"The trouble with simple things is that one must understand them very well."

- Anonymous

LITHO-TECTONIC SETUP 2

GENERAL BACKGROUND

The Eastern Kumaun Himalayas comprises whole of Pithoragarh District and eastern parts of Almora and Chamoli Districts. The Kumaun Himalayas includes three hundred twenty kilometres stretch of mountain range, which lies between the Tons in the west and the Kali River in the east and can be divided from north to south into four longitudinal belts, based on the thrusts and the metamorphic sequence, as follow:

(i) Tethys Himalayan Belt: Exhibiting an elevation range between 3000-4000m representing Pre-Cambrian basement crystalline and the marine sedimentary sequences from Cambrian to Cretaceous with well preserved fossil assemblage (Plate II.1).

(ii) Higher/Great Himalayan Belt: Highly rugged terrains with an average altitude of 6500m comprising predominantly rocks of Crystallines with subordinate younger meta-sedimentaries.

(iii) Lower/Lesser Himalayan Belt: Zone of parallel ranges with an average altitude range of 2000-3000m; lithologically this belt comprises rocks of Crystallines and meta-sedimentaries of Pre-Cambrian-Cambrian age (Plate II.1).

(iv) Sub-Himalayan Belt: Abutting with the Indo-Gangetic alluvium plains (Plate II.1) with an average altitude range of 1300m and comprising sedimentary sequences (molasses) of Tertiary Period (The Siwaliks).

The stratigraphy and structure of Kumaun Himalayan Range is highly complicated than other parts of Himalayas. The tectonic complications are more severe in the Lower, Higher and Tibetan (Tethys) Himalayas, however, in the Tibetan region the excellent faunal evidences are well preserved. The Kumaun Himalayan terrain due to its vast diversity in geological environment and structural intricacies have attracted many earth scientists, who have significantly contributed on one or other aspects of geology. The noteworthy contribution to the geology of Kumaun region has come from Pilgrim (1928); West (1928); Auden (1934); Heim (1939) and Gansser (1939, 1964, 1993). Heim and Gansser (1939) have confirmed the findings of various thrust sheets of Auden. The traverse taken along the Kali River by these two workers has given wealth of data on parts of Kumaun region. Later, notable contribution on the Geology of Kumaun Himalayas has been made by Valdiya through his work (Valdiya; 1964, 1972, 1980, and 2005). However, he had often changed his opinion on various tectonic and structural features.

The Geological Survey of India has contributed towards the immense pool of information by systematic mapping of the Lesser, Higher and Tethys Himalayas. Some of the noteworthy contributions have been made by the workers namely; Gopendra Kumar (1976, 1982, 2005); Sinha Roy (1982); Ahmad, Saxena and Siddhanta (1982), Ravishanker et al. (1996) and others. Significant contributions to the Geology of Uttarakhand (Uttaranchal) were made by the Departments of Geology from different Universities such as the Lucknow, Delhi, Kurukshetra, Roorkee, Pune, Banaras Hindu University, The Maharaja Sayajirao University of Baroda and the research institutes' like Wadia Institute of Himalayan Geology, particularly Powar (1972); Merh and Vashi (1976); Mishra and Bhattacharya (1976);

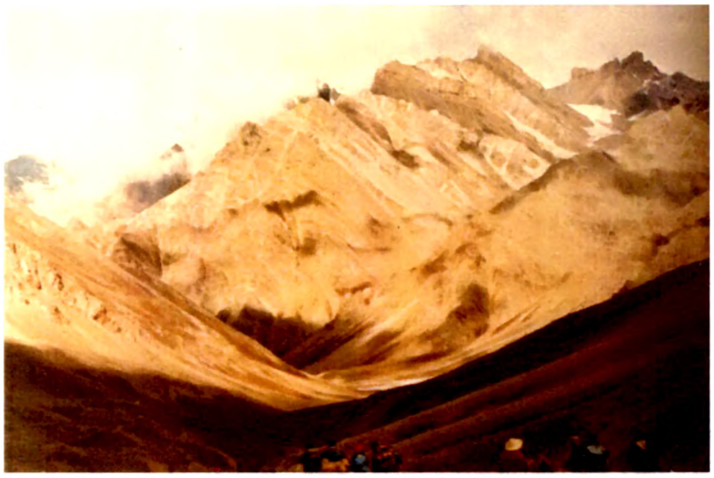
Sinha (1989); Kumar and Patel (2004); Thakur and Choudhury (2005); Yedekar and Powar (2005); Luirei (2006).

GEOLOGICAL SETUP

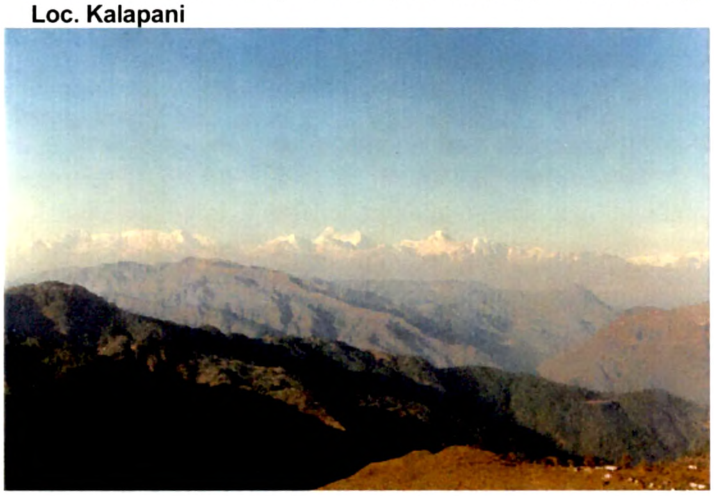
Geologically the Kumaun Himalayas is characterized by a series of Pre-Cambrian Crystalline nappes with associated younger metasedimentaries and intrusive rocks. An illustrative geological (Litho-tectonic) map compiled along Tanakpur – Jipti highway corridor (Figure 2.1) exhibits almost all the litho-stratigraphic units of Kumaun Himalayas and its comprehensive stratigraphic succession as worked out by Ravishanker et al. (1996) is given in Table-2.1.

A great pile of highly fossiliferous sediments ranging from Pre-Cambrian to Cretaceous in age and occupy the vast region north of the Malari-Martoli Thrust, in the Kumaun and Tibetan terrains belongs to **the Tethys Himalayas.** These sediments were deposited on the gneissic rocks belonging to Pre-Cambrian, which forms the basement for all younger units. The Central Crystalline gneissic rocks [Rungling Crystalline-referred by Valdiya (1980)] pass upward into partially metamorphosed sequence of biotite-porphyroblastic, calc-schist of Budhi Schist Group. The upper meta-calc sediments of Garbyang Series of Heim and Gansser (1939) belongs to Cambrian age. The Garbyang and Budhi rocks exhibit gradation in metamorphic effects and the structural style.

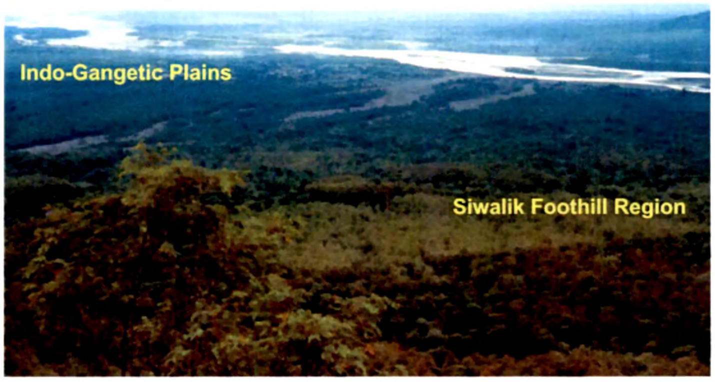
The region between the Main Central Thrust (MCT) and the Malari-Martoli Thrust, **the Higher Himalayas** is made up of regionally metamorphosed high-grade metasediments, migmatites with Paleoproterozoic intrusive granite gneisses and younger granites. These metasediments underlying the Haimanta were grouped under the Vaikrita 'System' by Griesbach (1891). Heim and Gansser (1939) later referred to this sequence as the Central Crystalline zone (SUPER SEQUENCE-I) or crystalline 'Series' and assigned to Archaean age forming the oldest basement.



A close view of Tethys Himalayan Hills, Upper Kali Valley; Loc. Kalapani

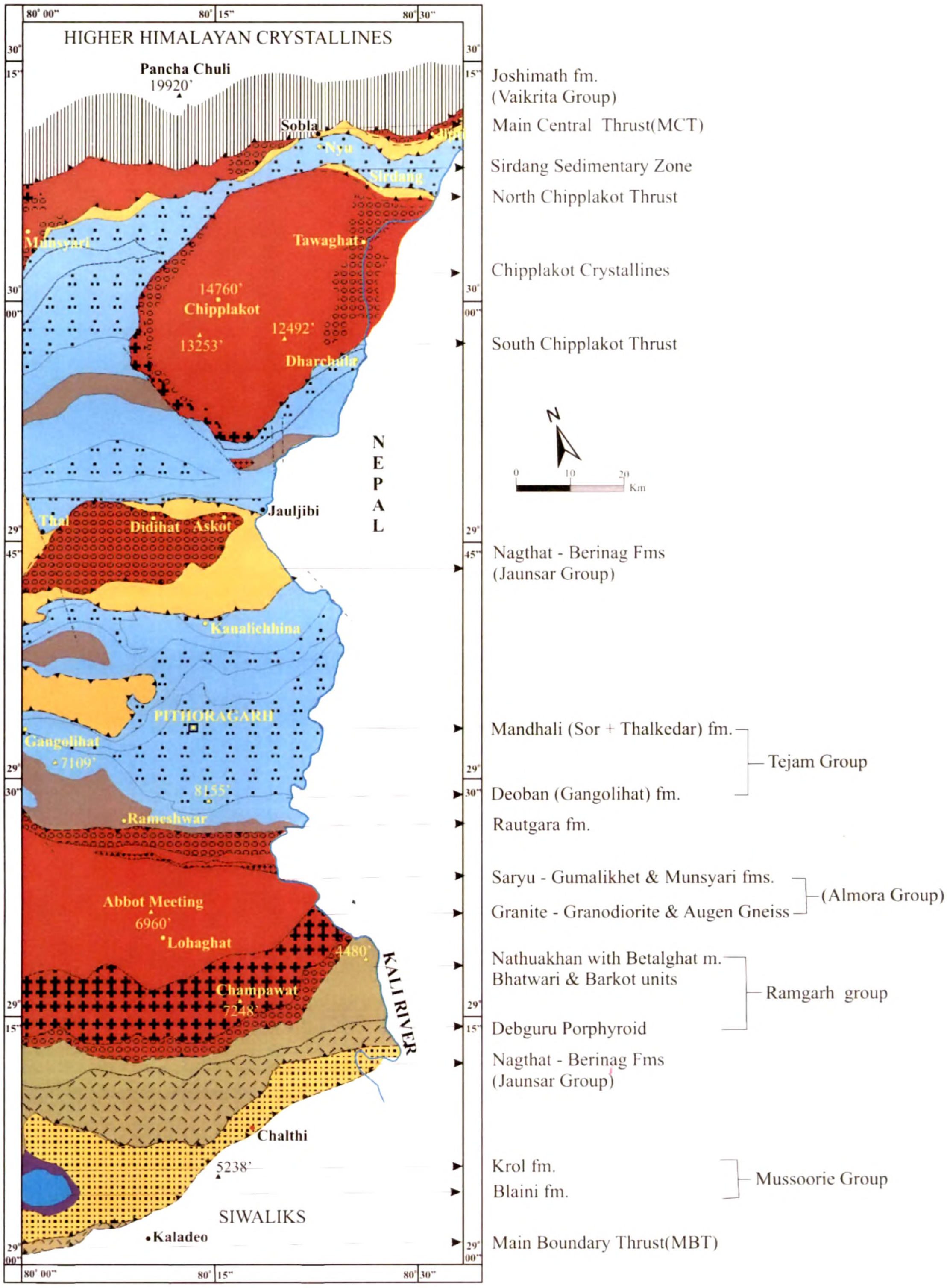


Panoramic view of Lesser Himalayan Range with the back drop of Greater Himalayas; Loc. Lohaghat



Panoramic view of Sub – Himalayan & Indo-Gangetic Plain Region; Loc. Purnagiri

Plate II.1 - Physiographic Views of Himalayan Mountain Terrain



(Modified after Valdiya, 1980)

Figure 2.1 - Litho-Tectonic lap along Tanakpur – Jipti Route Corridor (Kali River), Kumaun Himalayas.

Table 2.1 - Litho-Stratigraphic Succession of Kumaun Himalayas

Geological Time		Super Sequence	Group	Formation
Holocene			Newer Alluvium	Active Channel Alluvium
		XV	Glacial/Lacustrine	Terminal Moraine
			Deposits	Terrace Alluvium
				Alluvium Fan
Pleistocene	L	----------	----------	----------
		XIV	Older Alluvium/	Terrace Alluvium
	M		Glacial/Lacustrine	Lateral Moraines
		----------	----------	----------
	E		Upper	Boulder Conglomerate
Pliocene	L		Siwalik	Pinjor
			Subgroup	Tatrot
			----------	----------
	E	XII	Middle Siwalik	Dhok Pathan
Miocene	L		Subgroup	Nagri
			Lower	Upper Palain
	M		Siwalik	Middle Palain
			Subgroup	Lower Palain
	E		Tourmaline Granite (ca 18 Ma.)	
Oligocene	L	XII	Murees/Dharmshala	
	E		Kasuli - Dagshai	
Eocene	L	----------	----------	----------
	M			
	E	XII	Subathu	Subathu
Paleocene	L			
		----------	----------	----------
	E	X		Manikot Limestone; Balchadhura
Cretaceous	L			Volcanics
		----------	----------	----------
	E			Chikkim Fm.
				Giumal Sandstone
Jurassic	L	IX	Lagudarsi	Spiti Shale
	M			Ferruginous Oolite
		----------	----------	----------
	E		Upper	Lapthal Fm.
	L	VII	Lilang	Kioto Limestone
				Passage Fm.
		----------	----------	----------
Triassic	M			Kuti Shale
	E		Lower	Kalapani Limestone
		VII	Lilang	Niti Limestone

Table 2.1 contd...

			Chocolate Limestone
			Kuling Formation
Permian L	--		
E	VI	-------------------	Gechang Fm.; Boulder Slate
L	--		
Carboniferous E		Kanawar	Po Formation
			Lipak Formation
Devonian			Aishmuqam Formation
	V		Muth Formation
Silurian		Sumna	Variegated Formation
			Shiala Formation
Ordovician			Garbyang Formation
			Ralam Formation
L		-------------------	-----------------------------------
			Granite (ca 500)
Cambrian M	IV	Tal/Martoli (part)	Deoka Tibba-Dhaulagiri/Milam
E			
Neo III		Baliana-Krol/	Blaini-InfraKrol-Chambaghat-Mahi-
Proterozoic		Martoli (part)	Jarashi-Kauriyala/Rilkot Bijlu
II		Granite (ca 750Ma)	-----------------------------------
	IIIb	Vaikrita (part)/	Undifferentiated Vaikrita; Manila
I		Dudatoli/Jutogh	Phyllite-Almora Fm.-Gumalikhet Fm.
Meso		Granite (ca1100Ma)	-----------------------------------
Proterozoic	IIIa	Vaikrita (part)/	Undifferentiated Vaikrita; Mandhali- Chandpur-
		Jaunsar	Nagthat Fm.

	IIb		Granite (ca 1900&1600 Ma)
			Berinag Fm.
			-----------?Disconformity----
Paleoproterozoic		Garhwal	Deoban Fm.
	IIa		Rautgara Fm.
			Granite (2200-2100 Ma)
			Uttarkashi Fm.
			Granite - gneiss (ca 2500 Ma)
			Badrinath Formation
Archaean		Central	Pandukeshwar Formation
	I	Crystalline	Munsiari Formation
			Bhimgora Quartzite
			Ragsi Formation

(after Ravi Shanker et al. 1996)

Later Heim and Gansser (1939) named the tectonic contact with the Garhwal Group (Supersequence II) in the south as the Main Central Thrust (MCT). Subsequently, the Central Crystalline was given a lithostratigraphic status and different workers subdivided and named it differently in different sectors. In case of study area the author has followed the views of Gopendrakumar et al. (1966) and position of the MCT as originally mapped by Heim and Gansser (1939). The rocks of Central Crystalline Zone in Kali Valley have been designated as Munsiari (Joshimath) Formation (Gopendra Kumar and Agarwal, 1975; Agarwal and Mukhopadhyay, 1983; Thakur, 1993). Valdiya (1980a) considered the contact between the lower Joshimath Formation and upper Pandukeshwar Formation as a tectonic plane and referred to as Vaikrita Thrust. It corresponds to Munsiari Formation exposed between Munsiari and Lilam in the Goriganga Valley where it abuts against the Garhwal Group (SUPER SEQUENCE-II) along the MCT in the south. It comprises regionally metamorphosed banded psammitic and pelitic sediments represented by interbedded sequence of garnet mica schist, staurolite-kyanite schist, sericite quartzite, quartz porphyry, amphibolite and associated coarse-grained biotite augen-gneiss. In the Senargad section (Goriganga Valley), the banded para-gneiss contains relicts of conglomerate containing pebble to boulder-size clasts of quartzite. In the Kali Valley, it includes the R1 to R3 units of the Rungling Crystalline Mass (Powar, 1972). Across the River Kali in Nepal it is known as "Annapurna Gneiss complex" (Bodenhausen et. al., 1964).

The Main Central Thrust (MCT) separates the High-grade metamorphic rocks of the Higher Himalayan Crystallines from low-grade Lesser Himalayan meta-sediments. There exists difference of opinion on the nature, location, and even naming of the MCT. Several models have been proposed regarding the presence of retrogressive metamorphism in the Higher-Himalayas of Kali valley region (Thakur, 1987; Sinha Roy, 1982; Jain and Manickavasagam, 1993). Valdiya (1980a, & b) had delineated the MCT (Also Vaikrita Thrust) within the metamorphic sequence, having abrupt change in the grade of metamorphism. Fuchs and Frank (1970) and Shrivastav and Mitra (1994) have also expressed similar views.

The Lesser Himalayan terrain is bounded by two regional tectonic features viz. the Main Boundary Thrust (M. B. T.) in the south and the M. C. T. in the North and comprises Proterozoic to Cambrian marine sedimentary formations with intermittent Nappes of Crystalline rocks. Their stratigraphic and palaeontological uncertainty has created complicated problems in understanding the geology of Lesser Himalayas. Sedimentary sequences of these tectonic units comprise the Berinag, Damta, Deoban, Krol Groups, and Sirdang; whereas the Crystalline units include Ramgarh, Almora Nappes and Baijnath, Askot, Chipplakot klippes. The Krol thrust has brought up a huge succession of sediments divisible into two groups, the lower Jaunsar Group comprising Mandhali, Chanpur and Nagthat Formations of Meso to Neo-Proterozoic ages (SUPER SEQUENCE-IIIA) and the upper Mussoorie Group comprising of Blaini, Krol and Infra-Krol representing *Ediacaran fauna* (Shanker et al. 1997) is a more or less conformable sequence of Neo-Terminal Proterozoic age, while, Tal Formation belongs to Lower Cambrian based on the presence of Brachiopods and Trilobite assemblages of Lower Cambrian age (Tripathi et.al.1984, 1986; Kumar et al.1987 Brasier and Singh 1987).

Lying conformably over the Damtha Group of rocks, the meta-sedimentary sequence of Inner Kumaun Himalaya has been designated as the Calc Zone of Tejam/ Tejam Group (Heim & Gansser, 1939; Valdiya, 1980). Based on the bio-stratigraphic chronology, the Tejam Group of rocks (SUPER SEQUENCE-II) have been assigned middle Paleo-Proterozoic (Ravishankar.et.al.1996). The Tejam Group has been thrust over in the Inner Lesser Himalaya by a huge pile of Quartz arenites and basic Volcanics of Berinag Formation (Valdiya & Pant, 1981).

The Sub-Himalayas is built entirely of the Siwalik sediments that have been thrust over by the Lesser Himalayan rocks. Based on lithology and faunal assemblages, the Siwalik Himalayas (SUPER SEQUENCE-XII) can be subdivided into three parts viz. Lower, Middle and Upper Siwaliks. The age is ranging from Miocene to Pliocene. The normal position of the Siwaliks clearly shows the large structural discrepancy between Siwaliks and the thrust over block of Lesser Himalaya (Heim and Gansser, 1939).

TECTONIC FRAMWORK OF KUMAUN HIMALAYAS

Structural studies have demonstrated that the Kumaun Himalayas exhibits full development of all the four litho-tectonic units. Also this region registers the most frequent seismicity, and provides eloquent evidence of neo-tectonic movements along thrusts and faults. Since the objective of the current study is mainly related to landslides, the tectonics history and the structural characteristics of the region were compiled from the earlier works and the author's own observations. Often the author has incorporated his own findings directly, based on his recurrent visits to the Kumaun Himalayas with his supervisor and research team from M. S. University of Baroda.

The youthful topography of the Siwalik Himalayas is rising in front of the Ganges Plains along the Himalayan Frontal Fault (H. F. F.), and the sedimentary thrust sheet of the outer Lesser Himalaya continues to advance southwards along the Main Boundary Thrust over the Siwalik. The Lesser Himalayas comprises three thrust sheets (Figure 2.2) over riding the autochthonous Riphean sediments (Valdiya, 1981) and characterized by a mature topography. As a consequence of recent rejuvenation rivers are deeply dissected. The thrust plane that separates the Lesser Himalayas from the extremely rugged realm of the Greater Himalayas to the north has thrown up the Precambrian basement to form the highest mountain rampart characterized by sharp peaks, precipitous scarps and deep gorges. To the north yet another regional thrust fault separates the Greater Himalayan block from the huge sedimentary sequence of the Tethys Himalayas. According to Valdiya (1980) higher seismicity and a number of geomorphic features indicate that the fault – delimited tectonic slab of the Greater Himalayas is rising at a faster rate than the Lesser Himalayas. The Tethys region is severely folded and cut by imbricate thrusts in the northern belt. There are four such major thrust faults, three of which are of intra-crustal or even deeper and they separate the various litho-tectonic provinces. A brief description on various tectonic units is given as under –

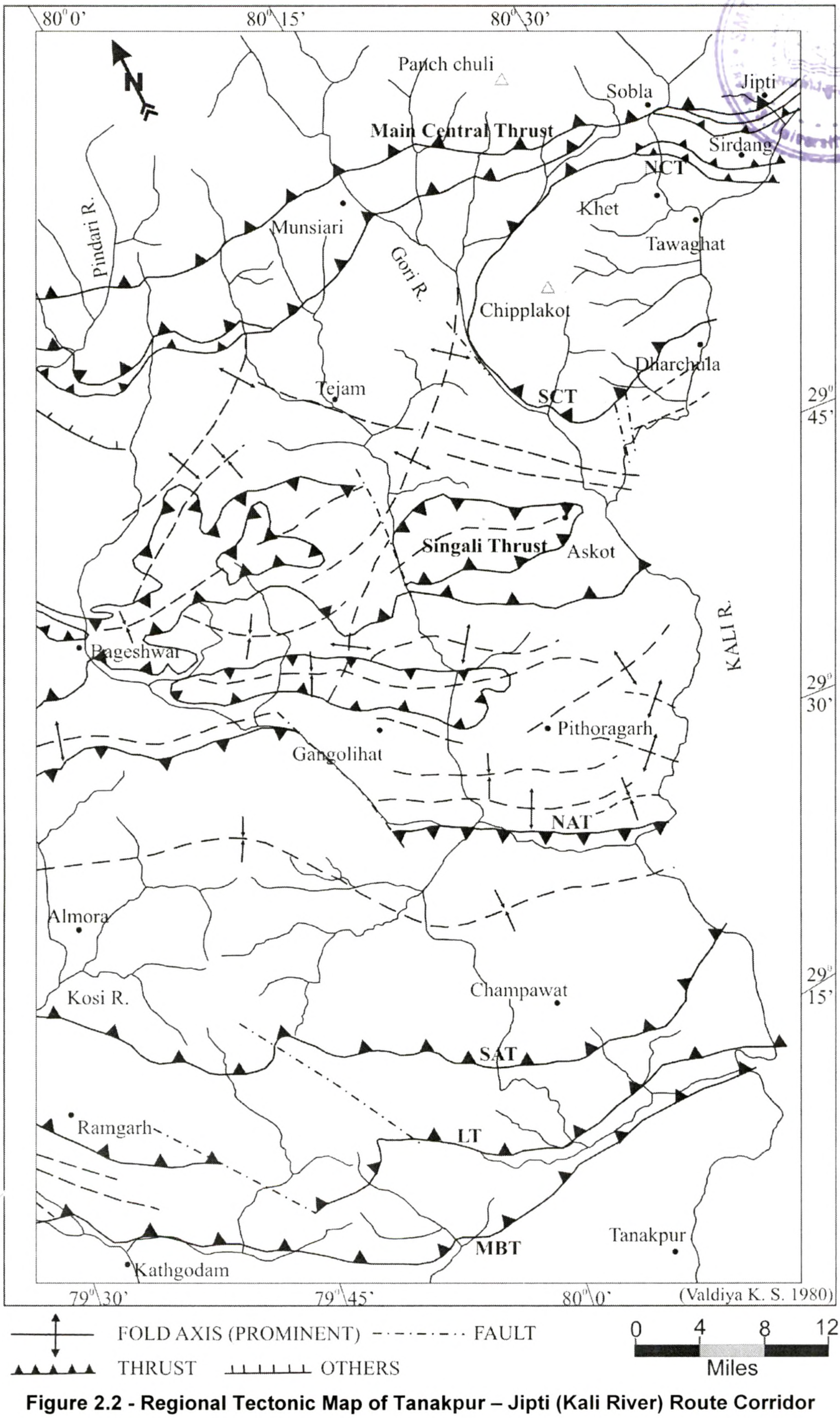


Figure 2.2 - Regional Tectonic Map of Tanakpur – Jipti (Kali River) Route Corridor

Sub-Himalayan / Siwalik Belt

The Siwalik Group sediments represent molasses, show folds, and their intensity increases from South to North considerably and at time in the vicinity of MBT overturning is also observed.

The Lesser Himalayan Belt

The Main Boundary Thrust (MBT) has been defined as a series of four steeply inclined thrusts that separate the autochthonous Cenozoic sedimentary zone and the older Lesser Himalayan province; in Kumaun, it is known as the Krol Thrust (Valdiya, 1980). Characterized by shattering and granulation of rocks, the Krol thrust is marked by perennial springs and straight wide valleys with slopes scarred by landslides.

The *Schuppen* structure is associated with this thrust, which can be seen in the Nainital region. Here the apparently conformable southern flank of the Krol Nappe is thrown into overturned isoclinal folds, with anticlines being split by minor thrusts on the upper part resulting in the repetition and inversion of formations (Pal, 1973). A large number of reverse faults on the northern slopes have given rise to lakes and the Nainital fault has uplifted the northern block compared to the southern block (Figure 2.3).

The Almora Thrust defining the base of the southeasterly plunging nappe is an asymmetrically folded plane. The southern flank, called the South Almora Thrust by Heim and Gansser (1939), dips $20^{\circ} - 30^{\circ}$ NNE/NE, while the northern limb is inclined $45^{\circ} - 70^{\circ}$ SSE/SE or even vertical to overturned as discernible in the Saryu Valley in the extreme east (Valdiya, 1963).

The klippen are likewise delimited by asymmetrically folded thrust planes. The asymmetry increases progressively northward towards the root so that near the root, the Chipplakot unit is an overturned iso-clinal klippe (Figure 2.4). The steeping or overturning of the thrust plane is a consequence of later movements which pushed up the underlying autochthonous sedimentaries against or above the Central Crystallines as seen in Sirdang Zone.

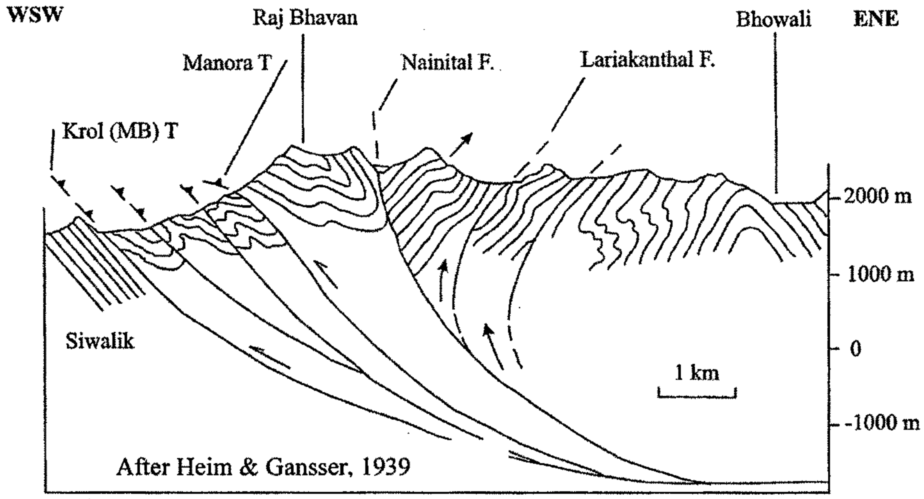


Figure 2.3 - Schematic Cross-sections Showing the Movement along Krol Thrust

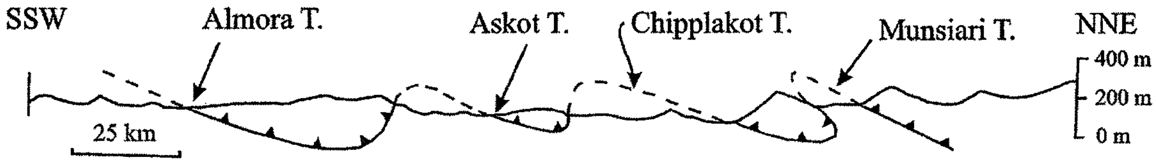


Figure 2.4 - Schematic Cross-sections Depicting Asymmetrical Nature of the Folding of the Crystalline Thrust Sheet (After Valdiya, 1980).

The steeply inclined North Almora Thrust (NAT), which Mehdi et al., (1972), Mishra and Sharma (1972), Saxena (1974) and Merh (1977) regarded as a reverse fault, is marked by a zone of chaotically crushed and complexly folded Rautgara rocks of the autochthon. A persistent band of phyllonite and mylonite with pronounced retrograde changes form the base of the over thrust sheet.

In the klippen, the rocks of the Central Crystalline and the rocks of Berinag Formation exhibit cataclastic deformation, including mylonitization accompanied by retrograde metamorphism. The low angle (10^o – 30^o) tectonic boundary plane between the sedimentary rocks (Berinag Fm. or Mandhali Fm.) of the para-autochthon and the crystalline rocks of Munsiari Formation at the base of the Greater Himalayas was described as the Main Central Thrust by Heim and Gansser (1939). However, Valdiya (1979b) named it in Munsiari region as Munsiari Thrust. Valdiya further opined that the Munsiari bifurcates into two thrusts namely Vaikrita in the South and MCT (sensu-stricto) in the north. This has brought the part of Greater Himalayan meta-sediments into a sandwiched block comprising of Central Crystalline rocks, amphibolites and intrusives (Porphyritic Granite) collectively called as Munsiari Formation. The intense cata-clastic deformation has converted a sizeable part of the Munsiari Formation into mylonitized rocks, including augen gneiss with sheared and fragmented feldspars particularly in the proximity of the Munsiari Thrust (MCT).

Judging from the scale and intensity of deformation suffered by the rocks in the proximity to the Thrust, it is quite obvious that the root zone had experienced severe compression and tectonic dynamism. The age of the granite gneiss of the Munsiari Formation near Kalamuni has been dated at 1895 ±100m.y. and of the Askot crystallines near Didihat at 1960 ±100m.y. (Bhanot, et al., 1977) and the leucocratic granite of the Almora unit near Almora, is approximately 700m.y. The granitic rocks thus point not only to the Almora– Munsiari rocks being of early Pre-Cambrian age but also to the litho-tectonic units of the Munsiari and Askot – Baijnath Crystallines. Possibly these crystallines constitute the basement on which the sedimentary rocks of the Lesser Himalayas were deposited.

At the junction of the Greater and Lesser Himalayas there is no perceptible discordance in the dip of the strata, however the change in the grade of metamorphism is abrupt. The $30^{\circ} - 45^{\circ}$ northward heading thrust is associated with a line of hot springs in the region, as seen at Dar (Dhauliganga), in Goriganga valley upstream of Madkot testifies of its being a deep thrust.

The Greater Himalayas

The Greater Himalayan rocks are characteristic of katazonal high-grade metamorphics (Vaikrita Group) intruded by Tertiary granite and is characterized by flowage folds of usually intra-stratal dimension. The Greater Himalayas represents a huge (~10,000m thick) homoclinal tectonic slab (Figure 2.2) demarcated by the moderately dipping ($30^{\circ} - 45^{\circ}$) M. C. T. (Vaikrita Thrust) in the south and the steeply dipping Malari – Martoli Thrust in the north (Valdiya, 1979a). Between the two tectonic planes the Vaikrita Group represents the up-thrust basement of the Tethyan sediments and the net throw being of the order of 20km.

Tethys Himalayas

The Malari - Martoli Thrust sharply cuts the Greater Himalayas Vaikrita rocks from the Tethyan sedimentary succession, Kumar et. al., (1972) and Shah and Sinha (1974) describe this as a fault. Normally the Vaikrita metamorphics transitionally grade upwards into Proterozoic sediments of the Tethyan succession in the Himalayas [e.g. in Spiti (Himachal), Dhaulagiri (Nepal), etc.]. However, in the Kali valley, the steeply dipping thrust has considerably attenuated and sheared off the Martoli flysch of the sedimentary unit. In the western Dhauliganga valley the Martoli Flysch rests discordantly over the sheared migmatized Vaikrita rocks.

STRUCTURAL STYLE

One of the remarkable features of the tectonic architecture of the Kumaun Himalayas is the existence of transverse structures i.e., folds and faults, affecting all the four litho-tectonic units. Two distinguishable structural regimes characterize the entire Kumaun Himalayas viz. the pre-Himalayan deformation and Himalayan deformation. Pre-Himalayan deformation is associated with at least one distinct episode of deformation 'D_1' while Himalayan deformation is characterized by three distinct episodes of deformation 'D_2, D_3 and D_4' (Kumar and Patel, 2004).

Earliest Deformation (D_1) is depicted in Central Crystallines by first generation folds (F_1), which are now noticeable on minor scale. These folds are developed on stratification plane (S_0) accompanied by development of an axial plane foliation (S_1). Where least oriented, the F_1 folds have nearly E – W trend. These folds are isoclinal and reclined type, having larger amplitude, than wavelength. Generally the F_1 folds occur as intra-foliation folds (Valdiya, 1976; Ahmad.et al.1982). At places asymmetric folds have also developed. Thus, it can be concluded that earliest deformational phase of the Central Crystallines resulted in the creation of isoclinal folds trending roughly in E-W direction with northerly dipping axial surfaces and are absent in the Lesser Himalayan sequences (Garhwal Group etc.) or Tethys.

The **Second Deformation** (D_2) has affected all the tectonic zones, right from Central Crystallines in the Greater Himalayas up to Sub-Himalayas, but it was post Nagthat-Chamoli-Berinag Formations because its imprints are seen in these rocks. This episode created F_2 folds which vary in their geometry from place to place. Development of large scale fractures are perhaps the expressions of this very second phase of deformation. These may be the late tectonic effects of the superposed co-axial deformation in the Higher Himalayan Crystallines and the first phase of deformation in the rocks of Lesser Himalayas. According to Ahmed et al. (1982) in the domains of maximum release of strains regional shear planes like Main Central Thrust (MCT), North Almora Thrust/Fault (NAT), South Almora Thrust/Fault (SAT), Salla Thrust/Fault and Ramgarh Thrust/Fault, were developed which in subsequent times were reactivated time and again. These regional shear fractures/faults are marked today by shearing, brecciation, mylonitisation and close association of certain minerals like talc, steatite and sericite etc. These zones of dislocation are sub-parallel trending in WNW-ESE or ENE-WSW directions with sub-vertical to moderate dips, which change at times to north or south with the exception of MCT which always dips to the north with moderate angle.

Third Deformation (D_3) can be easily understood in post-Subathu (Eocene) times when the entire cross section of tectonic zones from Central Crystallines up to Krol Belt was affected and large scale anticlinoria and synclinoria trending in WNW-ESE to NW-SE direction were formed and the Krol Belt was also uplifted (Ahmed.et al.1982). This stage is responsible of forming Close to Open F_3 folds and crenulation folds during D_3. The F_3 folds plunge gently due N-NW (Kumar and Patel, 2004).

The **Last Deformation** (D_4) had affected all the tectonic zones and the newly created folds, faults and shear planes are almost at right angle to the earlier trends. It is detected from the curvature of the trace of axial surface of earlier folds in N-S to NNE/NE-SSW/SW directions. From the nature of superposed structural pattern, it is evident that this deformation was less penetrative and was in the form of very broad open forms (Valdiya, 1976). The effect of superposition of this deformation (D_4) on the earlier trends has caused widening of hinge zone of superposed folds and formation of box folds; due to almost right angle attitude of hinge lines of two system of folds, distorted domes and basins were formed; conjugate joint system also developed during this deformation; warping and shear fractures and axial plane schistosity of earlier folds also ensued due to this deformation; marked variation was caused in the orientation of earlier folds. In the domal parts, older rocks are seen peeping through the eroded mantle of younger sequences; and might have been instrumental in horizontal translations of Central Crystallines etc. to some extent during the subsequent impulses of Himalayan Orogeny (Ahmad et al. 1982). Kink bands, extensional gashes filled with quartz veins, slickensides and joints are developed on the composite foliation during D_4 brittle deformation (Kumar and Patel, 2004).

The information about sub-Himalayan-Ganga Basin zone is meager and it is not known, how the Pre-Cambrian basement of the Late Tertiary sequence has reacted during the folding of younger sequences in last phases of Himalayan orogeny. However, the monocline low dips of late Tertiary sequences below the Gangetic alluvium suggest that the Pre-Cambrian basement in the Ganga Basin has slightly titled towards the north (Ahmad and Alam, 1978).

GEOLOGICAL SETUP OF TAWAGHAT – JIPTI ROUTE CORRIDOR

Although very comprehensive information on geological aspects of the Kali River Valley has been worked out by various workers viz. Heim and Gansser (1939), Valdiya (1971), Powar (1972) and Kumar and Patel (2004); the author's requirement of geological data on discontinuity specific information and rock identification has necessitated to undertake an independent mapping of the study area. To work out the geology of the TJRC of which Mangti Landslide also constitutes a part, the author had taken three traverses in the Tawaghat – Jipti region, namely,

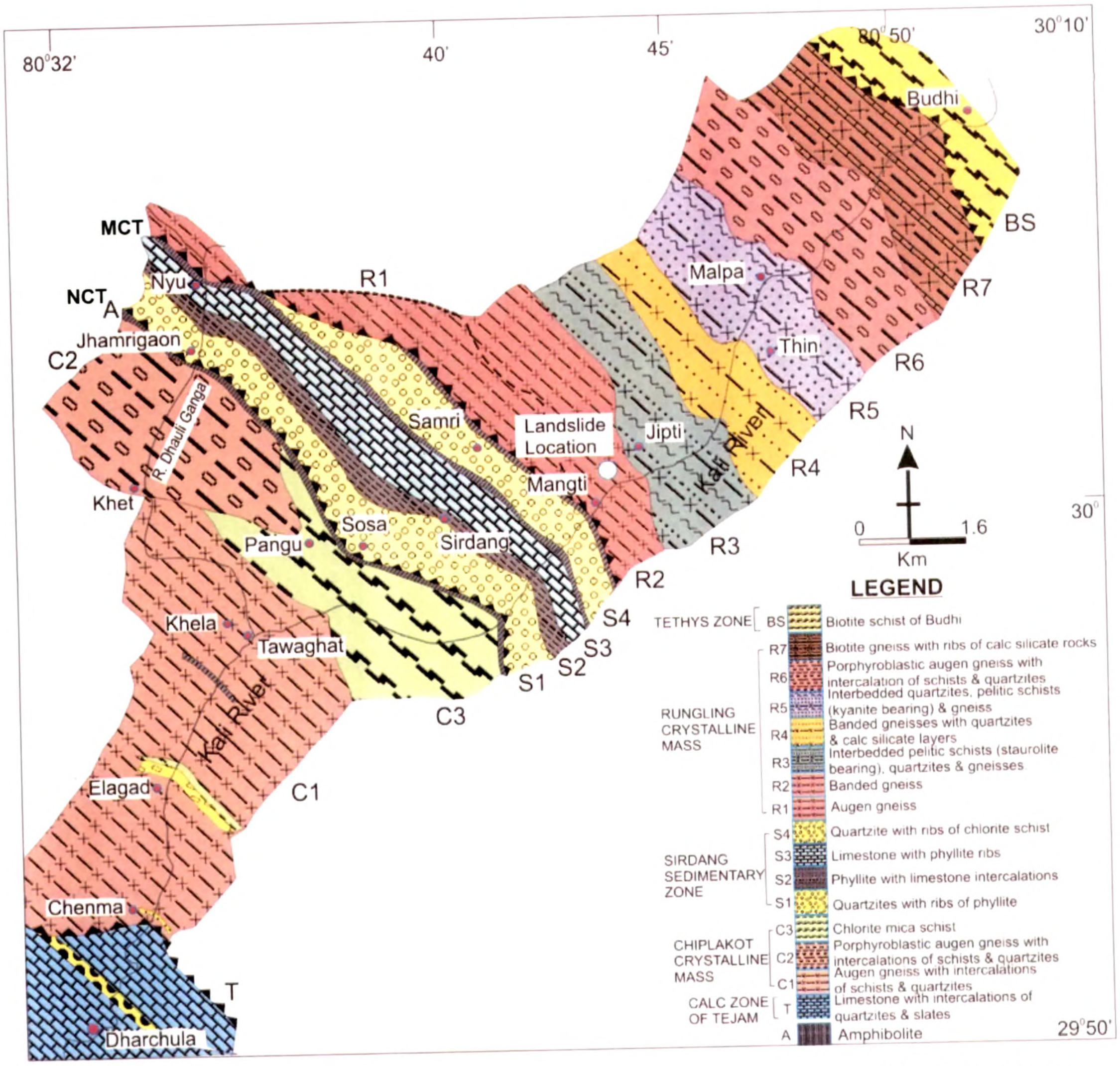
1. Tawaghat - Jipti road traverse along the Kali River.
2. Tawaghat – Dar along Dhauliganga River and
3. Tawaghat – Narayan Ashram Hill Track (in between 1 and 2).

The purpose of these traverses has been mainly to identify and delineate various lithologic and structural contacts, measuring the attitudes of various joints, fractures, lineaments, etc. Further, the representative samples have been collected for subsequent laboratory studies. The mapping was done using Leica make ***GS5*** GIS-GPS Data Collection System (Plate II.2).

Plate II.2 - Use of Leica GS5 GIS-GPS data collection system for inventory of field data

This system gives a non-differential (RMS) accuracy of less than 3 metres. The field points of rock contacts, locations of observation sites, landslides and Ground Control Points (GCP) were collected on WGS84 datum and Geographic Lat/Long as projection parameter. These values were then reprojected to Everest Datum and Polyconic Projection in ERDAS IMAGINE 8.7 software. The obtained co-ordinates of GCP's were then utilized to geocode the Survey of India Topographic Sheets number 62 B/12 and 62 C/9. The resultant geocoded map was used as a basemap on which the rock contacts and observation sites were plotted. Finally a buffer zone of 2km on either side of Kali River from Tawaghat to Jipti was created to outline the study area and the final geological map of Mangti Landslide Region and the entire Tawaghat – Jipti Route Corridor was developed (Figure 2.5 & 2.6).

The geological setup of this region (Figure 2.5) as worked out by Powar (1972) and studied by the author shows more or less parity in observations. The MCT separates Higher Himalayan Crystallines (gneisses, etc.) and metasedimentaries belonging to Tejam Group (Misra and Bhattacharya, 1973). Tejam Group of rocks are bounded between northernly dipping MCT and NCT, while south of NCT follows the rocks of Chiplakot Crystalline. Further, the counterpart geology (Nepal Region) of the route corridor has been adopted as such from the works carried out by Jnawali and Jha (1997).



(After Powar, 1972)

Figure 2.5 - Litho-Tectonic Sequence Between Dharchula and Budhi, North Eastern Uttaranchal State

The litho-tectonic sequence of the T- J Route Corridor is given in Table – 2.2 and the geology of the area is given in Figure – 2.6. The observed field characteristics of available groups' viz. Higher Himalayan Crystallines, Sirdang Sedimentaries and chiplakot Crystallines along with petrographic characteristics are discussed in ensuing paragraphs.

Table 2.2 – Litho-Tectonic Succession of Tawaghat - Jipti Route Corridor

Tectonic Unit	Sub-Tectonic Unit	Lithology
Higher Himalayan Rocks	Higher Himalayan Rocks (Central Crystallines)	Porphyroblastic and Augen gneiss, migmatized banded gneiss, amphibolite, tourmaline granite; garnet mica schist, biotite gneiss, quarzite
	Main Central Thrust	
Lesser Himalayan Rocks	Sirdang Sedimentary Zone (Tejam Group)	Carbonaceous phyllite, schistose quartzite, amphibolite, arenaceous marble, calc-schist, marble
	North Chiplakot Thrust	
	Chiplakot Crystallines	Mylonite gneiss, Augen gneiss, quartz veins, chlorite schist, granitoids
	South Chiplakot Thrust	
	Calc - Zone of Tejam (Tejam Group)	Massive quartzite, schistose quartzite, schist, slate, massive and bedded marble, carbonaceous slate and phyllite

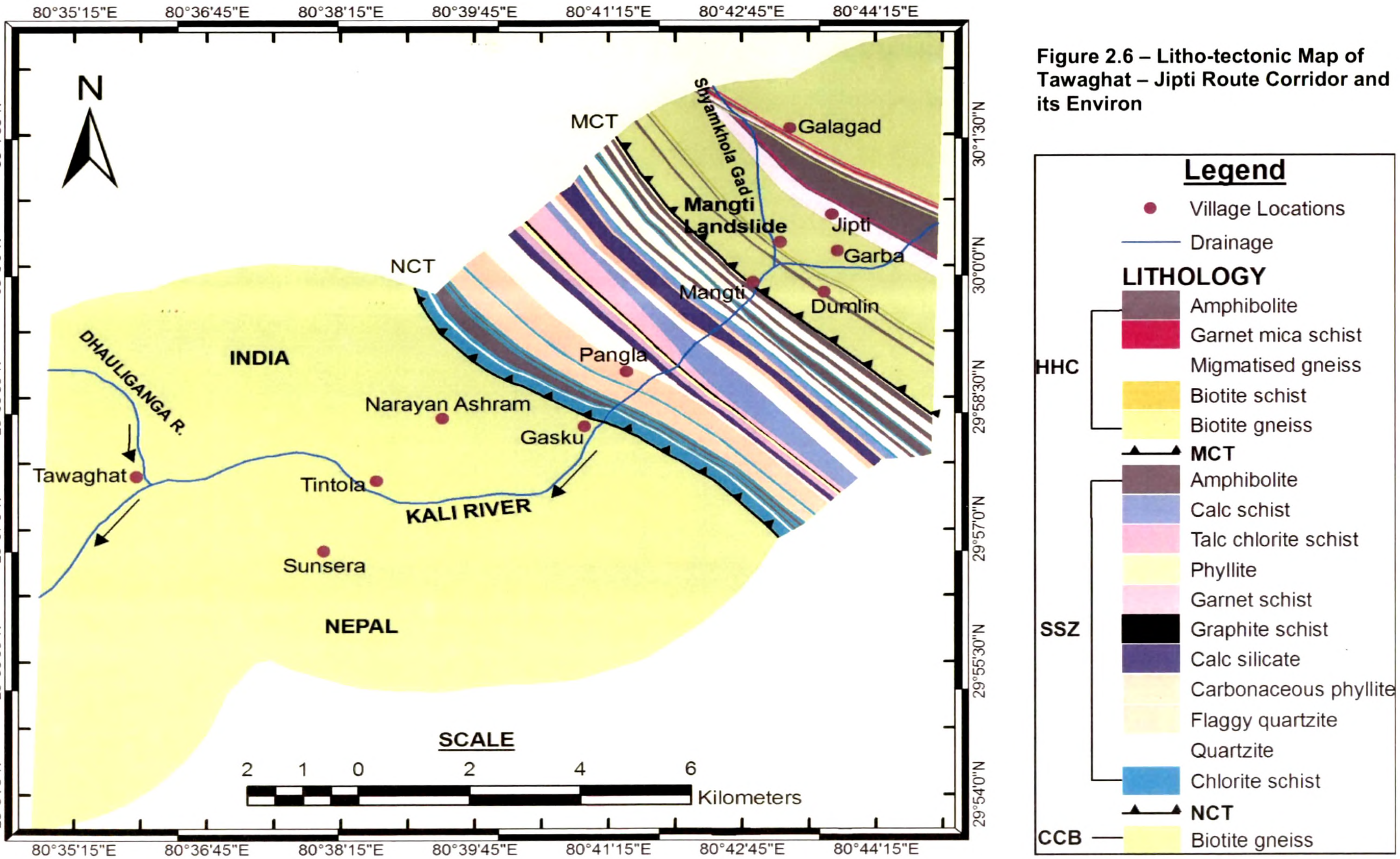


Figure 2.6 – Litho-tectonic Map of Tawaghat – Jipti Route Corridor and its Environ

HIGHER HIMALAYAN CRYSTALLINES (HHC)

The lithology of Higher Himalayan Crystallines (HHC) / Rungling Crystallines (Powar, 1972), is much more varied than the Chipplakot Crystallines. The rocks of HHC are characterized by variety of gneisses having intercalations of schists, amphibolites and quartzites. Radiometric data on a regional scale indicate that the HHC represents a Precambrian basement, 1800-2000 Ma old or may be even older, and has been reactivated during orogenic phases at 500Ma and 12-18 Ma ago (Thakur, 1980; Thakur and Choudhury, 1983).

The following description accounts author's own field descriptions – As it has been enumerated in the preceding geological review that the Higher Himalayan Crystallines are thrust over the younger meta-sedimentaries of Tejam Group (Sirdang Sedimentary Zone and this tectonic contact (Plate II.3A) has been assigned as M.C.T. (Powar, 1972; Kumar and Patel, 2004). From M.C.T. as one moves upward along the road a thick zone representing intercalated sequence of quartzites, biotite gneisses and biotite schist is encountered. Within schistose bands a number of quartz boudins are seen showing pinch and swell structure and their axis is parallel to the foliation plane. Here also four sets of joints can be seen but they are slightly obliterated on account of competent and incompetent sequence of rocks. The general attitude of foliation plane is 148^{o} / 57^{o} due NE. As one moves northward the schistose character diminishes and the gneissose starts dominating.

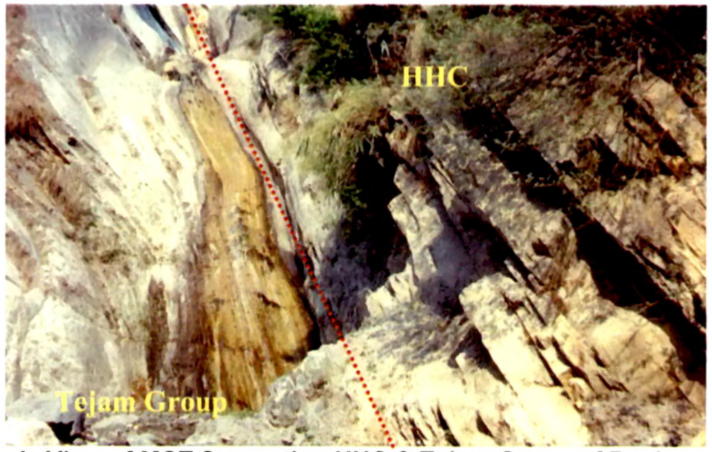
Traversing further upstream for about 400 meters a thin band of amphibolite intrusive body is seen exposed within the biotite gneisses that appear to be almost vertical. The biotite gneissic rocks between the amphibolite zone and the Mangti Landslide zone at Shyamkhola Gad, shows the development of augen structures. Quartz-feldspar grains are seen forming porphyroblasts around which biotite and muscovite are arranged in a preferred orientation giving rise to eye shaped structure. Within these rocks tight recumbent folding and ptygmatic folding of quartz veins are seen at number of places (Plate II.3B&C). The effect of weathering is pronounced and the minerals on the surface are easily getting peeled off. The slide debris contains sandy soil which is on account of the quartz and feldspar grains being expelled out of the main rock as a result of weathering of the surface minerals. The weathering is so pronounced near the landslide zone that the rock can be easily broken with a minor blow of the hammer. The effect of weathering is seen up to a depth of about 1 to 1.5 meters from the surface.

Within the body of Mangti Landslide at the toe region, i.e., Shyamkhola Gad, of the left flank a small outcrop of biotite gneiss show two sets of joints J_1 – 88° / 25° due N and J_3 – 123° / 72° due SW. The other sets of joints are not clear as the bedrock is covered by the debris mass.

As one traverse upward towards the Jipti village the zone of banded biotite gneiss gradually grades into porphyroblastic gneiss (Plate II.3D). The feldspar porphyroblasts are seen embedded in the ground mass of small quartz-mica groundmass. The size of these porphyroblasts ranges from a centimeter in length to about 4cm.

The porphyroblastic gneiss gradually grades to migmatized gneiss (Plate II.3E) just below Galagad village containing bands of Garnet-Mica schists. Perfect porphyroblastic crystals of garnet are observed within these Mica-Schists (Plate II.3F). Marked absence of the garnet mica schist in the adjoining Dhauliganga valley gives an indication that this band pinches out as lensoid body. A thick band of amphibolite rock is seen occurring within the migmatized gneiss, forming the core of the isoclinal folds. Amphibolite appears as dark greenish to black in colour showing pepper and salt texture when examined in hand specimen and at places show pinch and swell boudinage structure of quartz veins (Plate II.3G&H).

Near Galagad village, huge accumulation of talus deposits are seen occurring, which may be the product of weathering and gravity falls of the country rock. Around Galagad village glacio-fluvial deposits have also been observed along streams channels.



A. View of MCT Separating HHC & Tejam Group of Rocks. (Loc. Mangti Village)

B. View of Tight Recumbent Folding in Biotite Gneiss (Loc. Mangti Landslide Zone)

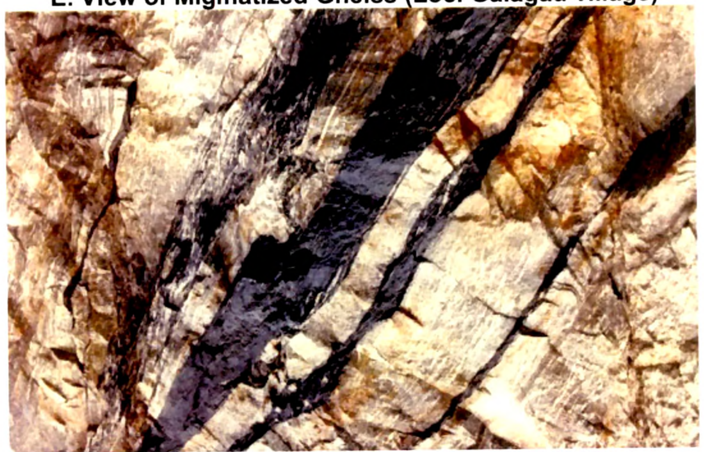
C. View of Ptygmatic Folding in Quartz Vein with in Biotite Gneiss. (Loc. Mangti Landslide Zone)

D. View of Porphyroblastic Geniss (Loc. Garbadhar Village)

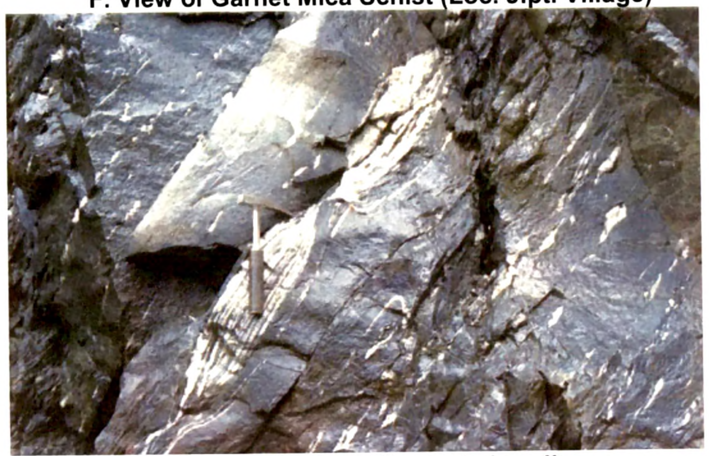
Plate II.3 – contd....

E. View of Migmatized Gneiss (Loc. Galagad village)

F. View of Garnet Mica Schist (Loc. Jipti Village)



G. View of Amphibolite Intrusive with in Biotite Gneiss.
(Loc. Galagad Village)



H. View of Amphibolite with quartz boudins
(Loc. Galagad Village)

Plate II.3 - Field Photographs of Observed Rock Types and Structures Associated with the HHC

Petrographic Characteristics

The present investigation of landslide in Mangti area comprises mainly rocks of Biotite gneiss, migmatites, garnet mica schist, amphibolite and porphyroblastic gneiss belonging to HHC. The petrographic characters of these rocks are described as under –

The Biotite gneiss exhibits porphyroblastic texture, having K-feldspars as porphyroblastic grains, which are enclosed by biotite flakes occurring as groundmass (Plate II.4A). The gneiss represents true mylonitic nature, their large feldspars are `porphyroclasts' that have survived the granulation that was responsible for the fabric of the surrounding matrix. In some slides, a special type of symplectitic texture comprising vermicular (worm-like) structure, having inter-grown Quartz with Plagioclase is seen. It is often referred as myrmekitic textures. At times, the relict alkali feldspar surrounded by muscovite show the development of myrmekite texture. This texture generally relates its development to the breakdown of K-feldspar from the original quartzo-feldspathic rocks (Barker, 1979).

According to Simpson and Wintsch (1989) these textures form in direct response to stress-induced K-feldspar replacement and that preferentially develops on the strained margins of the feldspars. The symplectitic texture reflects retrogression of Hornblende + Garnet or Lime Clino-Pyroxene + Garnet+ Quartz rocks. It is observed in thin sections that some of the Augen Gneiss (Plate II.4B) show changes of Garnet to Biotite; Biotite to Magnetite; and Feldspars are altered into sericite and muscovite in addition to strained quartz porphyroblasts. The presence of relict garnet shows development of poikiloblastic texture (Plate II.4C). In this rock, the feldspars form augen which are wrapped around by the foliation, are shattered and contains deformation twins. Further, tourmaline crystals are also observed at few places.

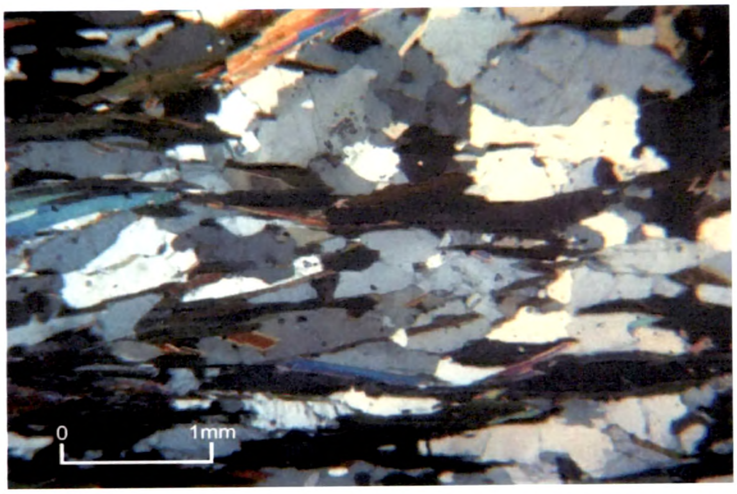
Migmatised Gneiss exposed between Garbadhar and Gala village shows the presence of leucosome and melanosome banding (Mehnert, 1968). Quartz and Feldspars form the leucosome bands while biotite mica forms the melanosome banding (Plate II.4D). Under thin section it also shows gneissose texture. As mentioned above the origin of this rock could be attributed to intercalation of granitic magma between thin layers of schist (lit-par-lit injection).

The **garnet mica schist** exposed in this region has porphyroblastic crystals of garnet having grain size 2 mm to 20mm (Plate II.4E). The garnets under thin section exhibit isotropic poikiloblastic metacrysts with many inclusions particularly of quartz minerals. These rocks may have derived mainly from siliceous and arenaceous sediments, based on their mineralogical composition viz; quartz, garnet, plagioclase and orthoclase with muscovite and biotite aligned in and defining the foliation.

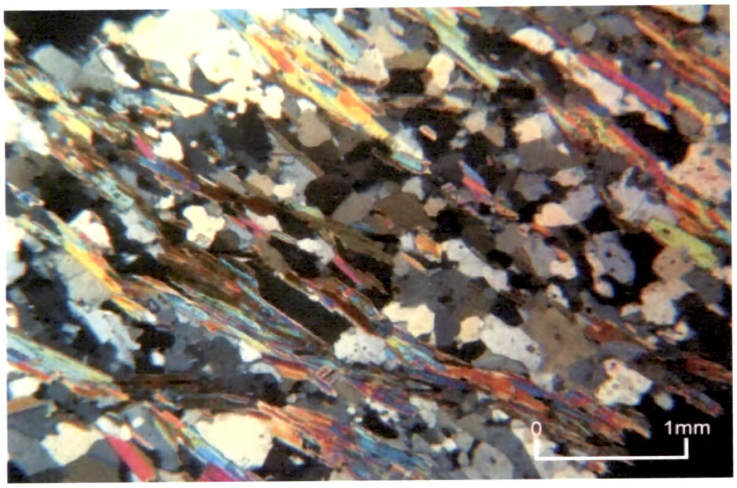
The **amphibolites** occur as an intercalation with country rocks. The minerals show parallel arrangement with dominance of hornblende. In thin section large scale of alteration of hornblende to biotite and chlorites has been observed (Plate II.4F).In general all rocks in this region have undergone retrogression on account of nearness to the structural contact.

SIRDANG SEDIMENTARY ZONE (SSZ)

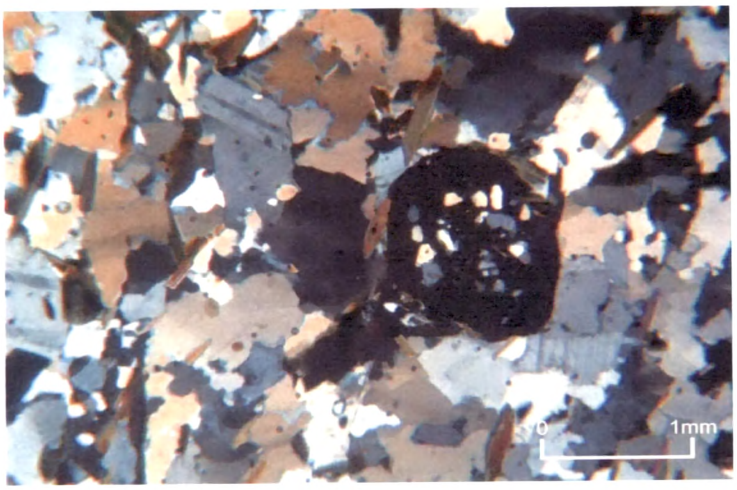
The meta-sediments lying between NCT and MCT belong to Tejam Group of Garhwal Super Group. Misra and Bhattacharya (1973) proposed the name Tejam Group for the Calc-zone of Tejam (Heim and Gansser, 1939) in the adjoining area of Kapkot in the Saryu Valley; Powar K.B. (1972) has named this rock association as Sirdang Sedimentary Zone in the Kali Valley, while Kumar and Patel (2004) have retained the original name as proposed by Heim and Gansser, 1939. The rocks are assigned an age of Precambrian to Silurian (Gopendra Kumar, et.al., 1976). The NCT is demarcated at Gasku village along the Kali River traverse (Figure 2.6), whereas in the Dhauliganga, it is observed north of Jhamrigaon. In between these two rivers in the hilly region NCT is observed at North of Pangu and South of Sosa having NW – SE trend. In the Kali River section the thrust contact is represented by chlorite schist, reflecting the retrogression of augen gneiss (Chipplakot Crystallines). Whereas, in the adjacent Dhauliganga valley, the white quartzites tectonically overlie on the Khet gneisses. They become buff and grey coloured in the upper part and through a zone of slate grade into massive grey limestone's just north of Nyu. These limestones are



A. Photomicrograph of Biotite Gneiss showing quartz, feldspar, biotite minerals.

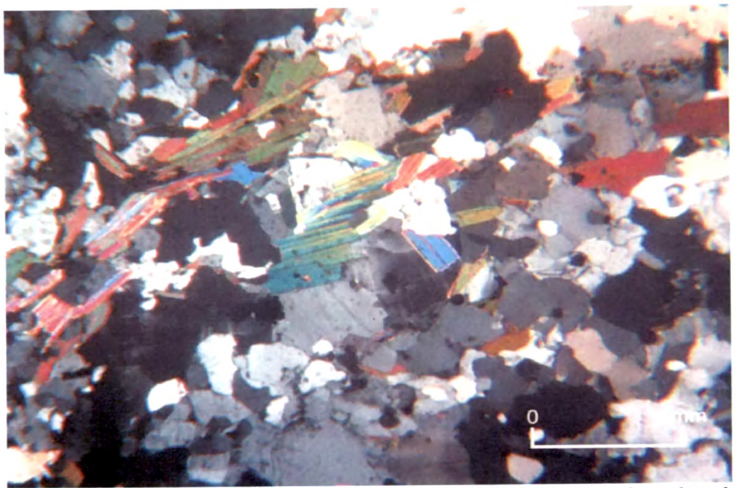


B. Photomicrograph of Augen Gneiss.

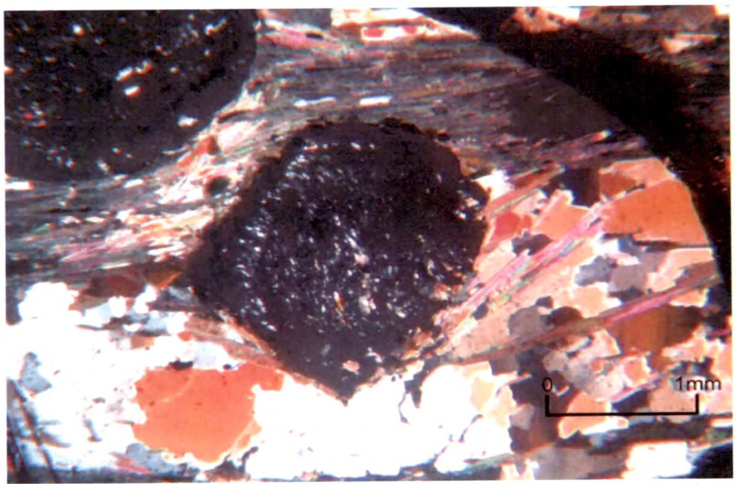


C. Photomicrograph of Granite Gneiss showing porphyro-poikiloblastic garnet mineral.

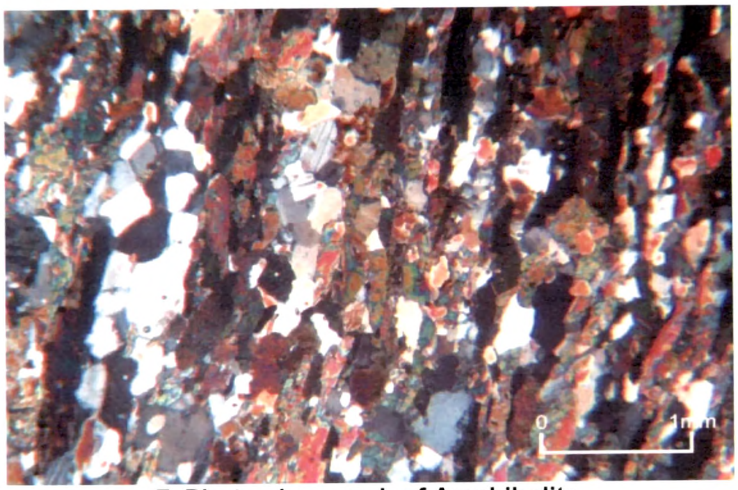
Plate II.4 – contd….



D. Photomicrograph of Migmatised Gneiss in crossed nicols showing leucosome quartz and feldspars with melanosome biotite mica.



E. Photomicrograph of Garnet-Mica Schist in crossed nicols showing isotropic garnet embedded within muscovite mica.



F. Photomicrograph of Amphibolite.

Plate II.4 – Photomicrograph of Different Rock Types and Structures Associated with Higher Himalayan Crystallines/Rungling Crystallines seen with an abrupt contact i.e., Nyu Thrust / MCT with the older gneissic rocks of the HHC.

The position of Sirdang Sedimentary Zone is of considerable tectonic interest. To the west it extends beyond the Dhauliganga and Goriganga valleys. Though it extends eastwards across the Kali river, it is absent in the Kanjiroba area of the western Nepal where Frank and Fuchs (1970) have recognized two crystalline nappes in direct contact with each other. Therefore, this part of Sirdang Sedimentary Zone (SSZ) represents an ideal example of a tectonic wedge between the two crystalline masses (Powar, 1972). In general, these sedimentaries are disposed, 63° due $N40^{\circ}E$ and are folded into an iso-clinal pattern. The axial trend is NNE - SSW direction.

The major rock types encountered within the Sirdan Sedimentary Zone are Quartzite, Schists, Phyllites, Carbonate rocks and Amphibolite as an intrusive body (Plate II.5). These sedimentary rocks show a very low grade of metamorphism (Blue Schist Facies) and at times under the thin sections it simply shows sedimentary characteristics representing the phyllomorphic stage of diagenesis (Dapples, 1962). At places, the pyrite crystals are seen embedded in the pelitic rocks. Three sets of joints are observed in quartzites and limestone, where as large number of boudins and micro-folds are seen developed in chlorite schist.

Field Characteristics

Quartzites

Quartzites of Sirdang meta-sediments have more variation in the textural and mineralogical association on account of their intercalations with phyllite, schists or calcareous sediments. Four different types of quartzites can be classified based on their different colour and jointing pattern. The quartzites exposed between Gasku and Pangla village show pale yellow or buff colour (Figure 2.6, Plate II.5A). The quartzite rock shows sharp contact with the adjacent rock sequences. On close observation of the fresh broken surface under hand lens the rock shows granular texture and layers of mica flakes. The rock chips out in layers on account of parallel layering of mineral grains and criss-crossing of different joint sets. Although quartzites are considered to be possessing high in strength but due to presence of mica and different intersecting joints has fairly affected the strength of this rock. Four different prominent joint sets have been recorded within this rock type. They are **J_1** (Foliation Plane)- 102° / 36° due NNE, **J_2** - 145° / 71° due NE, **J_3** - 106° / 47° due SSW, **J_4** - 10° / 74° due W. The average spacing of foliation plane joints is about 15cms, J_2 is 24cms, J_3 is 2m and J_4 is 60cms. On account of such close spacing of these joints the rock is cut into a number of small slabs. The joint surfaces are slightly weathered and shows no deposition of any clay gouge as the opening between these joints is <1mm.

At some places within the sedimentary sequence occurs ***Flaggy Quartzites.*** The out crops of these are observed near Pangla village and in between Pangla and MCT (Figure 2.6). These rocks are highly jointed with very close spacing of discontinuities having an average joint spacing of 5cms. Criss-crossing of these discontinuous joint planes has given rise to small rhombic shaped blocks of sizes upto 6cm in length. These rocks show no sign of intense weathering and have very tight jointing pattern with opening ≤1mm. As and where the road alignment becomes parallel to any of the joint planes, small rock pieces are seen getting dislodged and fall as shooting stones on the road. These isolated plucked pieces keep falling down from great heights and pose great danger to pedestrians walking in windy weather and also cause considerable damage to the road.

The third category of quartzite is the ***Grey Quartzites.*** They are seen exposed beyond Pangla village (Figure 2.6) and occur as an intercalated sequence with carbonate rocks. The rock is very much compact and shows sachroidal texture. On the fresh surface one can see twinkling of little mica flakes which are arranged parallel to foliation plane. Although the rocks are quite massive in character but where ever the concentration of mica minerals is more, they show development of close spaced jointing. It seems that the preferred orientation of mica minerals is responsible for the development of such closed spaced foliation plane joints. These quartzites display effect of local shearing whose intensity is observed maximum in mica enriched zones. Further, these quartzites occur in the middle of the sedimentary zone and they show massive character but as one move towards north nearing to

MCT, it shows pronounced jointing with decreased spacing in joints (Plate II.5B). The attitude of foliation and joint planes recorded in this unit are –

Foliation (J_1)-119° / 54° due NNE, **J_2**-46° / 85° due SE, **J_3**-122° / 43° due SW and **J_4**-30° / 88° due WNW.

The ***Green Quartzites*** are seen north of Pangla village and very near to MCT (Figure 2.6). They occur in intercalation with chlorite schists and amphibolite. These rocks show very close spacing of jointing and show sharp contacts with chlorite schist and amphibolites. Adjacent to contacts with schists, quartzites show number of planar and wedge failures (Plate II.5C). This region is bestowed with number of perennial springs which keeps on charging the joints with ground water. Characteristically they are similar to other quartzites occurring in the region and only difference is in colour appearance. These rocks are in the proximity of MCT and show prominent four sets of joints- **Foliation (J_1)**- 131° / 63° due NE having an average spacing of 20cm, **J_2**-45° / 62° due SE having an average spacing of 24cm, **J_3**-99° / 23° due S having an average spacing of 2m and **J_4**-5° / 67° due W having an average spacing of 60cm. The joint opening is ≤1mm and has little or no clay infilling material.

Schistose Sediments

Within the sedimentary zone varied type of schists occur ranging from few metres to maximum 200m in thickness. Since the sedimentary zone is isoclinally folded, there exists repetition of beds on either side of the core. North of Pangla a band of **Graphite Schist** is observed in the core of massive isoclinal fold (Plate II.5H). It is jet black in colour and shows silky luster. The thickness of this Graphite Schist band is just about 2m. Parallel arrangement of mica and graphite minerals along foliation plane can be seen on fresh broken surface. The foliation plane shows attitude 132° / 38° due NE. The graphite schist shows sharp contact with biotite muscovite schist.

The **Biotite Muscovite Schist** on either side of graphite schist shows an intercalating relation with quartzite bands (Figure 2.6). These rocks occur between Gasku and Mangti village. In hand specimen silver coloured muscovite and dark greenish brown coloured biotite flakes can be identified easily. Just near to graphite schist sub-millimeter studded garnet crystals can be observed within the schistose rock. This particular stretch of rock since being in the core portion of the fold shows very tight stacking. The foliation plane joint is very well developed on account of preferred orientation of mineral in this direction with absolutely no open spacing of joints. Schists are embibed with number of quartz boudins having their axes parallel to the trend of the foliation (Plate II.5D). Within the schistose rocks the other three sets of joints are not very well developed as seen in other competent rocks and are obliterated.

Chlorite Schist is found in sharp contact with the Chiplakot Crystallines (NCT) and in intercalation with quartzites in south while in north occurs as intercalating sequence with quartzite and amphibolite near MCT. It forms at the outer limb of regional isoclinal fold. This rock at the NCT shows attitude 102° / 54° due NNE while near MCT it trends 110° / 76° due NNE. A substantial increase in inclination is observed from south to north. The rock has characteristic green colour and shows pronounced weathering. The effect of weathering can be observed upto a depth of 1m or so depending on the vicinity to a water body. North of Pangla village an isolated patch of talc schist is seen in contact with chlorite schist. Along the shear planes drag folds are seen (Plate II.5E) and further near to the core of the fold the chlorite schists show crinkled nature (Plate II.5F). Quartz boudins are seen deformed on account of shearing movement (Plate II.5G) and the developed shear plane (N20° – 200°) indicates the direction of shear movement.

The schists in the southern part near NCT are in contact with phyllites. The ***Phyllites*** in hand specimen show preferred orientation of mica minerals in the direction of foliation plane and also considerable amount of quartz minerals. On moistening it the rock gives a typical earthy smell of phyllitic rock. It is hard and compact with a lot of rhombic shaped pyrite crystals of upto 2cm in length (Plate II.5I). Three prominent sets of joints are observed – **Foliation (J_1)**-115° / 45° due NNE with an average joint spacing of 6cm, **J_2**-63° / 81° due SSE with an average joint spacing of 1m and showing obliterated characteristics, **J_3**-121° / 44° due SW with an average joint spacing of 1m. On the rock face throughout the exposed surface rust and yellow coloured powdery deposition is seen which is on account of weathering of pyrite mineral rich in iron and sulphur.

Carbonates

The Carbonates in the Sirdang Sedimentary Zone consists of carbonaceous phyllite, calc-silicate rock and calc schist. These rocks are mainly exposed in the centre portion of the sedimentary zone. The outcrop of carbonaceous phyllite is seen at Pangla village (Figure 2.6). It appears grey in colour, hard and compact and intersected by three sets of joints namely- **Foliation (J_1)**- 114° / 49° due NNE having an average spacing of 15cm, **J_2**-20° / 53° due ESE having an average spacing of 2m and **J_3**-135° / 44° due SW with an average spacing of 20cm. The orientations of the joints are such that they cut the rock into small slabs, which are utilized by local people as building stones. On close examination using hand lens the calcite together with quartz can be easily identified. It gives a very fine grained texture. These rocks lie in sharp contact with the quartzites in north forming an intercalating sequence. Succeeding to this towards north calc-silicate rock is exposed.

The ***Calc-Silicate Rock*** is grayish black in colour and contains considerable amount of silica. On the exposed rock surface profused lime precipitate and white powdery deposition is observed (Plate II.5J). Compared to mica schists the three joint sets are prominently developed and their trends are similar to that of carbonaceous phyllite (Plate II.5K).

Calc-Schist rocks are seen in the northern part of Sirdang Sedimentary Zone near to MCT. The schistosity is seen increasing towards north. The amount of quartz mineral as seen in hand specimen is less and contains more platy calcite minerals. The rock can be easily scratched with a pen knife and likewise the former is intersected by four sets of joints viz. **Foliation (J_1)**-138° / 56° due NE having an average spacing of 4cm, **J_2**-50° / 48° due SE having an average spacing of 42cm, **J_3**-105° / 40° due S having an average spacing of 40cm, **J_4**-30° / 71° due WNW having an average spacing of 50cm.

Amphibolite

The amphibolites in SSZ occur at the base and top of sedimentary zone (Figure 2.6). They occur as intrusives in the form of a sill within the sedimentary zone showing concordant relationship with the country rock. Freshly broken pieces of rock shows characteristic pepper in salt texture and the predominance of hornblende mineral, while at some places sub-millimeter sized garnet crystals have also been identified. The rock shows massive outcrop in southern part of Pangla village near to NCT while in the northern part of Pangla village near to MCT (Mangti village) it is cut into small blocks due to presence of very closed spaced jointing. The joints show less than 1mm opening and devoid of any infilling material. Near to NCT the joint attributes recorded are – **Foliation (J_1)**-113° / 42° due NNE with an average spacing of 20cm, **J_2**-15° / 86° due ESE with an average spacing of 1m, **J_3**-124° / 55° due SSW with an average spacing of 1m. The joint attributes recorded within the amphibolite rocks in vicinity to MCT are- **Foliation (J_1)**-131° / 63° due NE with an average spacing of 20cm, **J_2**-45° / 62° due SE with an average spacing of 24cm, **J_3**-99° / 23° due S with an average spacing of 2m. J4-50 / 670 due W with an average spacing of 60cm and an isolated joint set is recorded showing attitude 67° / 41° due SSE with an average spacing of 2m and having a continuity of about 9 metres. On comparison with both the observed joint spacing the severity of jointing is increasing towards MCT.

Petrographic Characteristics

Quartzites

These quartzites are showing granoblastic texture wherein the grain size vary from medium to coarse, long contact to sutured contact. Owing to the impurities in the original sediments/or quartzwacke and greywacke composition; now they exhibit pure quartzites to micaceous quartzites (Jackson, 1970). These rocks display elongated grains of quartz with parallel oriented micas. The micas are represented by muscovite, biotite and sericite either independently or in any combination. In addition to mica chlorite is also present. At places, the quartzite consists of calcite and quartz occuring as granoblastic grains and at the same time, they are elongated in shape with interlocking arrangement. At times, the rock appears to be of highly diagenetic sedimentary rocks or low-grade metamorphic nature, this may be attributed to their original grain boundaries and presence of recrystallized sparitic cement (Plate II.6A).

Schistose Sediments

In Sirdang Group; the Schist's occurring have wide range of mineralogical changes from Prehnite-pumpellyite facies to amphibolite facies (Turner & Verhoogen, 1960). Texturally, all schist's exhibit typical well parallel oriented flaky minerals in association with elongated quartz grains. Very fine grained minerals of quartz, chlorite and micas represent the phyllite rock which is generally occurring as intercalated bands within the quartzitic rocks and in limestones.

The **graphite schist** displays well oriented laths in association with quartz, fine to medium grains, along with muscovite, chlorite and at times biotite and calcite minerals. These suggest that the carbonaceous argillaceous rocks have undergone low grade regional metamorphism. The graphite schist marks the nearest to the dislocation plane as is reflected from the crushed quartz occurring in augen shape surrounded by the mica flakes (Plate II.6B).

Another type of schist exposed in the region, is the **Chlorite Schist** at the junction of Chipplakot Crystalline and the Sirdang Quartzites. This chlorite schist mainly comprises elongated, porphyroblastic grains of quartz, feldspars and linear chlorite minerals (Plate II.6C). They show parallel orientation.

The **Mica Schists** essentially contains muscovite and biotite along with quartz grains (Plate II.6D), owing their origin to recrystallization under conditions of active shearing or active orogenic pressure (Jackson, 1970). Therefore, these minerals reflect strong unidirectional orientation properties normal to the direction of maximum shortening of the rock. Quartz occurs as lenticular streaks or as vein like bands. Many times, the micas crystallize as unoriented metacrysts and enclose grains of quartz, feldspars or other minerals. They are not oriented parallel to the schistosity, although they have a tendency to lie more near to the foliation planes. Crenulation in the schist is not uncommon, particularly in the crests of folds, where

A. A view of thick white quartzite band (loc.south of Pangla village Geo.lat/lon-29°58'29.40"N/80°41'19.33"E)

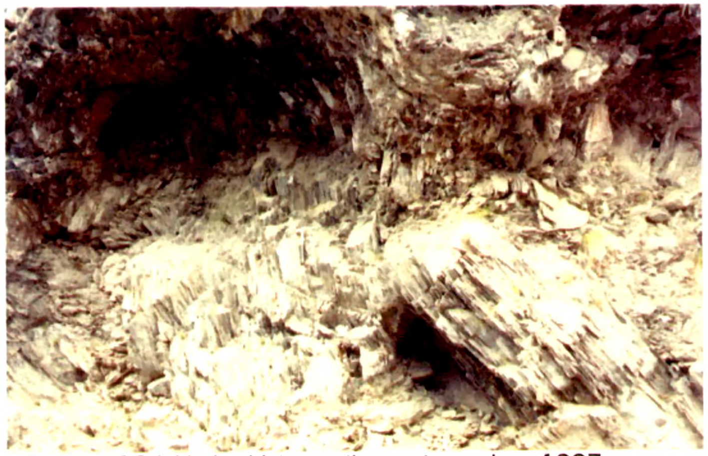
B. View of steeply dipping quartzite north of Pangla village near MCT (Geo.lat/lon-29°59'31.88"N/80°42'39.06"E)

C. View of planar failure in quartzite at MCT as foliation plane joint daylights on the road. (Geo.lat/lon-29°59'50.55"N/80°42'48.26"E)

D.View of Mica schist with quartz boudin (loc. North of Pangla village Geo.lat/lon-29°59'01.03"N/80°41'56.56"E)

Plate II.5-contd....

E. View of Chlorite Schist showing drag folds (loc. North of Pangla village, Geo.lat/lon-29^{0}59'02.93"N/80^{0}41'59.19"E)



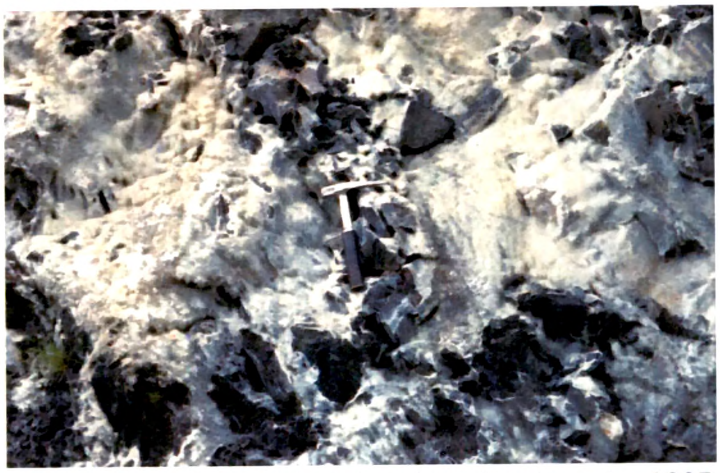
F. View of Crinkled schist near the centre region of SSZ (Geo.lat/lon-29^{0}59'02.93"N/80^{0}41'58.75"E)

G. View of deformed quartz boudins on account of shearing in chlorite schist, the deformation shows the direction of shear movement (Geo.lat/lon-29^{0}59'26.55"N/80^{0}42'32.05"E)

H. View of thin bands of Quarzo-Phyllites with intercalated Graphite schists (Geo.lat/lon-29^{0}58'58.36"N/80^{0}41'53.50"E)

Plate II.5-contd....

I. View of Phyllite with embedded Pyrite Crystals (loc. South of Pangla village, Geo.lat/lon-29°58'34.74"N/80°41'22.83"E)



J. View of lime precipitate deposit on the carbonates rocks of SSZ (Geo.lat/lon-29°58'52.26"N/80°41'49.11"E)

K. View of Calc-Silicate rock traversed by shear zone and showing steeply dipping foliation plane (loc. North of Pangla village Geo.lat/lon-29°59'04.45"N/80°42'01.82"E)

Plate II.5 - Field Photographs of Different Rock Types and Structures Associated with SSZ

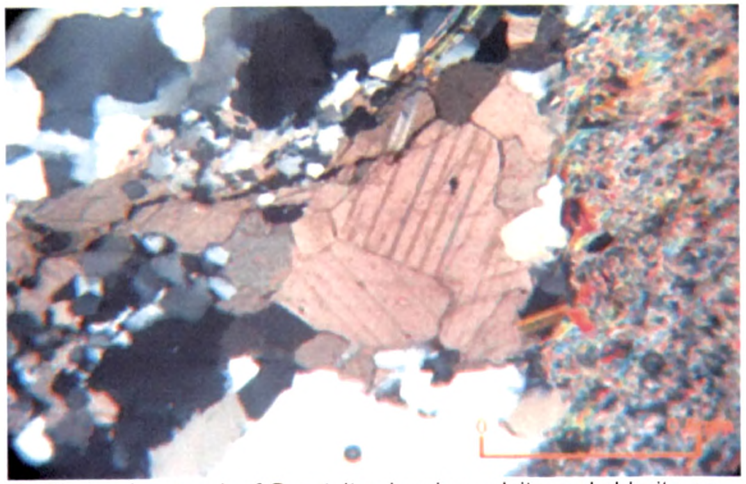
crumpling rather than shearing is to be expected. However, in certain schists, the orientation of mica clearly points the directional orientation indicating two deformational events. It is not uncommon that this mica schist shows crinkled nature (Plate II.6E) suggesting two deformational events.

Meta – Carbonates

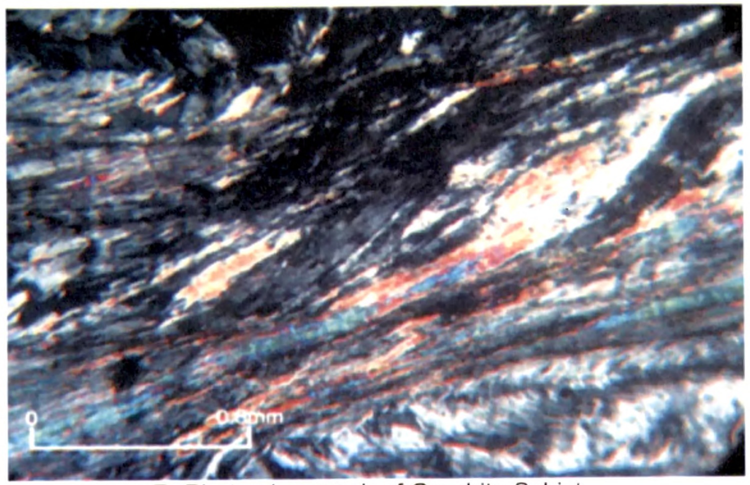
The limestone bands of Sirdang Sedimentaries consist of calcite grains having the size >4μ and few quartz grains are embedded within the calcite. At first glance it appears to be a sedimentary rock, i.e., quartz sparite; however, calcite and quartz porphyroblasts show elongation pointing to low grade metamorphic nature (Jackson, 1970). The impurities such as clays in the limestone parent rocks and also the intercalation of argillaceous rocks have given rise to micaceous minerals and alternate meta-carbonates and schistose structures. Such relationships are observed in between Gasku and Mangti locality (Plate II.6F). These carbonates also display granoblastic textures with equi-dimensional grains of calcites. Owing to its massive nature, they are brittle in character.

Amphibolites (Hornblende Schists)

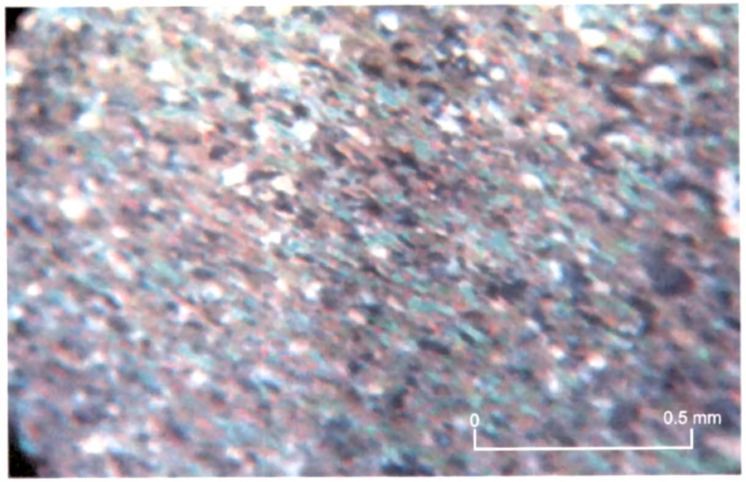
Often the hornblende schists are called amphibolites (Plate II.6G) and are formed by the metamorphism of calcareous rich argillites. Amphibolites occur within the Sirdang Sedimentaries more or less parallel with the foliation of the country rocks. Under the microscope the hornblende occurs as dominant mineral. Commonly oriented parallel to the schistosity (Plate II.6G). However few grains exhibit perpendicular relationship indicating two deformational natures. Often the hornblendes have changed into biotite and released Fe minerals such as magnetite (Plate II.6H). In addition to hornblende, quartz, k-feldspar and garnet are present. The garnets have lots of inclusions of quartz grains and exhibit alteration along the fractures. The altered products are chlorite minerals. The quartz appears as crushed grains, whereas k-feldspars have altered into sericite. The amphibolite bands occur near to the MCT and NCT, which reveal the above evidence points to the retrogression of the rocks (Jackson, 1970).



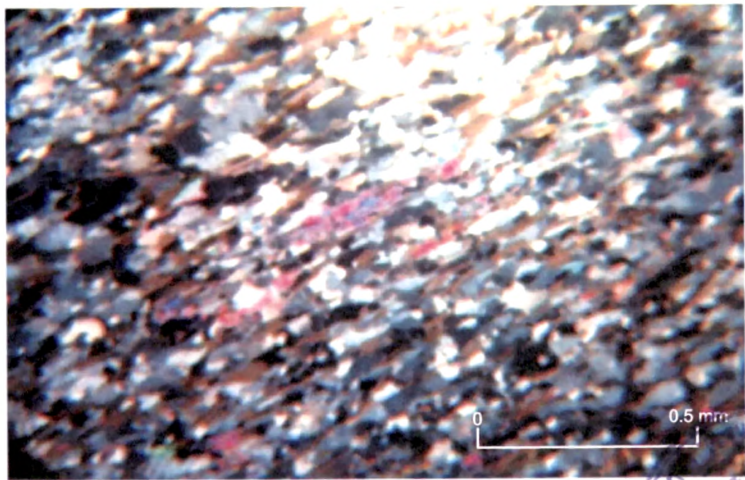
A. Photomicrograph of Quartzite showing calcite and chlorite as accessory minerals.



B. Photomicrograph of Graphite Schist

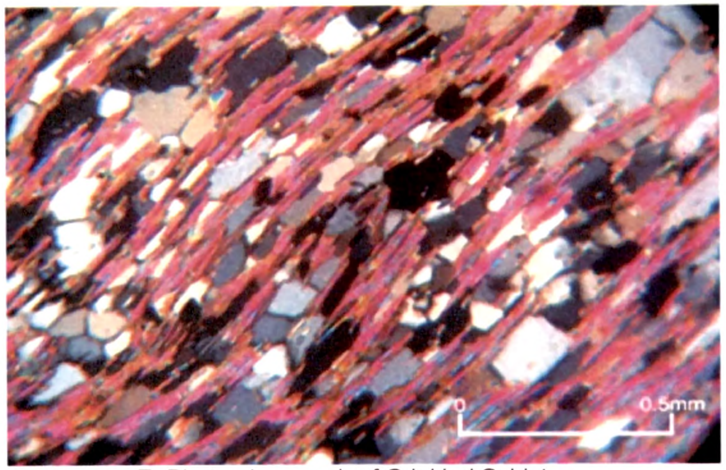


C. Photomicrograph of Chlorite Schist

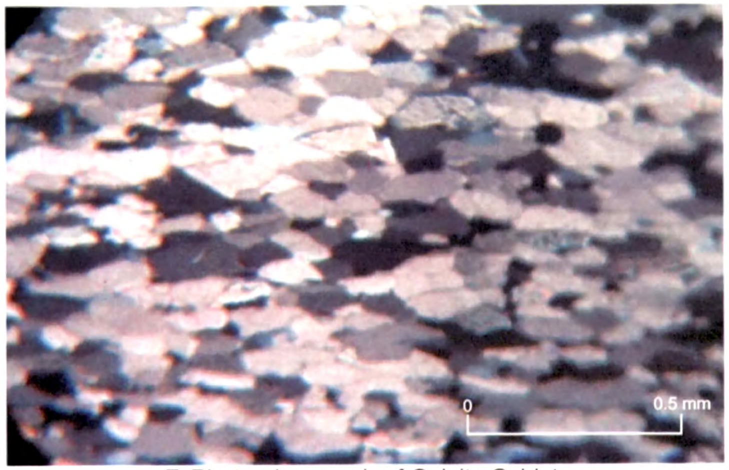


D. Photomicrograph showing Biotite Muscovite Schist

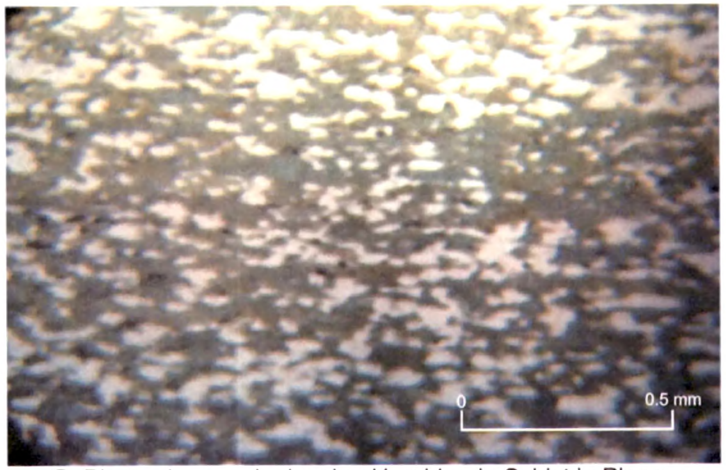
Plate II.6-contd....



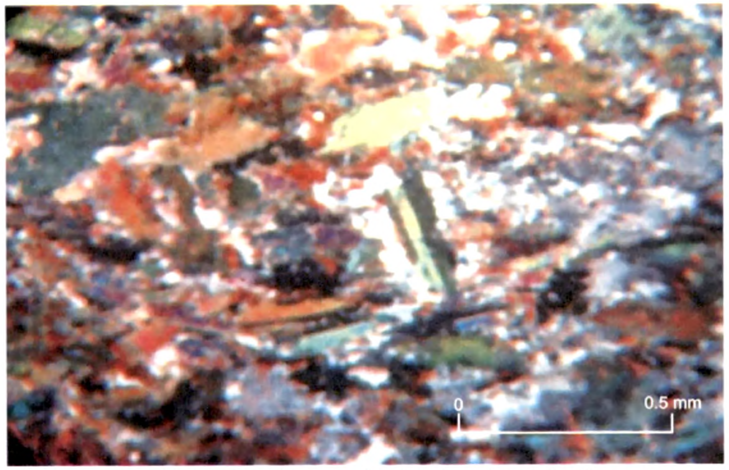
E. Photomicrograph of Crinkled Schist



F. Photomicrograph of Calcite Schist



G. Photomicrograph showing Hornblende Schist in Plane Polarised Light



H. Photomicrograph showing Amphibolite

Plate II.6 - Photomicrographs of Different Rock Types and Structures Associated with the Sirdang Sedimentary Zone

CHIPLAKOT CRYSTALLINE BELT (CCB)

The Chiplakot Crystalline Belt (CCB) is a major thrust sheet within the rocks of Calc-Zone of Tejam of the Lesser Himalaya. It is separated by thrusts at the base and top from the Calc-zone rocks of Tejam of the Lesser Himalayas (Figure 2.6). The southern margin of the crystalline unit is a well-defined steeply northeast dipping thrust surface and is best exposed in the north of Dharchula along Kali River. It is designated as South Chiplakot Thrust (SCT). The upper most contact of the CCB is a northerly dipping thrust along which the Calc-zone of Tejam (north) is thrust over the CCB. It is named as North Chiplakot Thrust (NCT). It occurs as a thin lensoid wedge within the meta-sedimentary sequence (Dubey and Paul, 1993). Two distinguishable structural regimes characterize the CCB, viz. one pre-Himalayan deformation episode D_1 and three Himalayan deformation episodes D_2, D_3 and D_4 (Kumar and Patel, 2004).

The rocks belonging to CCB covers long stretch from north of Dharchula to south of Gasku village ~28 km. However, the author's area begins from Tawaghat, i.e., Kaliand Dhauliganga confluence; therefore the proceeding description of CCB begins from Tawaghat onwards and upto NCT. The confluence of Dhauliganga and Kali River is characterized by a deep and narrow gorge (Plate II.7A). This gorge continues along Kali River for a couple of kilometers in upstream direction then near Tintola village the valley broadens up with moderate valley slopes. The valley segment is dominated by Biotite Augen Gneiss (Plate II.7B) characterized by leucocratic to mesocratic in colour. However, near confluence there exists a solitary exposure of quartzite-schist band. Occasionally these gneisses are porphyroblastic in nature with quartz and quartzo-feldspathic veins occurring along the foliation planes.

The gneiss shows distinct foliation having more or less uniform dip of about 45° in the direction of N and NE (Plate II.7C). These gneisses show prominently four sets of joints viz. J_1-115° / 47° due NE with an average spacing of 0.6 – 1m, J_2-77° / 48° due SSE with an average spacing of 1.5m, J_3-122° / 52° due SSW with an average spacing of 1m and J_4-15° / 45° due W. The joints in CCZ are very widely open (> 1mm) with a lot of infilling rock fragments, soil and clay material (Plate II.7D). At places thick vegetation is seen growing from within these joints (Plate II.7E). Also in proximity of a water body the dampness on account of seepage of ground water has facilitated growth of moss and algae within the open joint surfaces. All together its not good situation to have mosses and algae as they themselves provide a frictionless surface on which blocks of gneisses keep getting detached from time to time.

The contact between augen gneiss and biotite gneiss is not sharp, it gradually grades from augen to banded gneiss. On account of intense fracturing and also proximity of the thrust these rocks are highly crushed and fragmented. Owing to this, they easily give away from their original position causing rock falls or scree materials (Plate II.7F). The emplacement of granitic mass (Granitoid) within this unit is observed between Tintola and Gasku villages locality (Plate II.7G). At places the euhedral tourmaline crystals are seen embedded within the Biotite Gneiss (Plate II.7H).

Petrographic Characteristics

The Chiplakot Crystalline Zone between Tawaghat and Gasku (Till North Chiplakot Thrust) the following rocks have been recorded.

- Augen gneiss with intercalation of schists and quartzites
- Porphyroblastic augen gneiss with quartzites and schists
- Granitoids and
- Chlorite mica schists at the contact of the thrust

The partial melting of the pelitic sediments on burial under regional metamorphism, produces inter-banding of quartzo-feldspathic layers and mafic layers to give a gneissose structure. Such bands are generally seen in hand specimens; is not readily appreciated in thin section.

The augen gneiss consists of augen {eyes} usually of feldspars (typically K-feldspar) and at times quartz; in a strongly foliated gneissic matrix. The matrix comprises micaceous minerals mainly biotite and muscovite; arranged in bordering feldspars and quartz porphyroblasts (Plate II.8C). The eye of the quartz is highly crushed reflecting the mylonitic nature. Microscopically, the minerals in these eyes of relic

A. View of nearly vertical sloping hills near the confluence of kali-Dhauliganga River.(loc.Tawaghat,Geo.lat/lon-29°57'33"N/80°36'12"E)

B. View of Biotite Augen Gneiss (loc. North of Tintola Village Geo.lat/lon-29°57'26"N/80°38'46"E)

C. View of Biotite Gneiss Foliation Plane trending in NE direction (Geo.lat/lon-29°57'37"N/80°40'39"E)

D. View of Joint System in CCB. Joints have opening >5mm and show rock fragment and clay gouge infilling. (Geo.lat/lon-29°57'26"N/80°38'46"E)

Plate II.7-contd....

E. View of thick growth of vegetation within the joints of biotite gneiss where continuously ground water is recharged through streams (Geo.lat/lon-29°57'56"N/80°37'38"E)

F. View of Massive Block Slides developed on accout of severity of jointing within the CCB (Geo.lat/lon-29°57'26"N/80°38'46"E)

G. View of Granitoid outcrop within the CCB. (Geo.lat/lon-29°57'27"N/80°39'56"E)

H. View of Euhedral Tournaline Crystal studded in Biotite Gneiss (Geo.lat/lon-29°57'24"N/80°39'28"E)

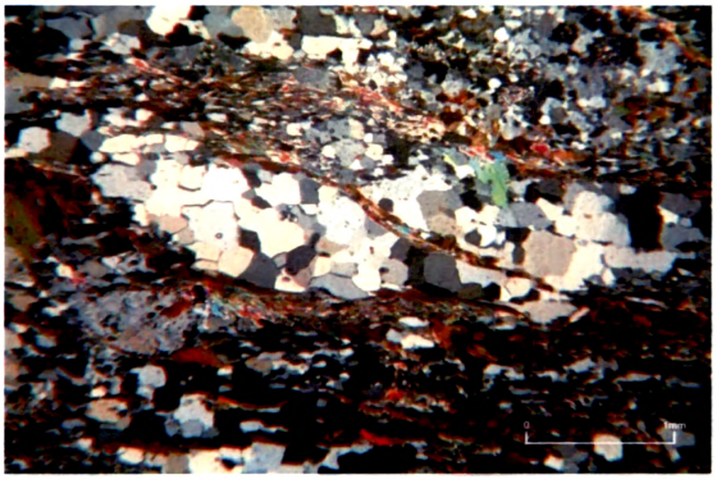
Plate II.7 - Rock Type Variation (CCB) and Associated Features Between Tawaghat - Gasku Segment Along Kali River Valley

material show such strain effects such as marginal granulation, undulatory extinction, and bending of cleavages cracks. Quartz develops undulatory extinction parallel to the 'C'-axis, and in many grains there are fine lamellae, emphasized by streaks of inclusions (Plate II.8A). The chlorite mica schist is seen occurring near the thrust show parallel orientation of the flakey minerals like chlorite, biotite and muscovite. These minerals reflect retrograde nature.

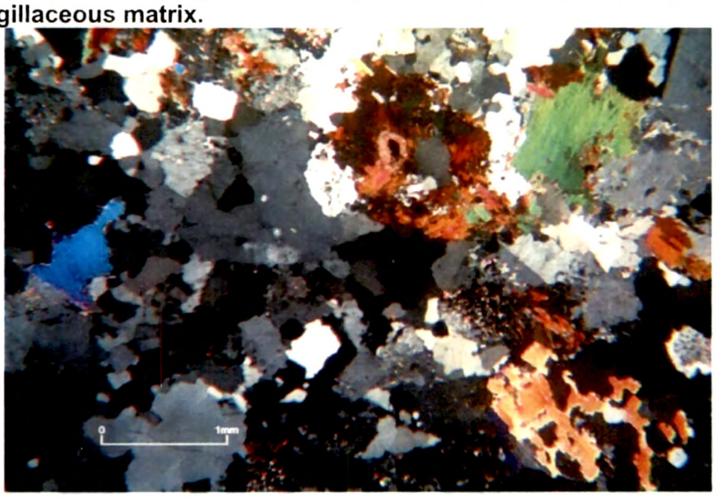
The Granitoid body that has emplaced within these gneisses is typically characterized by hypidomorphic texture with quartz-feldspar-muscovite-biotite-tourmaline as important minerals (Plate II.8B).

STRUCTURAL ANALYSIS

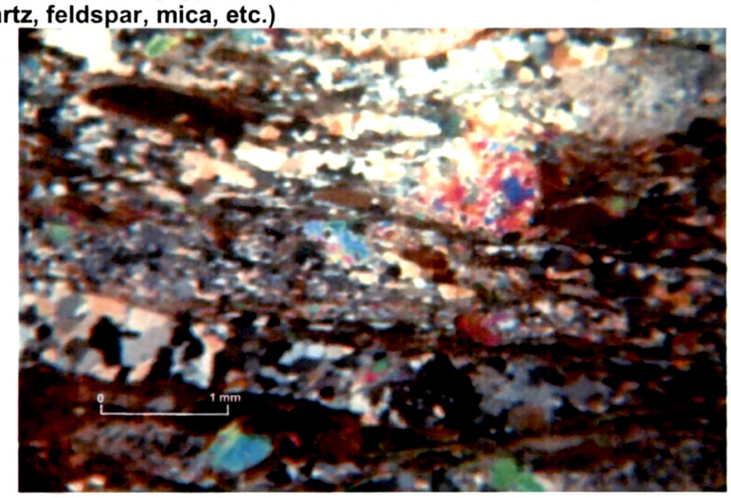
The structural aspects of lithology have been considered to be the foremost important conditioning factor accentuating the slope failures. Information on available joints gathered through scan line survey was subjected to routine but important office techniques of structural analysis (Hoek & Bray, 1974). To work out the regional variation in structural trend based on the occurrence of three different litho-tectonic groups of rocks; the study area has been divided into three zones, viz. Higher Himalayan Crystallines (HHC), Sirdang Sedimentary Zone (SSZ) and the Chiplakot Crystalline Belt (CCB). From north to south, HHC area corresponds to region between Jipti and Mangti, SSZ area forms the region between Mangti and Gasku village, while CCB area forms the region between Gasku and Tawaghat along the Kali River Corridor. In order to work out lithological specific structural details of Tawaghat – Jipti Route Corridor, detailed mapping has been carried out. To record precise locations and observations Leica Make (GS5) GIS – GPS Data Collection System was used. Based on data gathered on foliation, joint sets and the major structural features developed in the area, stereograms have been prepared for each sub-area by plotting poles for different joint planes and foliation in lower hemisphere of Lambert's equal area projection net and subsequently, contoured by Dimitrizevic net (Dimitrizevic, 1956). Entire exercise of structural plotting has been carried out using GEO-ORIENT software and with its help rose-diagram, pi-diagram and contour diagrams have been developed. Structural analysis of all three litho-



A. Augen Gneiss showing well developed quartzo-feldspathic augens surrounded by argillaceous matrix.



B. Granitoid showing typical hypidiomorphic texture and granitic mineralogy (quartz, feldspar, mica, etc.)



C. Gneiss showing quartz and feldspars in lensoid form, muscovite, biotite and tourmaline as pale blue coloured mineral.

Plate II.8 - Photomicrographs of Different Rock Types and Structures Associated with the Chiplakot Crystalline Rocks.

tectonic domains is given in **Pocket Map-1** and a detailed interpretation derived from structural analysis follows as under –

The foliation trends show considerable variation and at places highly obliterated. This may be attributed to superimposed deformation and the local shearing respectively. Regionally the rocks show tight iso-clinal folding, dipping in north-easterly direction. Five prominent categories of joint sets have been recorded, which are developed on account of intense tectonic activity in the past geological time. A brief description of these prominent joint sets is as follow –

Joint Set 1: The foliation joints are the most penetrative structural element of the area this joint set has dip varying from 25° - 64° and the amount of dip varies from as low as 12° to as high as 70°, which creates plane of fissility and imparts schistosity to the rock with parallel orientation of the micaceous minerals. The joint plane developed parallel to foliation is also represented by schistosity formed by the parallel alignment of flaky minerals, platy calcite, felsic minerals and stretched quartz grains, etc. it is the most pervasive plane of the Central Crystallines.

Joint Set 2: this joint set has dip varying from 110° - 150° and the dip amount varies from as low as 56° to as high as 88°.

Joint Set 3: this joint set has dip varying from 191° - 230° and the dip amount varies from as low as 50° to as high as 80°.

Joint Set 4: this joint set has dip varying from 240° - 289° and the dip amount varies from as low as 54° to as high as 80°.

Joint Set 5: this joint set has dip varying from 308° - 350° and the dip amount varies from as low as 30° to as high as 85°.

The joint set 2, 3, 4 and 5 occur at an angle and intersects each other, forming wedges at many places. The last set 5 does not have wide occurrence and is seldom seen in SSZ and CCB, while its frequency of occurrence is conspicuously seen more in HHC. Apart from these major sets of joints there are various other sets of crisscrossing joints exits which show their dips in north, south and eastern directions. These stray joints might have been resulted due to excessive blasting works for the road development. Amongst these the radiating joints are ubiquitously seen.

The structural analysis of the observed joint pattern shows considerable variation in terms of joint intensity and trends within the CCB and HHC domains from that of SSZ (Figure 2.7). Although NW-SE joints consistently prevails in all three litho-tectonic domains but their frequency tends to increase as one move from lower Chiplakot through Sirdang to Higher Himalayan Crystallines. Further, the N-S and E-W trending joints frequency is extremely high in HHC rocks. Whereas, the Sirdang Sediments although occurring between two crystalline mass show very low jointing frequency (Figure 2.7).

This observed drastic variation in joint intensity and patterns may be attributed to basic composition of the rocks and the prevailing tectonic compression experienced by the HHC, adjacent to the Main Central Thrust. The role of anthropogenic activities also cannot be ruled out due to the ongoing road development activity in Mangti – Jipti area. Also from south to north it is observed that the inclination of foliation plane joint is increasing towards MCT. Near the Tawaghat it has a dip of 40°, at NCT it shows dip of 54° and on reaching MCT the dip angle increases to 63°. On crossing the MCT the gneisses again show decrease in dip angle to 57°.

MAIN CENTRAL THRUST

The Main Central Thrust demarcates the contact between Lesser Himalayan Sedimentaries (Sirdang Sedimentary Zone) and the Higher Himalayan Crystallines (Rungling Crystalline Mass). This is a low angle thrust (Valdiya, 1972). The tectonic contact in Mangti village shows its attitude - 130° / 61° due NE. A perennial stream is seen flowing over its surface which also keeps recharging the surrounding rock masses with ground water (Plate II.9A). At Mangti village, there forms a thick zone of around 30 meters where intermixing of quartzite with gneissic rock can be observed. Then it gradually grades into a full-fledged Biotite Gneiss of Rungling Crystallines. In Nepal side, the MCT shows juxta-position contact between younger Quartzite of Sirdang Sedimentary Zone and the older Biotite Gneiss of Crystalline mass, which is very sharp. It can be clearly delineated by the difference in the dip of the two rock types (Plate II.9B).

NORTH CHIPLAKOT THRUST (NCT)

The North Chiplakot Thrust marks the contact of Biotite Schist in the south of CCB with the Chlorite Schist in north of SSZ in Kali River Valley. The outcrop of this thrust is concealed in the regolithic mass upon which Gasku village is situated. On either side of the Kali Valley there exists considerable amount of regolithic mass, therefore the contact is concealed. But on the traverse from Tawaghat-Dar in Dhauliganga Valley, the NCT can be traced north of Chirkila village towards Sobla. Here instead of chlorite schist the quartzites are in direct contact with the Biotite Gneiss (Plate II.9C), thus the chlorite schists found in Kali Valley may be getting pinched out in between these two regions. The contact is sharp and no gradation or intermixing of rocks is seen. The attitude of the thrust plane recorded at this location is 102° / 54° due NNE.

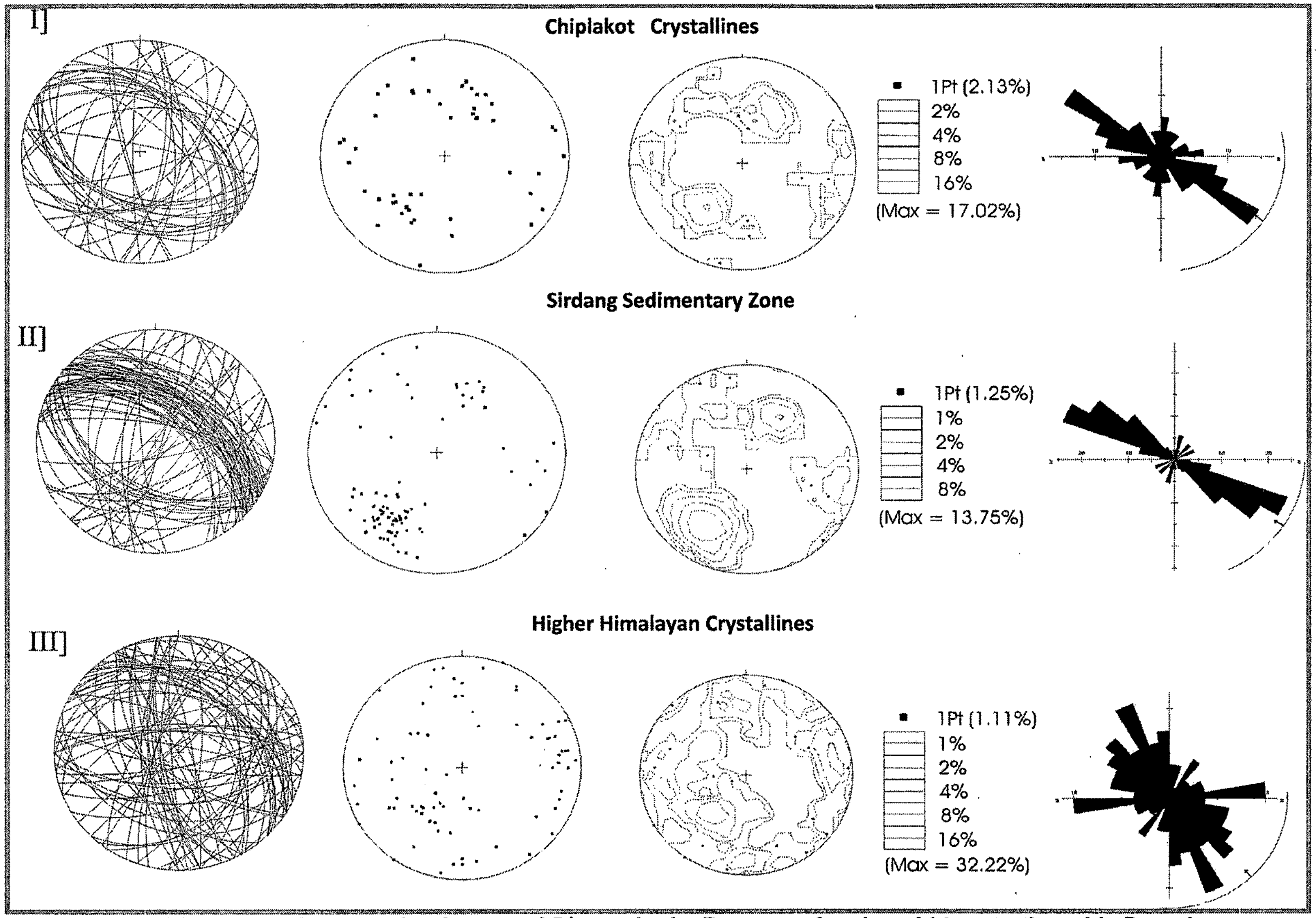


Figure 2.7 - Comparative Structural Discontinuity Patterns of various Litho-stratigraphic Domains

A. View of MCT in Indian Side. A perennial stream flows down this thrust plane (loc. Mangti village)

B. View of MCT in Nepal Side. Difference in Dips between quartzite and biotite gneiss is sharply visible

C. View of NCT in Dhauliganga Valley north of Chirkila Village (geo.lat/lon-

Plate II.9 - Field Photographs Showing Field Disposition of MCT and NCT in Kali and Dhauliganga Valley