

# Basement Rocks of the Kumaun - Garhwal Himalaya: Implications for Himalayan Tectonics

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## Abstract

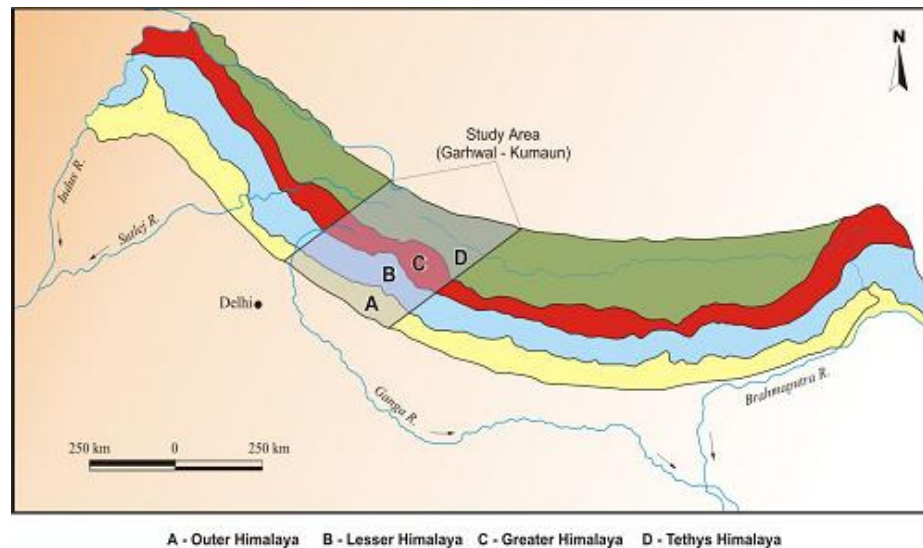
The Himalayan orogenic belt is characterized by the presence of basement rocks. These rocks got involved in the evolution of the mountain belt and, as such, have played a great role in the structural architecture and tectonic framework of the orogen. These rocks have evolved from depth due to concentration of compressive stresses generated by plate collision and rose vertically up because of buoyancy up to the surface and were then pushed southwards over the less- or un-metamorphosed, younger rocks of the sedimentary belt of the Lesser Himalaya. In order to make room for such a vast chunk of the basement, the sedimentary pile had to undergo large scale deformation sympathetically. As such, the present tectonic setting, structural architecture and deformation pattern of the upper crustal rocks of the Himalaya owe much to the rise of the basement rocks during evolutionary stages of the Himalaya. The paper examines some aspects of the tectonics and structural framework of the Himalaya as related to the basement rocks in the Kumaun - Garhwal sectors.

## Introduction

Basement rocks constitute an integral part of crustal rocks. These constitute the foundation on which thick pile of sedimentary rocks are deposited. The basement rocks mostly constitute an assemblage of crystalline and metamorphic rocks that behave in accordance with the overall tectonic behaviour of the crust, *i.e.* whether the crust is undergoing vertical or epeirogenic movements or compressional or orogenic movements. Also, there are situations when the crust undergoes extension or buckling to give rise to intracratonic basins that in turn give rise to a thick pile of sedimentary rocks deposited unconformably over the basement rocks. Thus, both stratigraphy and structure of a region are, by and large, controlled by the presence or absence of the basement rocks. Because of all these factors, coupled with some others also, the regional stratigraphic setting, structural design and tectonic framework of the cratons of the Peninsular India, Proterozoic basins of Central India and that of the Himalayan region are different from each other. In this paper, the role of basement rocks in controlling the structure and tectonics of the Himalaya is discussed. The work is based on author's studies in the Kumaun-Garhwal sectors of the Himalaya.

The Himalaya has been geologically divided (Fig. 1) into four lithotectonic subdivisions (Gansser, 1964). From south to north these are: (1) *Outer Himalaya*, that mostly includes the molassic Siwalik Supergroup of Mio-Pliocene ages and is demarcated by two tectonic planes, the Himalayan Frontal Thrust (HFT) to the south and the Main Boundary Thrust (MBT) to the north. (2) *Lesser Himalaya*, that exposes a thick pile of highly folded Proterozoic sedimentary strata together with a few outcrops of older crystalline rocks; this subdivision is bounded by the MBT to the south and the Main Central Thrust (MCT) to the north. (3) *Greater or Higher Himalaya*, that exposes a massive, north-dipping pile of metamorphic rocks – the Central Crystalline Zone – and is demarcated by the MCT to its south and the Dar-Martoli Fault or Tethys Fault or the South Tibetan Detachment (STD)

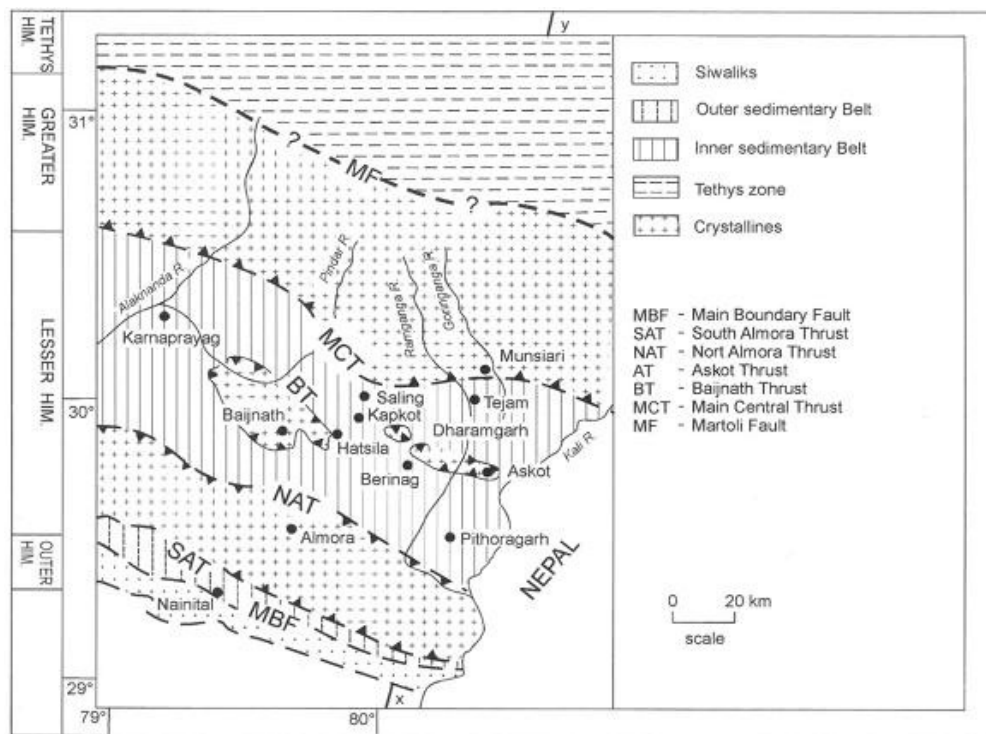
to the north. (4) *Tethys Himalaya* that includes with a thick pile of sedimentary rocks of Cambrian to Lower Eocene ages.



**Fig. 1:** Geological sketch map of the Himalaya. A - Outer Himalaya, B - Lesser Himalaya, C - Greater Himalaya, D - Tethys Himalaya. The Main Central Thrust (MCT) is defined by the contact between the Lesser and the Higher Himalayas (After Gansser 1964).

Heim and Gansser (1939) and Gansser (1964) presented an overall geological framework of the Himalaya. Le Fort (1975) presented some specific structural and petrological aspects of the Himalaya. Molnar *et al.* (1977) interpreted the structure and tectonics of the Himalaya in the light of some relevant geophysical observations. Valdiya (1981) described the geology of the Kumaun region. Bouchez and Pecher (1981) studied fabrics of the Main Central Thrust pile and its quartz-rich tectonites in Central Nepal. Burg *et al.* (1984) discussed the deformation pattern of leucogranites of the Crystalline Main Central Thrust Sheet in southern Tibet. Burg and Chen (1984) described the tectonics and structural zonation of southern Tibet. Colchen *et al.* (1986) discussed some aspects of collision tectonics in the Indus Suture Zone, Ladakh. Grujic *et al.* (1996) studied quartz microfabrics of Bhutan Himalaya and discussed the nature of ductile extrusion of the Higher Himalayan Crystallines. Grasemann *et al.* (1999) presented a kinematic flow analysis from the Main Central Thrust of NW Himalaya in the light of implications for a decelerating strain path and extrusion of orogenic wedges. Beaumont *et al.* (2001) explained Himalayan tectonics as an extrusion of low-viscosity crustal channel coupled to focus surface denudation. Vannay and Grasemann (2001) discussed Himalayan inverted metamorphism and syn-convergence extension as a consequence of a general shear extrusion.

The present work is based on the author's study in the Kumaun and Garhwal sectors of the Himalaya (Fig. 2). These two sectors represent all the four major lithotectonic subdivisions of the Himalaya. As such, interpretations made from these sectors should have region implications for the Himalayan region.



**Fig. 2:** Geological sketch map of Kumaun-Garhwal Himalaya (After Bhattacharya, 1999)

### Basement rocks of the Himalaya

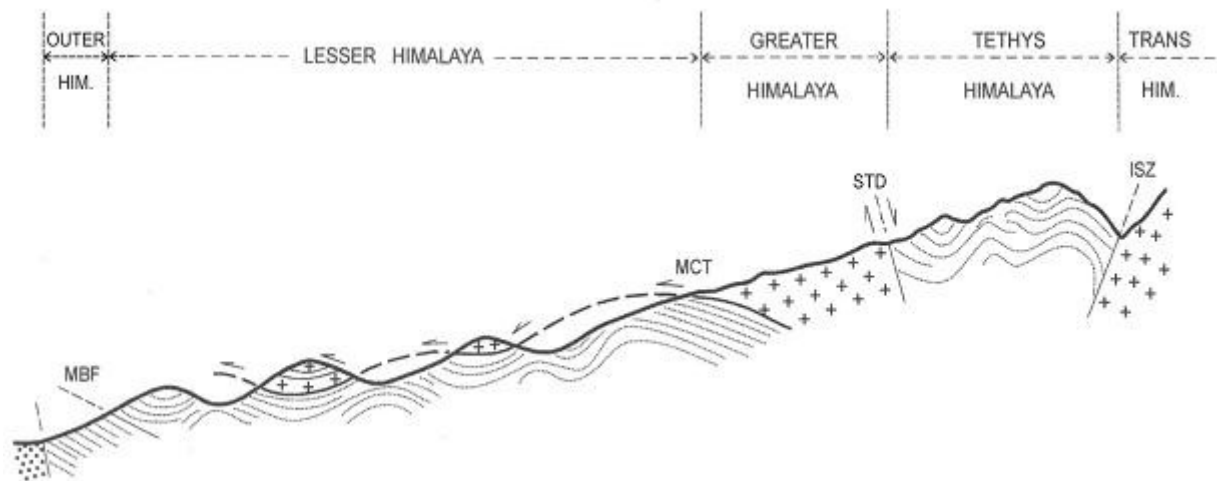
In the Himalayan domain, the basement rocks appear to have played a great role in controlling and governing the overall stratigraphy, structure and tectonics. The vast stretch of Greater Himalaya exposes a massive pile of crystalline-metamorphic rocks that are designated as the Central Crystalline Zone (CCZ). It includes a remobilized basement of about 30 km thick medium to high grade metamorphic sequence. The dominant rock types include augen gneiss, granite gneiss, garnetiferous biotite gneiss, biotite-muscovite gneiss, calcsilicates and quartzites. Dikes of aplites and pegmatites are common in the rocks of higher (northern) horizons of this zone. The major rock types are gneisses, quartzites, variety of schists, calcsilicates, and leucogranite dikes especially at higher (northern) horizons.

Barring the vicinity of the MCT, the observed strain levels of the folds of the vast stretch of the Central Crystalline Zone (CCZ) of the Greater Himalaya, has been found to remain rather moderate. Flattening strain in folds range from about 15 to about 95 percent (Bhattacharya and Siwal, 1985; Bhattacharya, 1999), and the strain data show a rather random pattern of distribution. Finite strain (shown by minor folds) shows a progressive increase towards the MCT such that the trace of the MCT shows the highest concentration of ductile strain. Also, the vicinity of the MCT shows the development a variety of shear-sense markers and the stretching lineation becomes progressively stronger towards the MCT. The deformational features around the MCT show marked differences with those developed in areas away from it, thus, suggesting marked differences in the deformational processes operative in the MCT zone and those away from it. The vicinity of the MCT has been regarded here as the center of the shear zone (see Bhattacharya and Weber, 2004).

Barring a zone of 10 to 12 km width from the MCT northwards, the structural features do not show any specific orientation or regularity of their occurrence. The rocks show moderate strain levels.

### Structural Architecture of Basement Rocks

The Central Crystalline Zone of the Greater Himalaya can, in a generalized way, be described to be the representative of basement rocks in the Himalayan domain. The structural/tectonic disposition of this zone in the framework of the overall structure of the Kumaun-Garhwal Himalaya has been shown in a generalized cross-section (Fig. 3). This zone exposes a massive pile of medium to high grade metamorphic rocks together with younger intrusives of aplite and pegmatite.

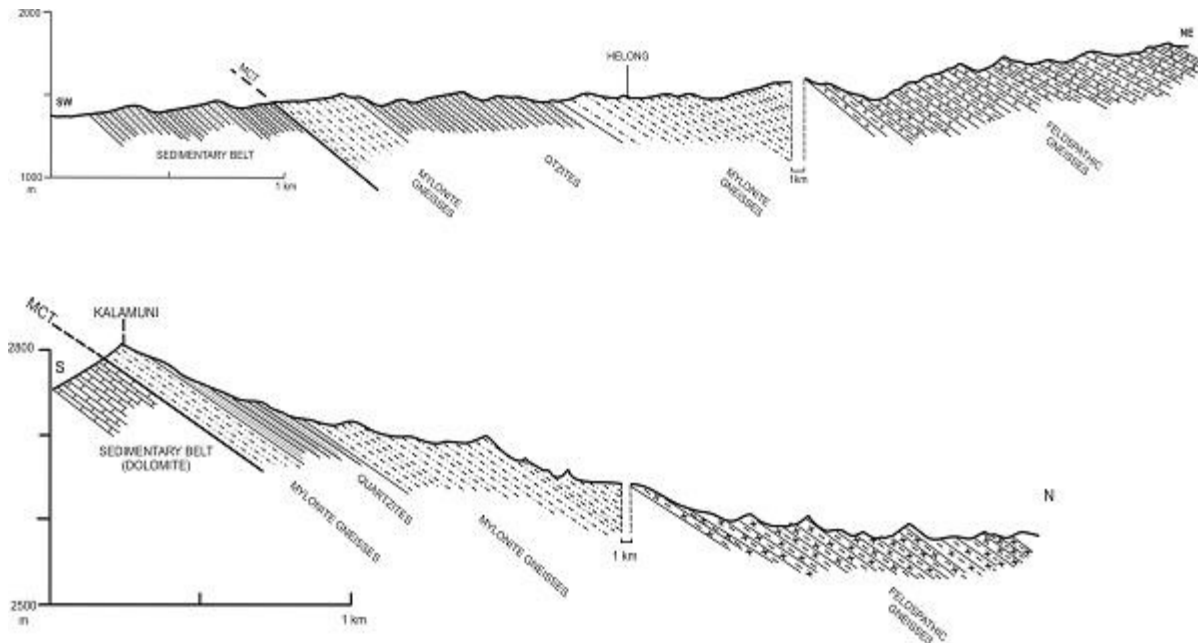


**Fig.3:** A generalized geological cross section of the Kumaun Himalaya (After Bhattacharya, 1999)

Typically, the foliation of these massive pile of metamorphic rocks show moderate dips northwards. Apparently, no large scale or kilometric scale folds are noticed, at least in the Kumaun-Garhwal sectors. As such, the overall structure of the Central Crystalline Zone can be described to be a homocline (Fig. 4). This general lithological sequence is noticed practically in all the sections of Uttarakhand (Kumaun-Garhwal) Himalaya.

The base of the crystalline pile includes mylonites and sheared rocks that have been included here to constitute the MCT shear zone. Physically, over these rocks lie a pile of medium to high grade rocks with gneisses and schists.

In contrast to the overall simple homoclinal structure for the CCZ, the rocks show complicated structures in their internal domain, *i.e.* on meso- to micro- scales. The folding is, especially, complicated. The rocks of the higher horizons have been found to show at least three episodes of folding.



**Fig. 4:** Structure of the Central Crystalline Zone in the Garhwal Himalaya in the Heong transect (Joshimath area) and in the Kumaun Himalaya in the Kalamuni transect (Munsiari area).

### Ductile Shear Zones

The southern part (10-12 km) of the Central Crystalline Zone is characterized by the development of a large scale shear zone formed due to large scale movement /translation of a part of this zone along the Main Central Thrust Zone. The rocks of the northern parts of the CCZ apparently do not show effects of shear deformation. Moving southwards, the rocks gradually show effects of shear deformation, as revealed by the development of a variety of structures/micro-structures and textures in the rocks, sigmoidal foliation, shear folds etc. All these structures gradually show an asymmetry with respect to the earlier or domainal foliation. This asymmetry has developed as a result of shearing, and this asymmetry becomes progressively stronger southwards, *i.e.* progressively with increase of ductile shear strain. The shear zone, thus developed at the southern fringe of the CCZ, is about 12-15 km wide and is mainly recognized by:

- (i) Progressive development of a variety of minor structures within the shear zone.
- (ii) Progressive development of fabric and grain orientations.
- (iii) Spatial variation of strain within the shear zone.
- (iv) Structures/micro-structures and shear-sense markers show progressive increase of asymmetry suggesting a southward sense of movement.
- (v) Rocks of the higher (northern) horizons gradually become mylonitized towards the MCT and show sequential changes in a variety of microstructures:
  - (a) Quartz shows progressive increase of dynamic recrystallization and decrease of grain size (down to 0.01 mm)
  - (b) Feldspar shows progressive recrystallization to muscovite

- (c) Quartz c- and <a> axis fabrics gradually become prominent and evolve from a random fabric outside the shear zone through coaxial to non-coaxial strain path close to the MCT.

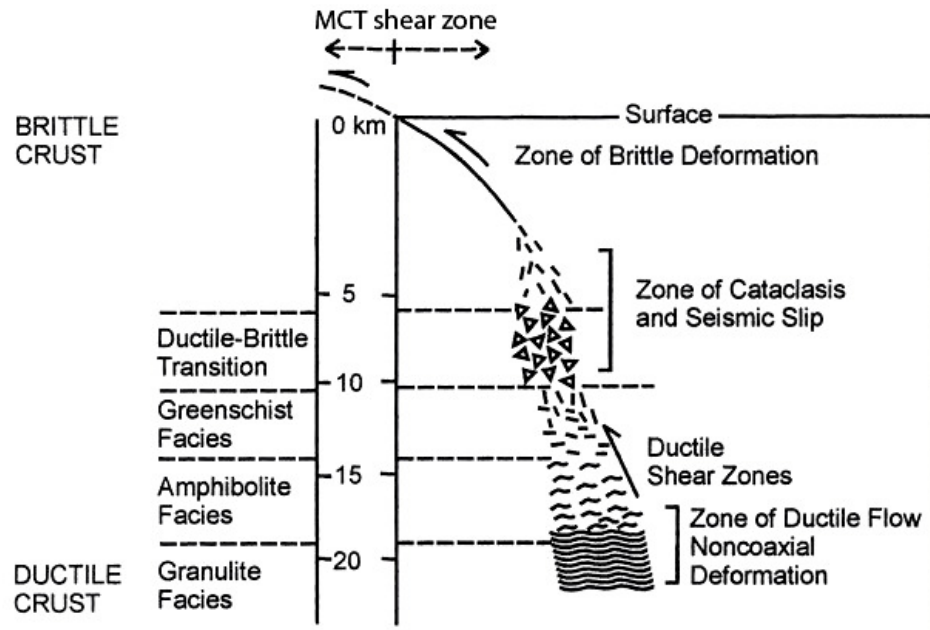
Thus three major deformation zones can be distinguished in the Central Crystalline Zone:

- (a) A northern, less deformed sector, with fewer deformation features
- (b) A central sector showing incipiently to weakly developed deformation features that progressively intensifies towards south
- (c) The southern sector (MCT zone) showing, from north to south, a sequential development of shear- related deformation features

### **Tectonic Framework**

It has been indicated by the author (Bhattacharya,1999) that as a result of collision of the Indian plate against the Asian plate in the Eocene time, very high ductile strain was concentrated along a narrow, linear zone at depth where the rock mass was highly ductile. As such, with continued collision, this mass could rise vertically up due to its buoyancy. In response to the persistent collisional stresses, this mass was brought to the surface and then pushed southwards along the MCT (Fig. 5). This long transport is evidenced by the occurrence of a thick zone of mylonites at the base of the CCZ as well all along the crystalline units physically occurring at the top of the sedimentary sequence of the Lesser Himalaya at several places (see Bhattacharya and Agarwal, 1985). These crystalline masses have been given different names in the Lesser Himalaya. In the Kumaun-Garhwal Himalaya, these include the Almora, Baijnath, Askot, Chhiplakot and Dharamgarh crystalline units. These mylonites represent products of very high ductile deformation under deep seated conditions.

According to Heim and Gansser (1939) and Gansser (1964), the above crystalline units of Lesser Himalaya show an inverted sequence, *i.e.* inverted metamorphism, in which the grade of metamorphism increases from base to top of the sequence. They interpreted the present disposition of the crystalline units of the Lesser Himalaya as due to a gigantic recumbent anticline of the crystalline axis of the Himalaya (*i.e.* the crystalline rocks of the Greater Himalaya) whose lower inverted limb is represented by the present-day, synformally-disposed crystalline rock units while the upper, normal limb might have been eroded away. Later workers, including the present one, are, on the other hand, of the opinion that there is no specific order of distribution of the metamorphic minerals and rocks within the sequence and hence there is no inversion of the sequence. Further, the occurrence of a thick pile of mylonites and highly sheared rocks at the base of all the crystalline units of Lesser Himalaya, and so also at the base of the Central Crystalline Zone, clearly indicate long transport of these rock masses. As such, the crystalline masses of the Lesser Himalaya can be described to constitute *thrust sheets* that have been transported from the north, *i.e.* from the Greater Himalaya (see also Bhattacharya, 1987, 1990, 1999; Bhattacharya and Siawal, 1985; Bhattacharya and Weber, 2004).



**Fig. 5:** An evolutionary model of the Main Central Thrust showing how it brings a part of the basement rocks up to the surface. (After Bhattacharya, 1990)

## Discussions

### (1) Why does the Central Crystalline Zone show a simpler (homoclinal) structure?

As we have indicated above, the CCZ shows a monotonously north-dipping sequence of crystalline-metamorphic rocks, thus displaying a homoclinal structure on a regional basis. It seems quite unusual that such a major subdivision of the Himalaya shows a relatively simpler structural architecture especially keeping in view of the complicated post-collisional structural-tectonic history of the Himalayan region. Unfortunately, there appears to be a lack of literature on this aspect. The author suggests one possible explanation for this, as outlined below.

It has been mentioned earlier that as a result of India-Asia collision, a part of the basement rocks was lifted up from the depth due to its buoyancy. The rock mass moved along the MCT that brought it up on to the surface and then pushed it southwards over the un-metamorphosed, younger sedimentary belt of the Lesser Himalaya. It is suggested that most of the collisional stresses that were of compressive nature were utilized in moving the mass up from the depth. This caused shearing process to be operative in the moving rock mass and this, in turn, triggered a series of deformational processes in the internal domain of the crystalline mass. This is also evidenced by the fact that while the overall structure of the CCZ looks homoclinal, the rocks show a variety of shear-generated structures in their internal domain. The intensity and complexity of shear-generated structures show a progressive increase towards the trace of the MCT, *i.e.* in the direction of higher ductile strains. All this possibly explain why the CCZ shows a rather simpler (homoclinal) structure while the occurrence of large scale folding and the related structures are common features of all the other three lithotectonic subdivisions of the Himalaya.

## **(2) Why is the contact of the Central Crystalline Zone with the Tethys zone a fault?**

An important geotectonic element of the Himalaya is an E-W striking, N-dipping normal fault at the base of the Tethys zone and this fault separates the Tethys sequence with the crystalline zone of the Greater Himalaya. According to Burg *et al.* (1984) and Burg and Chen (1984), this fault and a few other similar types of faults in the Higher Himalaya and southern Tibet were formed during the post-collisional convergence of India and Tibet. These faults extend for at least 600 km along strike. Royden and Burchfiel (1987) interpret them as possible late (?) Miocene extensional features with perhaps several tens of kilometers downward northerly displacement and they are of the opinion that N-S extension produced in this way is probably confined to upper crustal levels only and are developed during convergence in many orogenic belts.

In the Himalayan scheme of events, the culmination of deformation and metamorphism is marked by the formation and subsequent development of the MCT that lifted a part of the basement on to the surface and then it was pushed southward over the less- to un-metamorphosed, younger sedimentary belt of the Lesser Himalaya. (see Le Fort, 1975; Burg *et al.* 1984; Grijic *et al.* 1996). This was also a period (mainly Oligocene to Middle Miocene) during which the Himalaya was lifted much higher. In the Himalayan region, this uplift could be considered as an up-buckling of the upper crust that was possible only because the crust has some 'flexibility' to large scale compressive stresses that, in turn, allowed a part of the collisional stresses could be accommodated within the dome-shaped Himalayan crust through deformation. However, after the optimum limit of this flexibility was attained, the outer part of this dome-shaped structure developed tensional stresses leading to the formation of a crack or a fault because of its brittleness. Since the contact of two different lithological assemblages, in general, constitutes a regional anisotropy, it was the contact of the Central Crystalline Zone and the sedimentary rocks of the Tethys zone that became more vulnerable or susceptible to brittle deformation by the formation of a fault. As the process of uplift, supported by mass transport along the MCT from below continued, the crystalline part continued to rise up (hanging wall) while, in order to counterbalance, the Tethyan pile continued to go down along the fault (down-faulting, foot wall). Thus, the throw of the fault – the Martoli Fault or the South Tibetan Detachment – continued to increase progressively yielding, as of now, a throw of some 7 to 10 km.

The formation of a major normal fault in a regime of compressive stresses, as described above, is a unique example of operation of extensional processes during an overall compressional regime (see also Royden and Burchfiel, 1987).

## **(3) Why are brittle faults rare in the Central Crystalline Zone?**

The rocks of the CCZ, as has been mentioned earlier, show a relatively simpler (homoclinal) structure. Faults are practically absent in the rocks of this zone, while all the other lithotectonic subdivisions of the Himalaya are characterized by the occurrence of numerous faults on various scales. This draws attention also due to the fact that during the evolution of the MCT, the rocks of the MCT zone have been subjected to ductile deformation at depth during earlier stages and later on when the rock masses came up nearer, or on to, the deformation regime was dominantly brittle in which faults could have formed. The author would like to suggest the following causes for this.

The rocks of the CCZ are characterized by strong development of foliation mainly due to the dominance of micaceous and other platy minerals. The MCT zone had evolved through very strong compressive stresses. Because of the strong foliation, these

compressive stresses have easily been transmitted to the rock masses along the foliation planes. Under the circumstances, movement or transport of rock masses are rather more facilitated along the foliation planes than across them. Also, the micaceous minerals have some tolerable ductility that could prevent development of cracks across their overall alignment, *i.e.* foliation. This suggests that mainly because of the strong foliation due to abundance of micaceous minerals, the cohesive forces are stronger than the frictional forces. As such, shear stresses could not develop cracks easily and instead, the component shear stress had allowed slip or movement along, or within, the layers of the micaceous minerals even at the later stages of evolution of the MCT zone when the rock masses were on, or very near to, the surface. This possibly explains why faults are rare in the rocks of CCZ.

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