-Bio-Chl schist, andalusite schist were developed within shear zone. M_1 isograds shows F_3 folding on mesoscopic scale. L_3 lineations and mylonites are present, near the thrust zone mainly in the southern part of the Central Crystallines.
D_4 (? about 8 Ma to present : see Sorkhabi et al., 1996)	F_4 minor kinks, large scale open folds. N-S movement extensional faults, S-C' structures, cataclasis and retrogression were developed. Minor brittle faulting were developed.	Very low-grade (M_3) metamorphic minerals developed. Chlorite schist, phyllonite, sericite schist, muscovite schist. Transverse faults (N-S movement) developed in all Himalayan Siwalik to Tethys rocks.

DISCUSSION AND CONCLUSIONS

Dating of deformation in the Lesser and Higher Himalaya is a still controversial. After the collision of the Indian and the Eurasian plates, the Central Crystallines of the Higher Himalaya underwent ductile shearing, which is characterised by the composite Main Central Thrust. Effects of the Tertiary orogeny are distinctly observed along the Himalayan Suture Zone characterised by deformation and metamorphism and emplacement of the Tertiary leucogranite. The Central Crystallines expose the Precambrian structures, which have been overprinted by the Tertiary Himalayan orogeny without any intervening phases (Gansser, 1993). In Garhwal, the Crystalline rocks are consistently uniform in their style of deformation and have undergone at least four to five phases of deformation (Schwan, 1980; Schwan and Saklani, 1991; Gairola, 1992 and Saklani, 1993).

The early phase (D_1 deformation) is characterised by rootless tight folding (F_1) as restite in migmatite and gneiss exposed near Bhatwari. The textural studies from biotite schist and quartzite rocks (Vaikrita Group) exposed near Jangla show development of biotite, muscovite, quartz and garnet minerals parallel to S_1 foliation during the D_1 deformation. These rocks showing asymmetric and open folding (F_2) and S_2 schistosity during D_2 deformation. The L_2 lineation is developed on the S_2 schistosity trending East-West direction is generally coaxial to the F_2 folds. During this phase of deformation, the high grade minerals like kyanite, staurolite, garnet, sillimanite and hornblende were developed by M_1 phase of metamorphism. Structural and textural studies reveal that the prograde M_1 metamorphic minerals and S_1 plane were concomitant with the D_1 phase of deformation. Subsequently, asymmetrical, disharmonic, tight isoclinal F_2 folds and mainly S_2 schistosity were developed during the D_2 deformation (Table 2).

The biotite-gneisses and granitoids associated with M_1 metamorphics exposed near Gangotri are possibly syntectonic (D_2). These biotite-granites are older than the Tertiary Gangotri leucogranites and are similar to the Cambro-Ordovician (500 ± 50 Ma) granites found in the Lesser Himalaya (Stern et al., 1989 and Sorkhabi et al., 1996). The conglomerate-bearing beds comprising the boulders and pebbles of granitoids and metamorphics have been obtained from the base of Tethys rocks of the Haimanta and Ralam Groups (Fuchs, 1992; Azmi, 1994). The field relationships of sillimanite-K-feldspar zone with migmatites, gneisses and granitoids suggest that ultrametamorphism finally resulted in partial melting and anatexis and S-type granitoids formed during D_2 phase (Singh et al., 1996). Geochronological data from lower parts of Crystallines in this region show clustering at 1850 ± 50 Ma and 500 ± 50 Ma (Trivedi et al., 1984 and Singh et al., 1986). The authors correlate the deformational phase, geochronology and metamorphic events with meso- and micro-structures in Fig. 5. Valdiya (1980), Sinha (1989), Schwan and Saklani (1991), Thakur (1992) and Fuchs (1992) are of the view that the Central Crystallines were deformed by Caledonian or earlier orogeny. This view is also supported by the

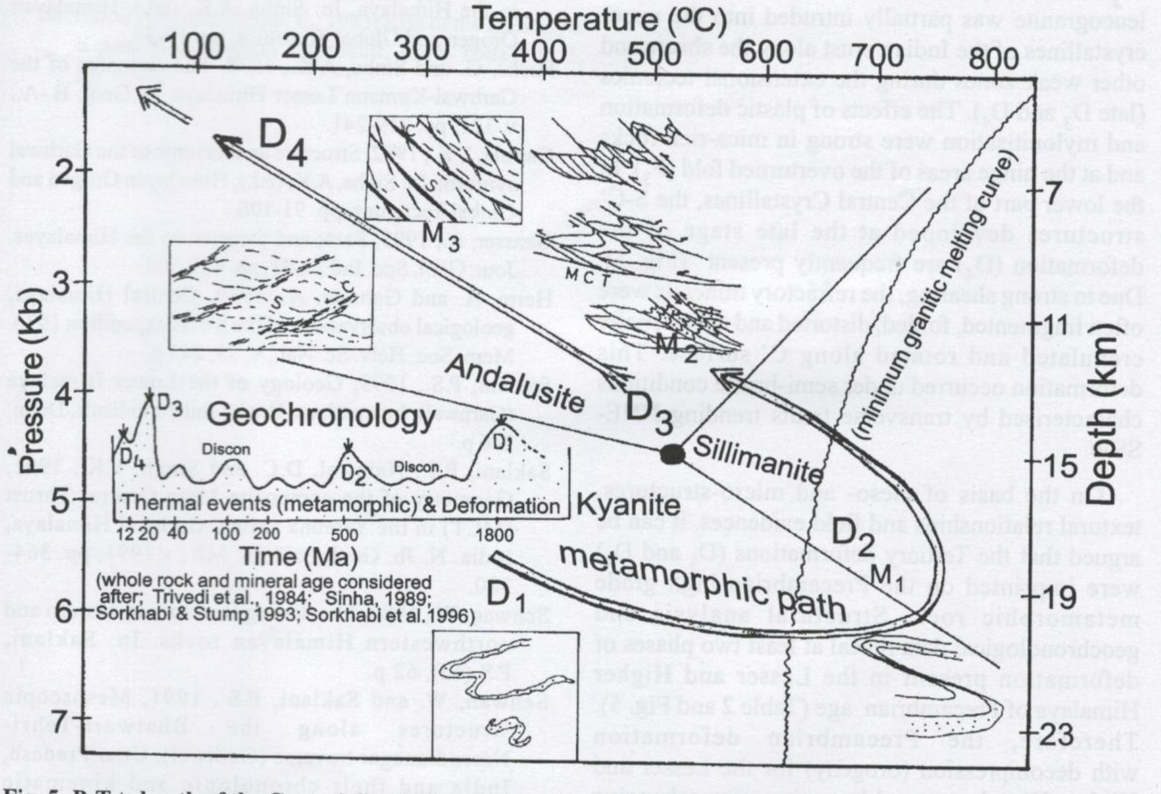

Fig. 5: P-T-t-d path of the Central Crystallines of the Bhagirathi valley, Garhwal Himalaya. The sketches out the important structures noticed in the different episodes of deformation. The geochronology of the Lesser and Higher Himalaya from adjoining region is taken from published data by different workers.

widespread generation of granites during 700-500 Ma with strong deformation (Sinha, 1989 and Gansser, 1993). These evidences indicate that the deformation with metamorphism and emplacements of granitoids dated back to the Precambrian time (Table 2 and Fig. 5).

The collision during the Tertiary produced a new set of penetrative fabrics (C-Surface) in the Crystallines. Due to the imposition of constant stresses from the northward movement of the Indian plate, subsequently deformed Crystallines present at shallow depth began to rise upward and then southwards over the Lesser Himalaya along various ductile shear planes (S-C fabrics) associated with duplex mechanism (D_3). Singh et al. (1996) suggested that andalusite, biotite-II, chlorite-II, staurolite-II, garnet-II metamorphic minerals of the Himalayan rocks are either of retrograde origin during the D_3 and D_4 deformations or of the prograde M_2 metamorphism (Table 2). The Gangotri leucogranite was partially intruded into the upper crystallines of the Indian crust along the shears and other weak zones during the extensional tectonics (late D_3 and D_4). The effects of plastic deformation and mylonitisation were strong in mica-rich rocks and at the hinge areas of the overturned fold (F_3). In the lower part of the Central Crystallines, the S-C' structures developed at the late stage of the deformation (D_4) are frequently present (Fig. 5). Due to strong shearing, the refractory minerals were often fragmented, folded, distorted and occasionally crenulated and rotated along C' surface. This deformation occurred under semi-brittle conditions characterised by transverse faults trending NNE-SSW.

On the basis of meso- and micro-structures, textural relationships and field evidences, it can be argued that the Tertiary deformations (D_3 and D_4) were imprinted on the Precambrian high grade metamorphic rock. Structural analysis and geochronological data reveal at least two phases of deformation present in the Lesser and Higher Himalaya of Precambrian age (Table 2 and Fig. 5). Therefore, the Precambrian deformation with decompression (orogeny) for the Lesser and Higher Himalaya would require comprehensive rethinking of models for the Tertiary Himalayan collision belt.

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