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Geology and tectonics of the Central Crystallines of northeastern Kumaun Himalaya, India

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ABSTRACT

Four major geo-tectonic domains are encountered in the northeastern Kumaun Himalaya between the Ramganga and Kali rivers. These tectonic domains are: (1) Sedimentary Terrain of the south, (2) Lower Central Crystallines, (3) Upper Central Crystallines, and (4) Tethyan Supergroup in the north. The Sedimentary Terrain comprises of the Beringag, Damtha and Tejam groups. The Lower Central Crystallines are divided into Rungling and Munsiari formations, separated by a thin lensoidal wedge of sedimentary sequence of the Sirdang Sedimentary Zone, which is the continuation of the Nawakot Complex in western Nepal. The rocks of the Nawakot Complex wrap around the Chhiplakot Crystallines of the Munsiari Formation in Nepal and join with the Berinag Formation in northeastern Kumaun region. The Munsiari Formation has been divided into Phalyati, Baram, Chhiplakot and Khet members.The Upper Central Crystallines are represented by the rocks of the Vaikrita Group, and form the basement for the Tethyan sedimentary sequence. The Vaikrita Group is divided into four formations namely Joshimath, Pandukeshwar, Pindari and Martoli. The Joshimath Formation is further subdivided into Dar and Sela members whereas the Martoli Formation is subdivided into Budhi Schist and Dugtu members.

The southern contact of the Munsiari Formation with the Lesser Himalayan sedimentary sequence forms a tectonic boundary designated as the Munsiari Thrust or MCT I. The southern contact of the Rungling Formation with the rocks of the Sirdang Sedimentary Zone forms another tectonic boundary designated as the Rungling Thrust or MCT II. The Munsiari Thrust (MCT I) has been interpreted to terminate near Chainpur in western Nepal at its branch point. The contact between the Upper Central Crystallines and the Lower Central Crystallines is designated as the Vaikrita Thrust or Main Central Thrust (MCT). The quartzite of the Berinag Formation exposed in the Sirdang Sedimetary Zone thrust over the Munsiari Formation along the Pangla Thrust. The northern part of the Martoli Formation of the Vaikrita Group is characterised by concordant relationship with the Ralam Conglomerate and also the Garbayang Formation of the Tethyan Super Group. Either side of this contact zone is characterised by a series of minor southward thrusts and associated shear planes, which are subsequently cut by a series of normal faults and related shear planes exhibiting down to the NE oblique slip displacement. The shear zone containing contractional and superposed extentional structures at the northern portion of the Vaikrita Group and at the basal part of the Tethyan Supergroup is designated as Tethyan Shear Zone.

INTRODUCTION

Strachy (1851) and Griesbach (1891) were the pioneer workers in the Central Crystallines who recognised the main lithological assemblages of the Higher Himalaya. Heim and Gansser (1939) laid the foundation for geologoical investigation of the crystalline rocks of the central Himalaya. In the recent years, Valdiya and Gupta (1972), Powar (1972), Mehdi et al. (1972), Kumar et al. (1972, 1976), Valdiya (1973, 1979, 1980,a,b, 1981, 1987, 1988), Shah and Sinha (1974), Gairola (1975), Misra and Bhattacharya (1976), Bashyal (1984), Valdiya and Goel (1983), Thakur and Choudhury (1983), Roy and Valdiya (1988), Paul (1985,1986,1989), Sinha (1989), Paul and Roy (1991) and Dubey and Paul (1993) studied geological, structural and petrological aspects of the northeastern sector of the Kumaun Himalaya.

According to Valdiya (1979, 1980a,b, 1981), the Central Crystalline Zone of Heim and Gansser (1939) is divisible into the northern Vaikrita Group consisting of katazonal sillimanite-kyanite-garnet schists and gneisses, calc-silicate rocks and migmatites with its upper part extensively penetrated by Tertiary granites, and the southern Munsiari Formation, made up of epizonal sericite-chlorite schist, micaceous quartzite, carbonaceous phyllite, lenticular marble and mylonitised porphyroblastic granodiorite and augen gneiss. The Main Central Thrust has been redefined by Valdiya (1979), as the one, that separates the Munsiari from the Vaikrita rocks. According to Mehdi et al. (1972), the Central Crystalline Zone is the oldest tectonic element of the Precambrian age, which has divided the Himalayan basin into the northern intrageosyncline and southern Lesser Himalayan intrageosyncline. Kumar et al. (1972, 1976) opined that the Central Crystallines and the Garhwal Supergroup constitutes two tectonic units separated by the Main Central Thrust, whereas, in the north, these crystallines are bounded by the Dar-Martoli Fault. According to Bashyal (1984), the Chhiplakot Crystallines to the east of the Kali River is traceable in the Seti River valley in northwestern Nepal. The Darchula-Paribagar Thrust or Mahabharat Thrust in western Nepal (Bashyal, 1984) is a continuation of the Munsiari Thrust of Valdiya (1980a) or the MCT of Heim and Gansser (1939). According to Thakur and Choudhury (1983), the crustal shortening has produced polyphased deformation and progressive regional metamorphism. According to them, the MCT or Munsiari Thrust has been inferred as a post D_1 and pre D_2 structure of Miocene age. There are diversified views regarding geological and structural complexities suggested by different workers as cited above. It was, therefore, felt necessary to work out detailed aspects of geological and structural setup for better understanding of the area. The study embraces mainly the belt of low to medium grade metamorphic rocks of the Lower Central Crystallines (Munsiari and Rungling formations) and the zone of medium to high grade metamorphics of the Upper Central Crystallines (Vaikrita Group). The details of the stratigraphic succession is solely dependent on the young overlapping sequence, since there is no chronological data from these lithounits. However, all rock types are regarded as Precambrian in age (Valdiya, 1980b).

The prominent thrusts and shear zones identified in the study area are, the Tethyan Shear Zone (TSZ) in the northern boundary of the Vaikrita Group, Vaikrita Thrust, Rungling Thrust (MCT II), Pangla Thrust, Munsiari Thrust (MCT I) in the Central Crystallines and the Berinag Thrust of sedimentary terrain. The study of sedimentary terrain around the Tejam-Dharchula area is dealt in Paul (1989). Significant lithounits and structural features in the crystalline rocks of the region between the Ramganga and Kali rivers have been discussed in this paper (Fig. 1, 2, 3 and 4).

LOWER CENTRAL CRYSTALLINES

The Lower Central Crystallines are divided into two formations: the northern Rungling Formation and the southern Munsiari Formation. Fine to medium grained basement crystalline rocks of the Rungling and the Munsiari formations are the oldest rock units in the Himalaya, which comprise of low to medium grade metamorphic rocks. These units are separated by a thin lensoidal wedge of the sedimentary sequence of the Sirdang Sedimenary Zone.

Munsiari Formation

The Munsiari Formation is made up of low to medium grade metamorphic rocks of greenschist to lower almandine amphibolite facies (Valdiya, 1979, 1980b). In the study area, it is exposed between Dobat and Pangla in the Kali valley, Tawaghat to Khet in the Darma valley, Munsiari to Polu in the Gori valley and from Hokra to Namik in the Ramganga valley (Fig.1). The Munsiari Formation is separated at the base from the Berinag Quartzite and also the sedimentaries of the Tejam Group by high angle Munsiari Thrust (MCT I).

The most characteristic features of the Munsiari rocks are intense mylonitisation and retrograde metamorphism. The mylonitised augen gneisses are highly foliated as compared to shattered rocks of the Tejam Group. The Berinag Quartzite of the Sirdang Sedimentary Zone or Nawakot Complex thrust over the rocks of the Munsiari Formation along the Pangla

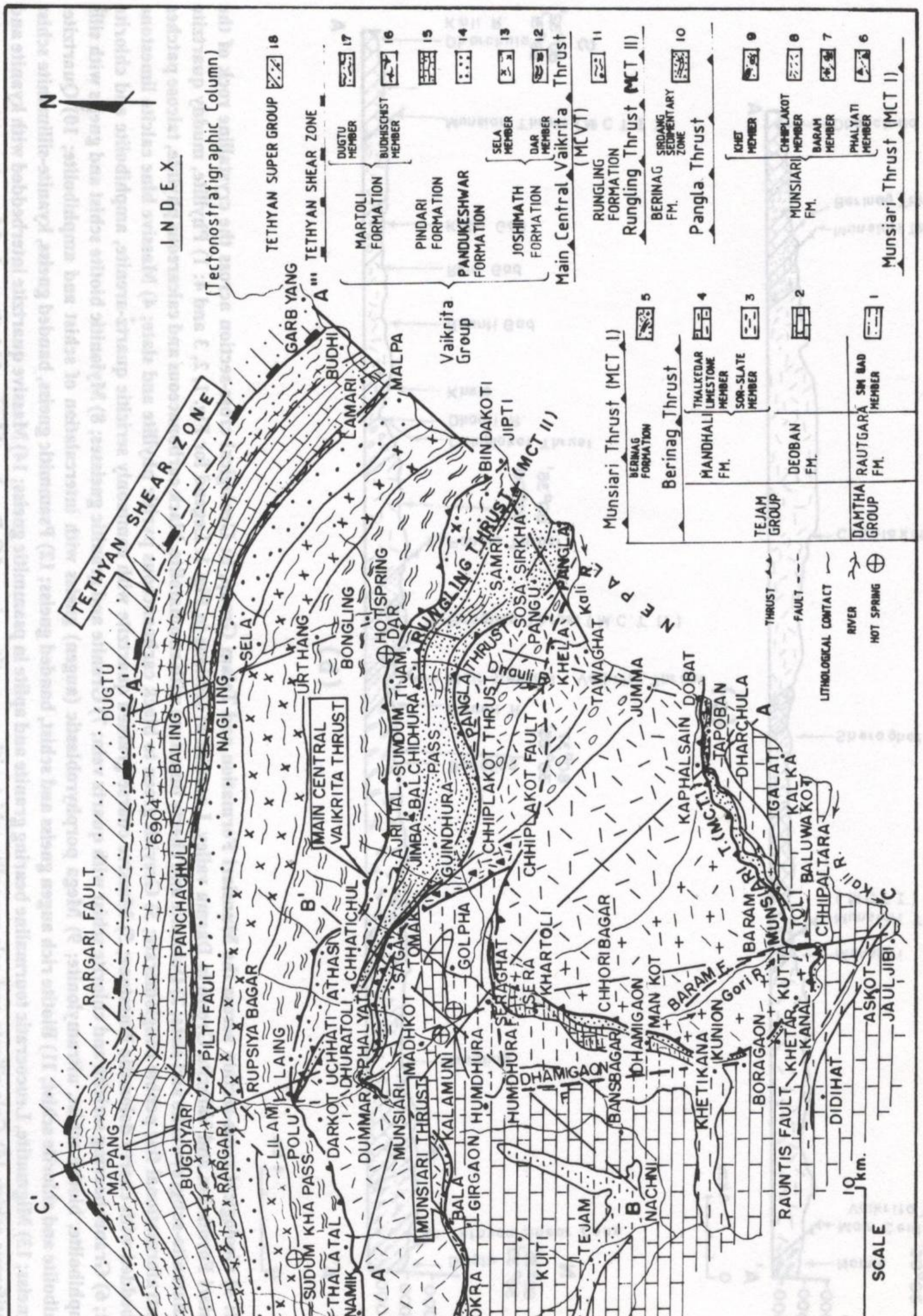

Fig.1: Geological map of the Central Crystallines around Dharchula-Munsiari of northeastern Kumaun Himalaya. (See legend in Fig. 2).

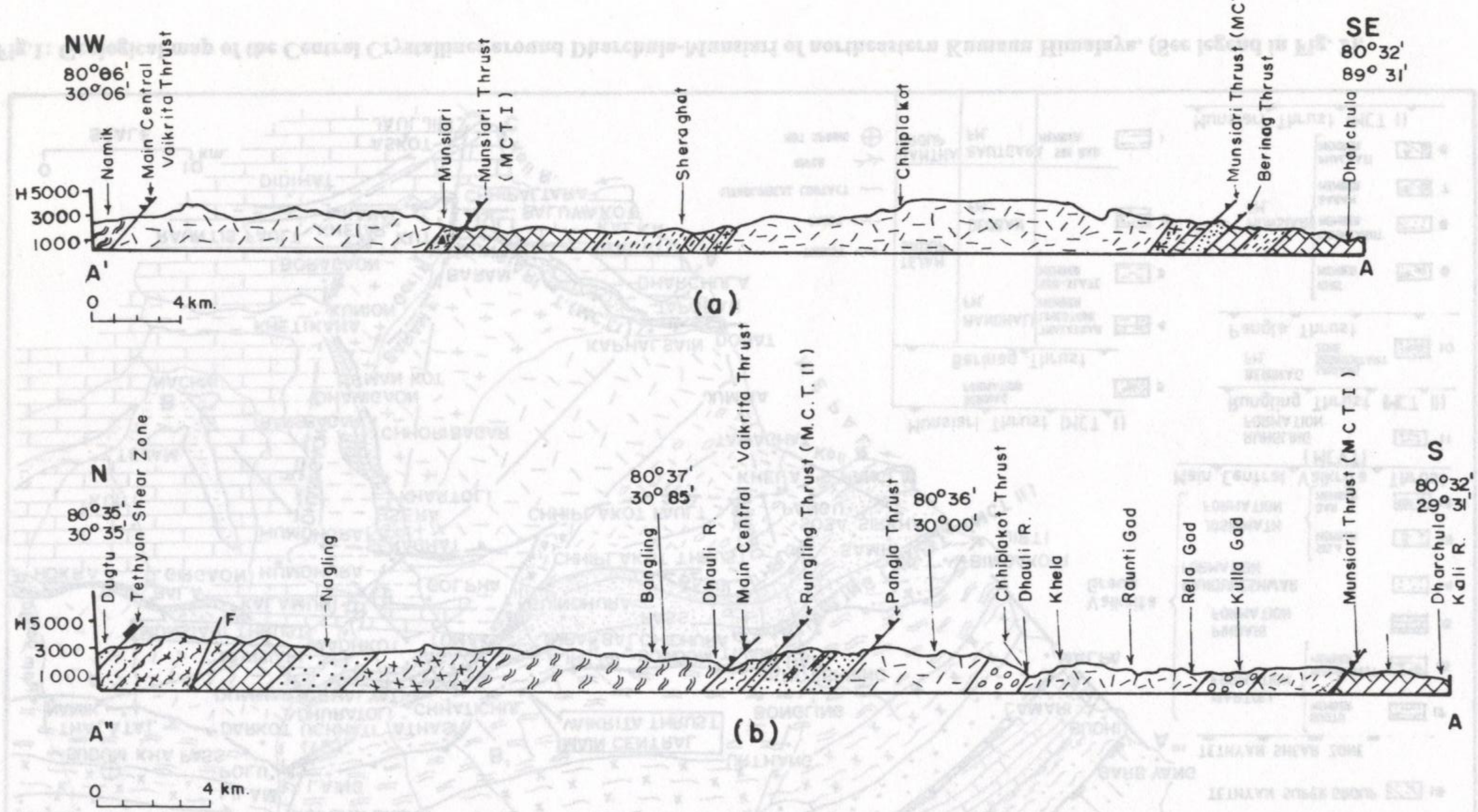

Fig. 2: a) Geological cross-section across the Munsiari Formation and Tejam Group, b: Geological cross-section across the crystalline rock of the Munsiari Formation and Vaikrita Group in Darma valley. Location of sections in Fig. 1. Legend for Fig. 1, 2, 3 and 4: 1) Phyllite, muddy quartzite sublitharenite-subgreywacke and slate; 2) Dolomite and cherty limestone with stromatolite, black carbonaceous and calcareous phyllite, talcose patches and intraformational flat pebble conglomerate; 3) Greyish green to black carbonaceous pyritic phyllite and slate; 4) Massive blue calcite limestone interbedded with cherty dolomitic limestone; 5) Massive coarse-grained quartzite with commonly sericitic quartz-arenite, amphibolite and chlorite schist; 6) Granet bearing sericite and chlorite schist with quartz vein; 7) Granite and granitic gneisses; 8) Mylonitic biotite schist and gneiss with sills of amphibolite, biotite schist, ultramylonite; 9) Mega porphyroblastic (augen) gneiss with intercalation of schist and amphibolite; 10) Quartzite, amphibolite and chlorite schist; 11) Biotite rich augen gneiss and schist, banded gneiss; 12) Psammitic gneiss, banded gneiss, kyanite-sillimanite schist and gneiss; 13) Migmatite, Leucocratic tourmaline bearing granite and aplite in psammitic gneiss; 14) Massive quartzite interbedded with kyanite and garnetiferous schist; 15) Calc-silicate and calc-granulite schist with pegmatite veins; 16) Porphyroblasts of biotite and phlogopite with pegmatite veins; 17) Grey quartzite, phyllite, carbonaceous phyllite and gritty quartzite; 18) Tethyan sediments.

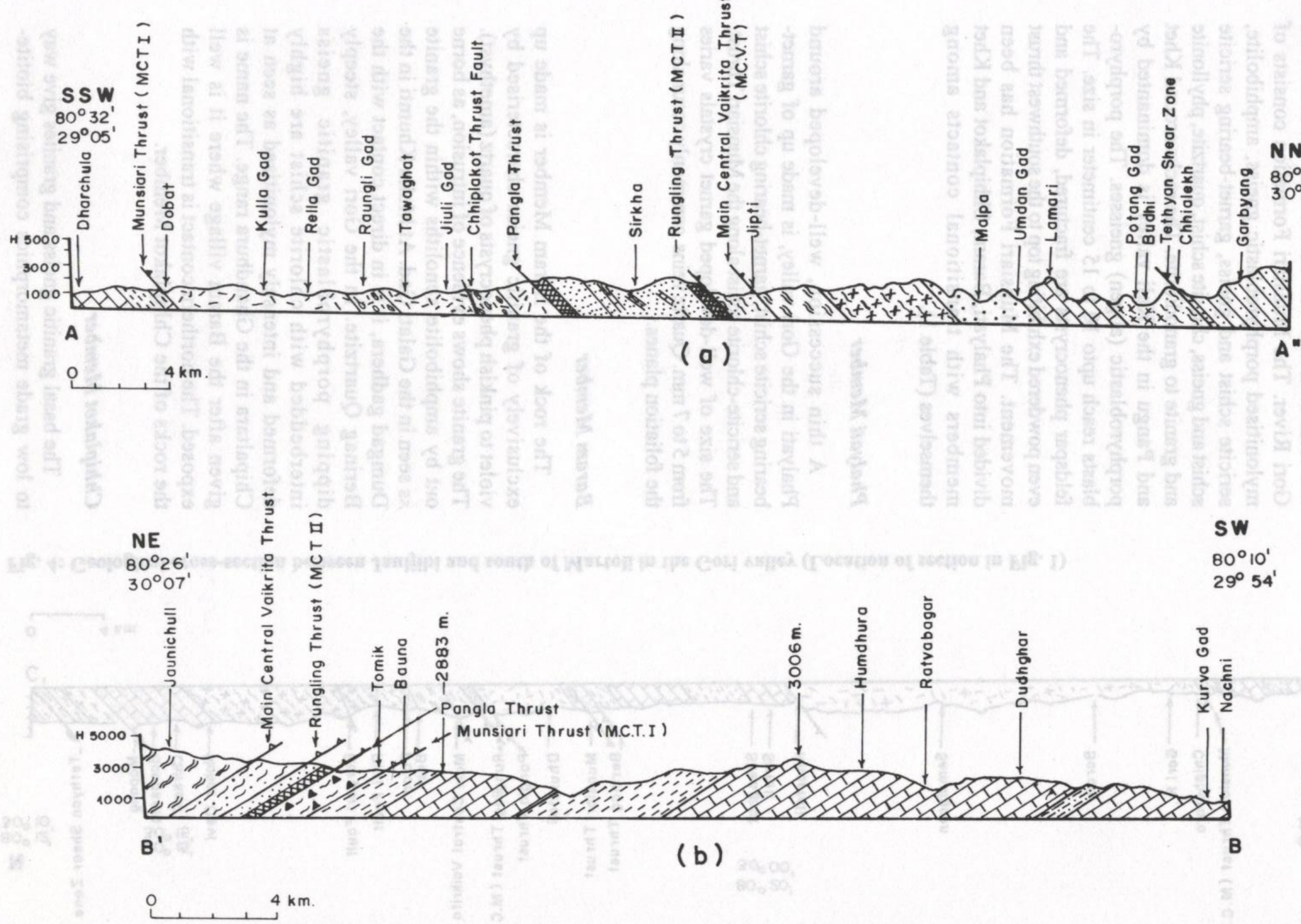

Fig. 3 a) Geological cross section between Dharchula and Garbyang in the Kali valley showing the position of Sirdang Sedimentay Zone between the Munsiari Formation and Rungling Formation. b) Geological cross section between Nachni and Jaulchuli (Chhati-Chul) showing relationship of the Tejam Group with MCT I and MCVT. Location of sections in Fig. 1.

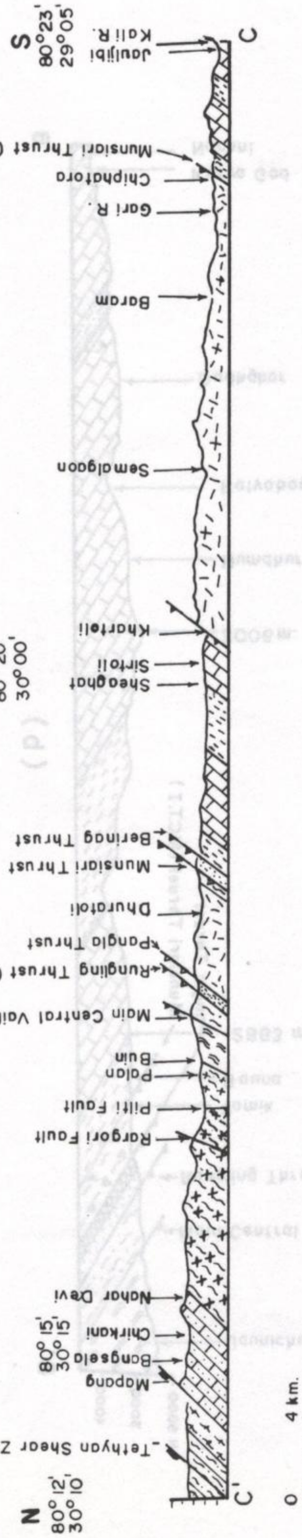

Fig. 4: Geological cross-section between Jauljibi and south of Martoli in the Gori valley (Location of section in Fig. 1)

Thrust, which demarcates the northern boundary of this formation and well-observed at the east of the Gori River. The Munsiari Formation consists of mylonitised porphyroblastic gneiss, amphibolite, sericite schist and gneiss, garnet-bearing sericite schist and gneiss, chlorite schist, quartzite, phyllonite and granite to granodiorite. The rocks around Khet and Pangu in the Kali valley is dominanted by porphyroblastic (augen) gneisses. The porphyroblasts reach upto 10 to 15 centimeter in size. The feldspar phenocrysts are fractured, deformed and even powdered exhibiting top to the southwest thrust movement. The Munsiari Formation has been divided into Phalyati, Baram, Chhiplakot and Khet members with transitional contacts among themselves (Table 1).

Phalyati Member

A thin succession, well-developed around Phalyati in the Gori valley, is made up of garnet-bearing sericite schist, garnet-bearing chlorite schist and sericite-chlorite schist along the Munsiari Thrust. The size of well-developed garnet crystals varies from 5 to 7 mm. Quartz veins commonly occur along the foliation planes.

Baram Member

The rock of the Baram Member is made up exclusively of granitic gneiss characterised by violet to pinkish phenocrysts of quartz (amethyst). The granite shows evidence of intrusion, as borne out by amphibolite xenoliths within the granite as seen in the Galati Gad. At Malla Khumti in the Dumgad gadhera, it is in direct contact with the Berinag Quartzite. In the Gori valley, steeply dipping porphyroblastic granitic gneiss interbedded with chlorite schist are highly deformed and intensely mylonitised as seen at Chipaltara in the Ghandhura range. The name is given after the Baram village where it is well exposed. The northern contact is transitional with the rocks of the Chhiplakot Member.

Chhiplakot Member

The basal granitic gneiss and granites give way to low grade metamorphics comprising biotite-

Table 1: Lithological subdivision of the Lower Central Crystalline Block - Munsiari and Rungling formations

Formation	Member	Lithology
Rungling	–	Biotite rich augen gneiss, banded gneiss
	Khet	Porphyroblastic (augen) gneiss, biotite-schist and gneiss
	Chhiplakot	Streaky biotite gneiss, porphyroblastic augen gneiss, quartzite, chlorite schist, sericite schist, amphibolite and phyllonite
Munsiari	Baram	Nonfoliated to feebly foliated granitic gneiss and granitoids, biotite schist and gneiss, chlorite schist in the southern part. In the northern part of the formation they are mylonitised (augen) gneiss, garnet bearing gneiss and amphibolite
	Phalyati	Well developed garnet bearing sericite chlorite schist

sericite schist, porphyroblastic (augen) gneiss, quartzite, chlorite schist, phyllonite, quartz-sericite schist and foliated amphibolite developed around the Chhiplakot summit. The rock is exposed to the north of Dharchula near Dobat in the Kulla Gad upto Pangla in the Kali valley. It extends from Munsiari to Polu in the Gori valley.

Khet Member

The Khet Member is designated after the village Khet in the Darma valley. The rocks of this member comprise of elongated porphyroblastic augen gneiss in the Dhauli valley. The feldspar porphyroblasts upto 15 cm long are aligned with their longest axes parallel to the foliation plane. The porphyroblastic gneisses show a considerable grain-size variation in which schist and quartzite are intercalated. Amphibolite and hornblende schist represent concordant sill. According to Powar (1972), this porphyroblastic gneissic unit pinches out near Pangu. However, the present study shows that this is a continuous unit passing across the Kali River in northwestern Nepal though the size of the augens reduced considerably.

Rungling Formation

The rocks exposed between Samri to Jipti (Bindakoti) in the Kali valley and Sobala to Dar in the Dhauli valley comprise of biotite schist, garnet bearing schist and augen gneiss not exceeding 500 m. These rocks have escaped from granitic intrusion as compared to the Munsiari Formation. The rocks are intensely mylonitised in the Dhauli and Kali valleys. Power (1972) considers them as a part of Rungling Crystalline mass. In the Samri-Bindakoti section, the rocks of this formation is made up of biotite-rich augen gneisses. With increase in the size of leucocratic bands, they grade into banded gneiss around the Rungling summit. The base of the Rungling Formation is defined as the Rungling Thrust (MCT II) observed between the Gori and Kali river valleys. The thickness of this formation reduces westward around Laing and Polu in Gori valley.

In the sedimentary belt to the south, the lithological succession similar to that of the Munsiari Formation are known as the Nandprayag Crystallines, Baijnath Crystallines, Askot Crystallines and Almora Crystallines. The Munsiari Formation represents the southeastern extension of the Jutogh Formation in Himachal Pradesh. According to Valdiya (1980b), the Almora-Munsiari rocks are comparable with the Lower Crystallines (Fuchs and Frank, 1970) and the Upper Midland Formation (Bordet et al., 1972; Le Fort, 1975; Pêcher, 1976) between Thulo-Bheri and Gandaki valley in western Nepal and with the Kathmandu Complex in central Nepal. Bhanot et al. (1977) gave Rb-Sr whole-rock age of the Munsiari gneiss near the Kalamuni Pass as 1830±200 Ma. The metamorphics are therefore older than 1830±200 Ma.

UPPER CENTRAL CRYSTALLINES (VAIKRITA GROUP)

Medium to coarse grained crystalline rock comprising of medium to high grade metamorphics form the Upper Central Crystallines or the Vaikrita Group. It is divided into Joshimath, Pandukeshwar, Pindari and Martoli formations (Valdiya, 1979, 1989a). The Vaikrita Group forms the bulk of the Great Himalaya and its southern boundary extending from Jipti (Kali valley) in the east to Namik (Ramganga valley) in the west. The name Vaikrita, first given by Griesbach (1891), represents the basement of the Tethyan sedimentary sequence. The southern limit of this group is marked by the Vaikrita Thrust (Valdiya, 1979, 1980a, 1981). The present author prefers to name the Vaikrita Thrust as Main Central Vaikrita Thrust (MCVT), observed between the greenschist to lower almandine-amphibolite facies rocks of the Rungling Formation and migmatite, kyanite-sillimanite schists and gneisses of the Joshimath Formation. A series of high angle normal faults passing through northern part of the Martoli Formation in the Gori valley (Valdiya, 1979, Kumar et al., 1970; Mehdi et al., 1972) and Budhi Schist Member in the Kali valley exhibit down to the northeast oblique slip movement. The rocks of the Vaikrita Group are exposed for about 18 km from Mangti to Budhi in the Kali valley, Dar to Dugtu in the Dhauli valley and from 2 km south of Lilam to Saspa gad in the Gori valley. The group is invaded by tourmaline-bearing leucocratic granite and pegmatite veins. The presence of sillimanite is noticed very close to these granitic bodies in the pelitic layers. On the basis of lithology and structural set up, the group has been divided into four formations (Table 2).

Joshimath Formation

The Joshimath Formation exposed in the southern part of the Vaikrita Group is divided into Dar and Sela members. The Dar Member consisting of coarse-grained-biotite-kyanite-garnet-muscovite psammitic gneiss interbedded with garnet-kyanite-sillimanite biotite schist and banded sillimanite-biotite gneiss, is named after the village Dar. The blades of kyanite are folded as noticed near Urthing in the Darma valley. In the Gori valley the succession is exposed between Lilam and Rupsiyabagar. In the Kali valley, it is seen from Bindakoti (near Jipti) to about 3 km NNE of Jipti. The Sela Member consists of a succession of migmatites, quartzite, biotite-schist, psammitic gneiss and schist discernible at Sela in the Darma valley. The tectonic contact between the rocks of the Joshimath Formation of the Vaikrita Group and the Rungling Formation of the Lower Central Crystallines is defined as the Main Central Vaikrita Thrust (MCVT). The kyanite-sillimanite schist and gneiss show extensive crushing, stretching and shearing, particularly in the proximity of the thrust.

Pandukeshwar Formation

It consists of massive, medium to fine grained, compact, white or fawn coloured quartzite, interbedded with thin layers of garnet and kyanite-bearing schist. Virdi (1986) is of the view that the Pandukeshwar Quartzite forms the core of a major isoclinal anticline and he opines that it is older than the Joshimath Formation. However, the increase in the grade of metamorphism in the center of the succession of the crystallines is due to the presence of a thermal high coinciding with the central part of the Upper Central Crystallines. In the Kali valley, the Pandukeshwar Quartzite is exposed around Malpa. The quartzite bands cyclically alternate with subordinate schist and gneiss. They represent metamorphosed shale and greywacke, reconstituted into schist and psammitic gneiss. Therefore, the repetition of gneisses and schists is due to repeated folding observed around Nagling in the Darma valley and around Suringhat nala in the Gori valley. The quartzite bands are interbedded with vary thin schistose layers characterised by well-developed garnet and about 4 cm long kyanite blades, parallel to the foliation plane observed 2 km south of Malpa in Kali valley. In the Darma and Gori valleys, rare development of kyanite within the quartzite is discernible.

Table 2: Lithological subdivision of the Upper Central Crystalline Block - Vaikrita Group (modified after Valdiya, 1973)

Formation	Member	Lithology
Martoli	Dugtu	Grey quartzite, phyllite, carbonaceous phyllite and gritty quartzite
	Budhi Schist	Calcareous schist with porphyroblasts of phlogopite and biotite. Intruded by pegmatite dykes and veins
Pindari	--	Calc-silicate rocks, biotite-garnet-kyanite schist and gneiss intruded by pegmatite veins and dykes
Pandukeshwar	--	White and grey massive quartzites, interbedded with bands of garnetiferous schist and kyanite-bearing schist
Joshimath	Sela	Migmatite interbedded with biotite schist, and intruded by leucocratic granite
	Dar	Banded kyanite-sillimanite schists, psammitic gneiss and quartz-mica-garnet schist

Pindari Formation

It is made up of calc-silicate rocks and marble characterised by actinolite-tremolite, and calc-gneisses, as exposed in the Pindari valley (Valdiya, 1981). A thick sequence of calc-silicate rock comprising calcite, diopside, quartz, hornblende, phologopite, scapolite, actinolite and tremolite is seen at Lamari in the Kali valley. The rock is extensively intruded by pegmatite veins and dykes. The quartzite interbedded with kyanite-sillimanite schist and gneiss grades into calc-silicate rock to the south of Lamari. Its northern limit passes through the Pathan Gad and to the south of Budhi in the Kali valley. Similar calc-silicate rock unit is also noticed around Baling in the Darma valley and 4 km south of Martoli in the Gori valley.

Martoli Formation

The Martoli Formation is the youngest unit of the Vaikrita Group, intruded by pegmatite veins and dykes. The contact between the Pindari and Martoli formations is trasitional. The rocks of this formation are divided into Budhi Schist and Dugtu members. The northern part of this formation comprises grey quartzite, phyllite, carbonaceous phyllite and gritty quartzite form the Dugtu Member, while its southern part comprised of medium grained schistose rock with abundant pophyroblasts of biotite and phlogopite form the Budhi Schist Member. Heim and Gansser (1939), and Gansser (1964) included the Budhi Schist within their Central Crystalline Zone. It comprises medium grained schistose rocks with abundant porphyroblasts of biotite and phlogopite. The gneisses and schists at Baling in the Darma valley are intercalated with thick bands of calc-silicate rocks and thinly foliated schist. The gneiss at Lamari is intercalated with thick bands of calc-silicate rock and thinly bedded porphyroblastic Budhi Schist. The Budhi Schist in the Kali valley is intensively intruded by pegmatite veins and dykes. The original calc-argillaceous sediments, subjected to metamorphism in the amphibolite grade (Powar, 1972), have given rise to this unit. Kumar et al. (1970) included the Budhi Schist in their Martoli Formation. Shah and Sinha (1974) showed a normal fault between the gneisses of the Central Crystallines and the overlying quartzite-phyllite sequence of the Martoli Formation. According to Valdiya (1980a,b), the Vaikrita rocks are comparable to the Upper Crystalline nappe of Fuchs and Frank (1970) in western Nepal, the Barun Gneiss of Bordet (1961) in the eastern Nepal and the Darjeeling gneiss of Acharyya (1975), Sinha Roy (1973) and Ray (1976) in eastern Himalaya.

Age of the Vaikrita Group

The tourmaline bearing younger Tertiary granites in the Vaikrita Group are genetically related to anatexis and formed during the Himalayan orogeny (Hamet and Allegre, 1976; Sinha and Bagdasarian 1977; Ferrara et al., 1983; Le Fort et al., 1986; Stern et al., 1989; DeCelles et al., 1998). The gneisses at Rohtang regarded as the Vaikrita rocks, gave an apparent age of 612±100 (634) m.y. (Bhanot et al., 1975) for a gneissic sample which was collected from south of the rohtang pass almost near the top. Mehta (1977) determined Rb-Sr whole-rock isochron age of 581 m.y. for gneisses near the south of Rohtang pass. Frank et al. (1977) also reported a whole-rock Rb-Sr isochron of 495±16 m.y. (512 m.y.) for intrusive granites in the gneiss and schist of the Chandra valley. Powell et al. (1979) collected seven samples for the whole rock analysis from the Chandra valley of Lahaul district in H.P. and gave age varying from 300 m.y. to 1065 m.y. However, the rocks of the Vaikrita Group is highly migmatised, thus no precise age can be determined. Various ages of the Vaikrita rocks given by different authors are mainly from the metamorphic rocks and indicate the last event of metamorphism related to granitisation. Therefore, the Vaikrita rocks are older than the granitic gneiss of Lower Palaeozoic ages. The Rb/Sr whole rock dating of the Munsiari granitic gneisses are 1830±200 m.y. (Bhanot et al., 1977). Thus, it may be inferred that the Vaikrita with the intrusions of younger Lower Palaeozoic granites may be younger to the older Munisiari rocks. It is possible that the Munsiari and Rungling formations may be basement for the Vaikrita Group.

LARGE SCALE STRUCTURES

The investigation embracing structural analysis shows that the study area is highly deformed due to folding, faulting and thrusting. The following large scale structures have been recognised in the area.

Major Folds

Anticlinal-Synclinal Structures of the Sirdang Sedimentary Zone

The Sirdang Sedimentary Zone encompassing mainly quartzite of the Berinag Formation forms a series of tight overturned anticlines and synclines. It is sandwiched between the Munsiari and the Rungling formations and brought to its present position as a result of the sub-vertical transportation of the crystalline blocks at its own base. The Sirdang Sedimentary rocks of the Tejam Group continue as the Nawakot Complex in Nepal. The WNW-ESE trending anticline-syncline folds of this sedimentary zone got folded during the second phase of deformation of the crystallines.

Chhiplakot Dome

The southern part of the Munsiari Formation forms an anticlinal structure around the Chhiplakot summit. The axis of this tight to isoclinal fold trends in the NW-SE direction, the axial trace passing through Dhamigaon near Dharchula in the Kali valley and Chhoribagar in the Gori valley. The southern limb of the Chhiplakot dome displays mesoscopic, open to isoclinal folds with axial plane dipping southward and trending NW-SE. The interference of early and superposed cross folds resulted in a broad doubly plunging open folds, which have been noticed near Ella Gad and Kulla Gad in the Kali valley. The structural data confirm that interference of the earlier folds F_1, F_2(a) and F_2(b) trending E-W or NW-SE, with the superposed late cross folds F_3, trending NE-SW has resulted in the evolution of the domal structure (Paul,1985; Dubey and Paul, 1993). The dome is elongated in the E-W direction. This domal structure is also characterised by stacking of minor NW-SE trending thrust sheets. The structure is neither a klippe as it is not an isolated block of rock detached from its root zone nor an inlier as these older rocks are not completely surrounded by the younger rocks. The domal structure is described as a partial inlier (Dubey and Paul, 1993).

Antiformal and Synformal Structures in Tejam Group

A series of antiforms and synforms have developed in the autochthonous sedimentary succession in the southern belt (Fig. 1). The folds trend NW-SE forming anticlinal valleys and synclinal hills. The Galati Gad and Chawa Gad follow NW-SE trend and Gujan Gad runs NNW-SSE in the Kali valley. The wave length of the folds varies from 500 m to a kilometre, whereas the amplitude varies from 100 to 200 m. An antiformal refolded fold (type three interference pattern, Ramsay, 1967), exposed around Tejam, Nachni, Madhkot, Bauna, Tomik and Golpha (Kumar et al., 1976) in the Rautgara Formation lies in the core of this F_1 fold. The hinge line of this fold plunges due NE which closes approximately 5 km SE of Golpha (southwestern part of the map; Fig.1). The F_1 Tejam fold is refolded by the NW-SE trending F_2 folds. The variation in the trend is attributed to the later F_3 folding (Paul,1989).

Faults

The are of study is traversed by a number of faults, viz. the Chhiplakot Thrust Fault, Baram Fault, Humdhura Fault, Madhkot Thrust Fault, Dhamigaon Fault, Rauntis Fault, Rargari Fault, and Pilti Fault. The east-west trending Chhiplakot Fault divides the Munsiari Formation into southern and northern blocks. The dextral strike-slip movement along this fault seems to be responsible for a large number of catastrophic earthquakes in this region (Paul, 1986). The truncation of garnetifeous mica-schist of the Phalyati Member along this fault plane testifies the existence of this fault (Fig. 1). The truncation of the Mandhali or Deoban rocks of the Tejam Group and the granitic gneiss of the Munsiari lithological units, slickensides near Chhiphaltara, landslides near Toli and Balmara, and the presence of mylonites throughout the fault zone are some of the noteworthy features of the Baram Fault. The E-W trending Humdhura Fault shows dextral strike slip movement, and the cumulative movement being of the order of four kilometres. The NNW-SSE trending Madhkot Thrust Fault acts as an oblique ramp between two frontal ramps, i.e. the Vaikrita Thrust in the north and the Chhiplakot Fault in the south. The Dhamigaon Fault, extending over 12 km within the Tejam Group, trends NNW-SSE. The Rauntis Fault trends NW-SE and demarcates the boundary between the Deoban Formation and the carbonaceous phyllite of the Mandhali Formation in the Rauntis Gad. The NE-SW trending Rargari Fault is characterised by vertical scarp with slickenside indicating that the northern block has moved up in relation to the southern block. Vertical triangular facet on the hill slope near the confluence of the Ralam Gad and Gori River and sharp turn of more than 90° of the Gori River near Rargari bear evidence to the existence of this fault. The NE-SW trending Pilti Fault passes through the Pilti Gad and characterised by Triangular fault facets, brecciation, crushing and sudden change in the trend of river course.

Major Thrusts

Berinag Thrust

Valdiya (1980b) postulated this thrust between the Berinag Quartzite and the underlying rocks of the Deoban and Mandhali formations in the Pithoragarh area. In the study area around Dharchula and Munsiari, the thrust zone is marked by deformation of the rocks on either side of the units. They are highly fragmented, jointed and fractured. The quartz grains of the Berinag Quartzite are elongated and granulated, forming mortar texture. Locally, recrystallisation has given rise to ribbon or streaky structures. The feldspar grains are highly sutured or sericitised. Away from the thrust zone the mortar structure gives way to simple granoblastic texture. Isolated lenticular bodies of quartzite of the Berinag Formation are seen within the sedimentaries of the Tejam Group in the Ramganga valley, the Phalyati-Tomik area in the Gori valley, east of Seraghat, Mankot in the Gori valley and in the north of Dharchula. The Mandhali slates are crushed, sheared and shattered along the Kalamuni-Girgaon bridle path and at Ghanadhura. The Berinag Formation commonly rests tectonically on the Mandhali and at places on the older Deoban, seen at Dhamigaon in the Galati Gad and Malla Khumti in the Ghat Gad and Dun Gad where Deoban is inverted under the Berinag. In the Sirdang Sedimentary Zone and near Phalyati in the Gori valley, the Berinag Quartzite and metavolcanics dip at about 45° towards NNE or NE while the Mandhali and Deoban in the Dharchula area dip at about 35° towards NNW or NNE.

Munsiari Thrust (MCT I)

The moderate- to high angle tectonic boundary between the sedimentaries of the Berinag or Tejam Group and the crystallines of the Munsiari Formation was designated as the Main Central Thrust by Heim and Gansser (1939). Valdiya (1977, 1979, 1980a,b) described it as the Munsiari Thrust. It has been noticed at south of Munsiari in the Gori valley, south of Dobat in the Kali valley and about 0.5 km south of Kaphalsain near Kana in the Galati Gad. The Munsiari Thrust, defining the base of the Lower Central Crystallines, passes through Garali, Kaphalsain, north of Kuta and Khetar Kanyal, east of Boragaon and Kunion, Mankot, east of Chhoribaggar, east of the Mawani and Khartoli village. It takes a sharp turn towards east near Khartoli and Sirtola and then swings north of Chhiplakot and passes through Bauna, north of Tomik, north of Ramthing and Okhali, north of Dhuratoli, north of Uchhati, Phalyati and Darkot in the Gori valley. Across the thrust, there is an abrupt and pronounced lithological change from the sediments to the metamorphics of the greenschist to lower amphibolite facies. The Berinag, Mandhali and Deoban rocks have also been locally truncated under the Munsiari Crystallines (Fig.1).

The shearing and mylonitisation of the Munsiari rocks is very pronounced. The cleavages are generally parallel to the bedding plane. The pronounced penetrative mineral lineations in NNE direction is noticed throughout the study area. The occurrence of low grade metamorphics is a consequence of retrogressive changes attending mylonitisation in the thrust zone. The presence of a persistent horizon of chlorite-sericite phyllonite seen at Khartoli, Chhipaltara, Garali, Kuta, Kaphliani, Kunion and Boragaon is very significant and establishes the existence of the Munsiari Thrust. The feldspar phenocrysts are much deformed and drawn-out into streaks, broken or even powdered. At a few places, the granitic rocks have been converted into ultramylonites. As Valdiya (1980b) has emphasised, the pervasive and profound post-crystallisation cataclastic deformation of augen gneiss and granitoids, testifies to the enormity of movement along the thrust plane. Steep vertical scarps delineate the Munsiari Thrust, and there is a dramatic change in the drainage pattern and drainage density. The decrease in the gradient of the rivers and the transition of the vertical walled valleys of the Great Himalaya to broad "V" shaped valleys in the Lesser Himalaya south of the thrust are further pointers to sub-Recent movements along it (Valdiya, 1980b).

Pangla Thrust

A thrust plane between the quartzite of the Berinag Formation and the underlying crystalline rocks of the Munsiari Formation noticed near Suwa in the Darma valley and Pangla in the Kali valley. The thrust zone is marked by mylonitization of rocks on either side of the thrust plane. The thrust zone is highly fragmented, jointed and fractured, showing dominant brittle deformation. The quartz grains of the Berinag Quatzite are elongated and granulated, forming mortar texture. Recrystallisation of quartz has given rise to ribbon or streaky structures. The Pangla Thrust has been interpreted as an oblique ramp joining the Vaikrita Thrust to the north and Munsiari Thrust to the south at their branch point. The northern branch point lie near Polu and the southern branch point lie near Chainpur in western Nepal.

Rungling Thrust (MCT II)

The garnet bearing biotite schists and gneisses of the Rungling Formation thrust over the Sirdang Sedimentary Zone along the Rungling Thrust (MCT II). The western extention of the Lower MCT of Paudel and Arita (1997) and MCT of Bordet et al., (1972) coincide with the Rungling Thrust (MCT II) of northeastern Kumaun Himalaya. The presence of augen gneiss and granitoid in the Rungling Formation signifies enormous movement along this thrust plane.

Main Central Vaikrita Thrust (MCVT)

Valdiya (1977, 1978, 1979, 1980a,b, 1981) separates the epizonal succession of the Munsiari and the Rungling formations from the high grade metamorphics of the Vaikrita Group, designating the tectonic boundary as the "Vaikrita Thrust". It is indeed a boundary between the fine to medium grained Lower Central Crystallines and medium to coarse grained Upper Central Crystallines and designated as the Main Central Vaikrita Thrust (MCVT). The eastern extension of the MCVT is called as the Upper MCT in western Nepal (Paudel and Arita, 1997). However, Heim and Gansser (1939) had not recognised any structural break within the Central Crystalline Zone in Kumaun, and their MCT separates the sedimentaries of the Lesser Himalaya from the low to medium grade metamorphics building up the great Himalaya. Departing from the original concept of Heim and Gansser (1939), Bordet et al. (1972), Bordet (1973), Le Fort (1975) places the tectonic boundary higher up in the Great Himalayan succession at a level where the mesograde rocks (Middle Midland Formation) give way to the high grade kyanite-sillimanite-bearing psammitic gneisses, schists and calc-silicate granulite of the Great Himalaya.

The Vaikrita Thrust (MCVT) is traceable in the study area from Bindakoti in the Kali valley to Thala tal near Namik in the Ramganga valley passing through north of Rungling, Dar in the Darma valley, at Jimba udiyar in Jimba gadhera and Laing in the Gori valley (Fig. 5).

Evidences for Existence of the Vaikrita Thrust

1) There is an abrupt change in the grade of metamorphism from greenschists to lower amphibolite grade associated with mylonitised gneisses and granitic augen gneiss of the Rungling Formation to the higher grade metamorphics represented by the kyanite-sllimanite-garnet bearing psammitic gneisses and schists, calc-silicate rocks and garnet-quartz-mica granulite of the Vaikrita Group.
2) The great thickness of the gneissic rocks of the Rungling Formation, sandwiched between the two thrust planes, shows strong shearing, intense mylonitisation and retrograde metamorphism resulting from the movement of rocks of the Vaikrita Group over them.
3) The style and orientation of folding of the Lower Central Crystallines (Munsiari and Rungling formations) and the Upper Central Crystallines (Vaikrita Group) are not much different. The Lower Central Crystallines show four generations of folding. The earliest is represented by tight to isoclinal folds plunging 30° to 40° toward ENE to NE. The second generation folds are open to tight similar folds plunging 25° to 70° towards WNW to NW. The third phase folds are tight to isoclinal, plunging 30° to 50° towards NNE or NNW and the fourth generation of folds are represented by broad and open folds doubly plunging 5° to 10° towards E or W. In contrast, the northern Upper Central Crystallines (Vaikrita Group) shows only three phases of deformation, the sparsely developed earliest ones are tight to reclined folds, plunging 10° to 12° towards ENE to E. The second generation folds are open to tight, plunging 30° to 40° towards NW to WNW, observed in the Joshimath Formation, although in the calc-silicate rocks of the Pindari Formation, they plunge 5° to 25° towards ESE. The folds of the third generation are isoclinal plunging 40° to 50° towards NNE. The east-west doubly plunging open folds are not observed in the Vaikrita Group.
4) The hot spring at Dar in the Darma valley indicates its close association with deep seated Vaikrita Thrust.
5) High grade rocks of the Vaikrita Group rest directly on the Rungling Formation observed at Bindakoti in the Kali valley and Kultham and Polu in the Gori valley. The MCVT truncates the rocks of the Rungling Formation and anticline-syncline structures of the Berinag Formation of the Sirdang Sedimentary Zone. The high grade rocks comprising of kyanite-sillimanite schist rest directly on the Munsiari Formation to the west of the Gori valley.
6) The Munsiari rocks show tight to isoclinal folds of the second generation in which quartz and quartz-feldspathic layers are folded whereas to the north of the Vaikrita Thrust, the Vaikrita rocks show ptygmatic folding and sigmoidal disharmonic folding in the psammitic gneiss.

Tethyan Shear Zone

A prominent shear zone separates the basal part of the Tethyan Sequence containing Ralam Conglomerate and even Garbyang Formation from

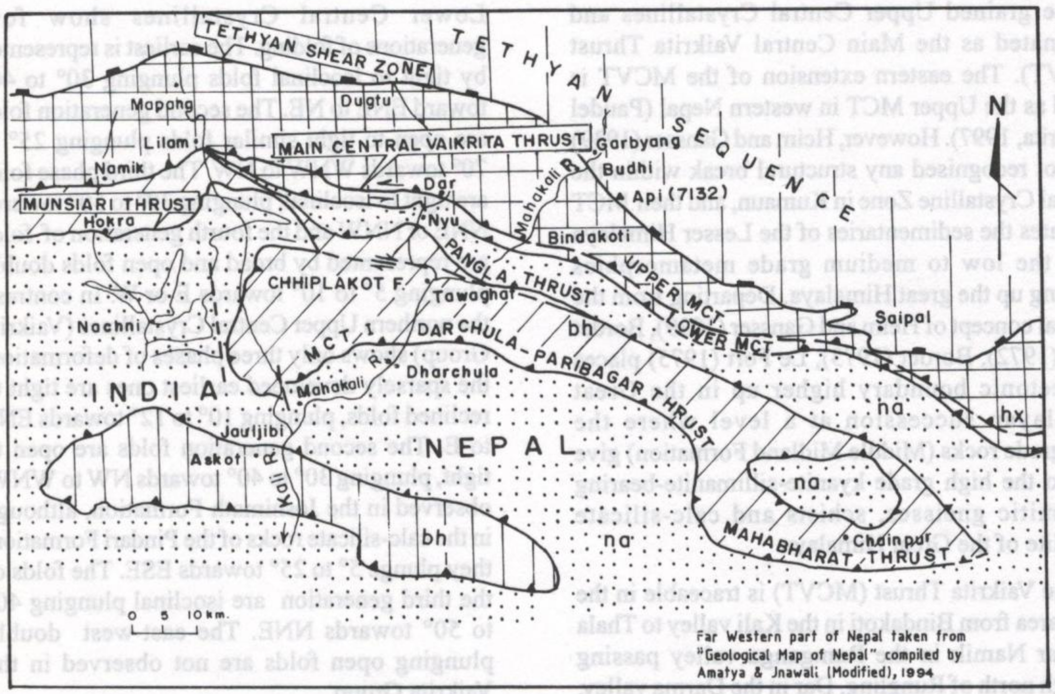

Fig. 5: Regional view of the Central Crystalline and its relationship with underlying Tejam Group and overlying Tethyan Sedimentary sequence. The Munsiari Thrust (MCT, Heim and Gansser, 1939) and MCT I of this paper are one and the same, terminates near Chainpur in western Nepal. The Upper MCT (Paudel and Arita, 1997) of western Nepal continues as Main Central Vaikrita Thrust (MCVT) in northeastern Kumaun Himalaya.

the upper part of the Vaikrita Group. The shear zone includes both contractional and superposed extensional structures. The southward movement of the Tethyan sequence over the northern border of the Vaikrita Group has produced a series of bedding parallel shear planes trending NW-SE with dips of about 40° NE. This contractional shear planes are displaced by northeast dipping normal faults and associated shear planes exhibiting down-to-the NE displacement. The dip of the shear planes with normal sense of movement is about 70° NE, observed in the northern side of the Budhi Schist in the Kali valley and to the south of Dugtu in the Darma valley.

TECTONIC RELATIONSHIP AMONG MCT I, MCT II, MCVT AND TSZ: A DISCUSSION

The southern tectonic contact of the Munsiari Formation is marked by the Munsiari Thrust or MCT I, while the southern tectonic contact of the Rungling Formation is marked by the Rungling Thrust or MCT II. The nomenclature of the MCT I and MCT II satisfies the original concept of the MCT given by Heim and Gansser (1939) in Kumaun Himalaya, where the MCT was defined as a tectonic boundary separating sedimentaries of the Lesser Himalaya from the metamorphic rocks of the Crystallines. The eastward extention of the MCT II is designated as the Lower MCT in western Nepal (Paudel and Arita, 1997). The MCT of Heim and Gansser (1939), the Munsiari Thrust of Valdiya (1978) in Kumaun Himalaya, the Jutogh Thrust in Himachal Himalaya, the Darchula-Paribagar Thrust in western Nepal and MCT I of this paper, are one and the same tectonic boundary, named differently at different places. Based on map pattern, in the 'Geological map of Nepal' compiled by Amatya and Jnawali (1994), the Munsiari Thrust (MCT I) continues eastward in western Nepal as Darchula-Paribagar Thrust (Bashyal, 1984) or Mahabharat Thrust, interpreted to terminate at its branch point near Chainpur. The present study indicates that the Munsiari Thrust or MCT I (MCT of Heim and Gansser, 1939) does not extend in the central Nepal. The MCT defined in Kumaun by Heim and Gansser (1939) and the MCT defined in Nepal by Bordet et al. (1972) are two different tectonic boundaries which do not join each other.

The high grade metamorphic rocks with anatectic granite of syn- to post F_2 or D_2 deformation (post Eocene, Miocene probably) rode over low-to medium grade rocks of the Rungling Formation and gave rise to the MCVT. The eastern extension of the MCVT (Vaikrita Thrust) continue as MCT (Bordet et al., 1972) and Upper MCT (Paudel and Arita, 1997) in Nepal. The northern boundary of the Vaikrita Group marked by a prominant shear zone designated as Tethyan Shear Zone (TSZ), includes both contractional and superposed extensional structures. The southward thrust movement of Tethyan sequence over northern boundary of the Vaikrita Group has produced a series of bedding parallel shear planes trending NW-SE with dips of about 40° NE. These contractional shear planes are displaced by steeply dipping normal faults and associated shear planes. These normal faults might have originated due to continued southward movement of the Upper Central Crystalline Block, primarily along the MCVT, and also along the MCT I, resulted in high rise of Himalaya and subsequent subsidence of the Tethyan sedimentary prism as a result of gravity collapse.

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