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Geology and micro-structure analysis of the MCT zone along Khudi-Bahundanda area of Lamjung District, west-central Nepal

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ABSTRACT

Geological mapping was carried out along the Marsyangdi Valley in the Khudi-Bahundanda area of west-central Nepal covering the Main Central Thrust (MCT) zone. The main objectives of the study were to draw a clear picture of lithology, geological structures and micro-tectonics in the rocks. A detail survey on stratigraphy and correlation with central Nepal reveals geological rock units such as the Benighat Slate, the Malekhu Formation and the Robang Formation of the Lesser Himalaya and the Formation I of the Higher Himalaya. Both regional and small-scale geological structures have been studied. The MCT zone has been mapped as a major regional structure in the region. The Bahundanda Thrust (BT), which has brought the older Malekhu Formation over the younger Robang Formation, is an another significant structure mapped. The BT is marked on the basis of fault breccia, slickensides as well as large deposits of debris mass at the fault zone.

The study area has undergone poly-metamorphism and dynamic crystallization of minerals. The Lesser Himalayan rocks resemble the garnet zone while the Higher Himalaya rocks resemble to the kyanite grade of metamorphism. The present section clearly shows the inverted metamorphism in the MCT zone as in the other sections of the Himalaya. Microscopic features like ribbon-quartz, polygonization of quartz crystals, grain boundary reduction, mica-fish and rotated garnet grains indicates the ductile shearing in the MCT zone suggesting the dynamic recrystallization during thrust propagation. Numerous outcrop-scale structures like meso-scale folds, quartz veins, boudinage and ptygmatic folds are abundant folds in the MCT zone and these are mostly E-W trending.

Keywords: MCT zone, Metamorphism, Deformation, Micro-structure, Marshyangdi valley

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INTRODUCTION

Nepal is a mountainous country with rugged topography and dynamic geology. The present study area lies in the Lesser Himalaya and partly in the Higher Himalaya of central Nepal (Fig. 1). The concept of the Main Central Thrust (MCT) was first proposed by Heim and Gansser (1939) in the Kumaun Himalaya to separate the overlying higher grade metamorphic rocks as mica schists and gneisses with the underlying lower carbonate autochthon. Dhital (2015) carried out the geological survey around the Marsyangdi-Nadi confluence and categorized the rock succession of the area into the garnet schist, graphitic schist and carbonate unit on the footwall of the MCT and into the kyanite schist and quartzite, augen or banded gneiss unit in the hanging wall based on the dominant lithology. He also clarified that the rock of the area belongs to the northern Limb of the Gorkha-Kuncha Anticlinorium. The Lesser Himalaya has undergone polyphase metamorphism and deformation (Paudel, 2008; Paudyal 2014). The area is highly deformed and it may be related to the MCT and other regional thrusts. The study area lies between the latitude of 28°30'00" to 28°15'00" and longitude of 84°30'00" to 84°20'00". The aims of study were to assess the micro-scale structures and the metamorphic history and the lithostratigraphic classification of the area based on new findings.

METHODOLOGY

A detailed geological mapping in the scale of 1:25000 around the Khudi-Bahundanda area was carried out taking field traverse along the Khudi Valley, the Marsyangdi Valley and the Nadi Valley. Many places of the area were inaccessible to carryout mapping due to the dense forest without settlements and steep slopes; hence traverse was planned according to the accessible routes covering all the three valleys. The significant

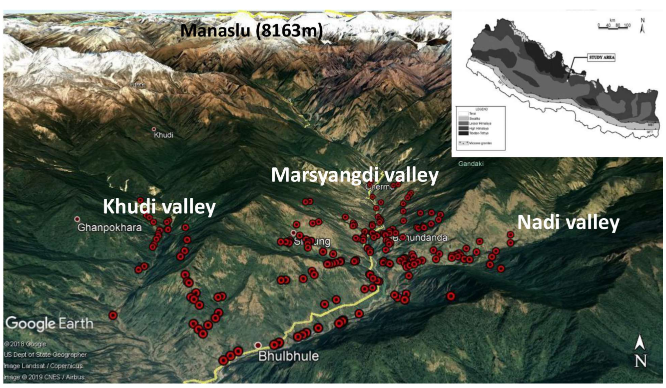

Fig. 1: Location map of the study area showing the observation from different locations

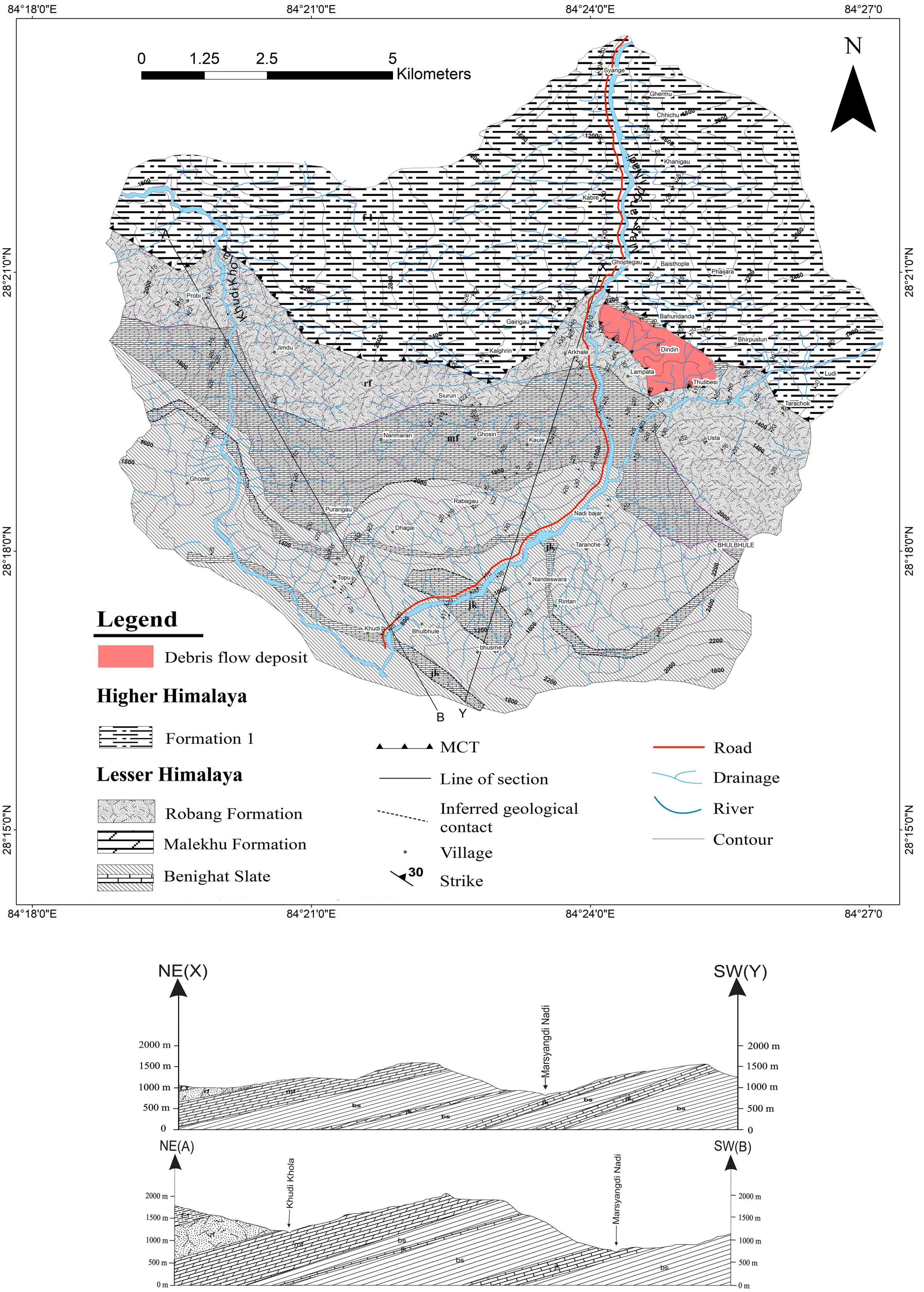

Fig 2: Geological map and cross-sections of the Khudi-Bahundanda area

representative samples of different rocks were sampled from each lithological unit and litho-bound to prepare thin section. Similarly, slabby rocks with well-defined foliation and lineation were selected for the sample collection and assured that samples were structurally in place. In order to orient the samples in the outcrop, simply preferred plane of the sample was measure and marked the attitude, and also marked U for up or D for down depending on the facing of the surface on which the sample orientation had been marked. Orientation of beddings, foliations and lineations were measured and recorded on the topographical map. After the completion of fieldwork, rock samples were thin-sectioned and studied under a polarizing microscope. Thin sections were made parallel to the lineation and across the foliation, in some samples perpendicular to the fold axis marking the trend of the lineation and the top of foliation. Using the standard V' rule , geological map and the geological cross section from the selected profile were prepared and verified in the verification field work.

LITHOSTRATIGRAPHY

Rocks of the two tectonic units i.e. the Higher Himalayan to the north and the Lesser Himalaya to the south separated by the MCT were mapped in this work (Fig. 2). The rocks of the Higher Himalaya can be mapped under one unit i.e. the Formation I. It comprises rock succession of garnet-kyanite gneiss and mica-schist in various proportions. Similarly, the Lesser Himalayan rocks comprise of the Benighat Slate, the Malekhu Formation and the Robang Formation from the bottom to the top, respectively. The Lesser Himalayan rocks consists of schist, foliated quartzite and dolomite-marble, which show the grade of metamorphism is quite higher as compared to the type locality where there are mainly phyllite, quartzite and dolomites. The study area mainly consists of highly deformed garnet-schist and laminated quartzite, black-schist bounded by footwall of the MCT towards north (Fig. 2).

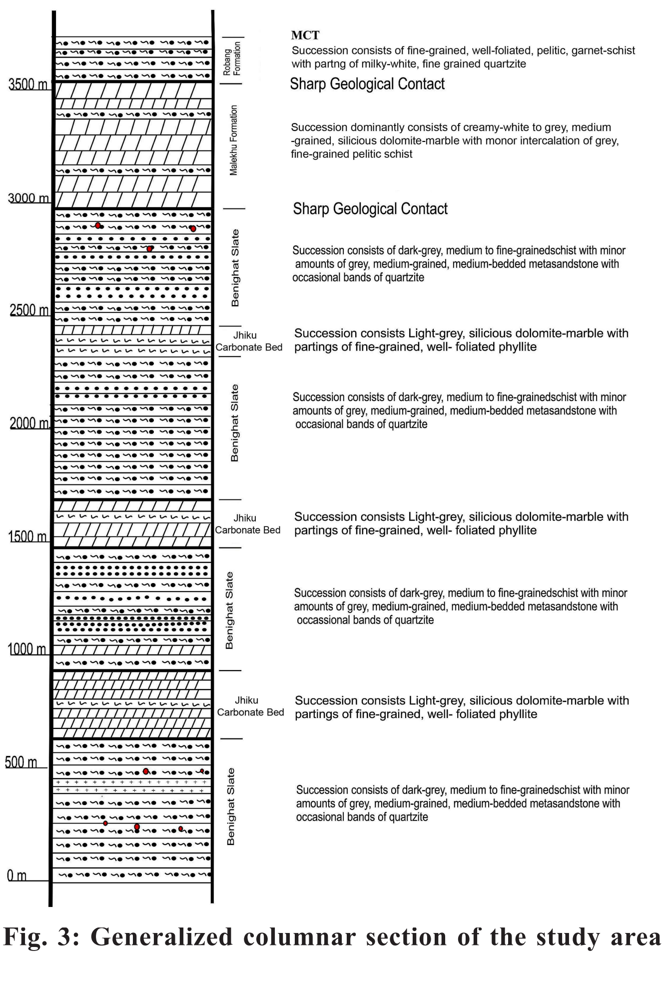

Fig. 3: Generalized columnar section of the study area

The rocks of the Higher Himalaya consist of high-grade metamorphic rock such as kyanite bearing gneiss and schist. The study area consists of only one unit of the Higher Himalaya which is correlable to the Formation I (Fig. 3). The succession of this unit consists of garnet and kyanite-gneiss and mica schist. The size of garnet varies from about 1 mm to 5 mm in diameter. It is well exposed near Tarachok, Arkhale, Baisthople, Ghoptegaun, Kabre in the study area. The lower part of this unit consists of garnet-kyanite containing gneiss with minor partings of schist (Fig 3). The size of garnet varies from about 1 to 5 mm in diameter. The middle part of this unit consists of paragneiss with abundant blades of kyanite and garnet. The size of garnet varies from about 2 to 4 mm in diameter. The upper part of this unit consists of paragneiss with the banding of schist with garnet and small proportion of kyanite. The mineral such as tourmailine can also be observed in the veins of quartz near the Tatpani Khola. The proportion of the dark colored paragneiss dominates in the upper part and lighter paragneiss dominates in the lower part of the unit. The sizes of the muscovite and biotite grain are also found to be increased from the south to the north of this unit. This unit also forms steep cliffs and ridges.

The Lesser Himalaya is represented by the three lithologically equivalent units of Stöcklin and Bhattarai (1977) and Stöcklin (1980) in central Nepal as: the Benighat Slate, the Malekhu Formation and the Robang Formation in stratigraphic upward sequence, respectively (Fig. 3). The Benighat Slate is well-exposed around Thakan village, Rintan, Bhusme, Nayagaun, Taranche, Nandeswara. Rock succession of this unit mainly consists of black to dark grey schist with thin-beds of meta-sandstone and carbonate. The lower part of this unit consists of dark-grey to greenish, medium- to fine-grained schist. Similarly, grey, medium-grained, thinly-bedded meta-sandstone is occasionally observed within the succession. In addition, meta-basic rocks of about 5 m band concordant to the bed of schist is observed. The middle part of this unit consists of dark-grey to black, fine-grained schist along with calcareous schist. The upper part of this unit mainly consists of black, medium-to fine-grained, garnet-schist and intercalation of grey, medium-grained meta-sandstone. Presence of garnet was observed whose size ranges from few mm to 1 cm in diameter. Occasionally, garnet is present in the uppermost part of this unit.

The Malekhu Formation is well-exposed near Thulibeshi village, Usta, Probi and Jhimdu village. The rock succession of this unit is represented by the massive beds of creamy-white-to grey, siliceous, dolomitic-marble with parting of phyllite including intercalation of schist. This unit is overlain by highly deformed garnet-schist and quartzite. The lower part of this unit comprises of calc-schist with thin-band of carbonate beds. The middle part of this unit consists of medium-to thick–bed, creamy-white-to grey, siliceous dolomite-marble with partings of phyllite. The thickness varies from few cm to 10m. The upper part of this unit consists of siliceous dolomite-marble with intercalation of dark-grey, calc-schist and light-grey to greenish-grey, schist. The proportion of schist is dominantly present towards north.

The Robang Formatiom is well-exposed in Usta, near the confluence of the Chhin Khola and the Nadi Khola, Lampata, Arkhale, Siurun, Jhimdu and Probi. The rock succession of this unit comprises of fine- to medium-grained, well-foliated garnet-schist with partings of milky white fine-grained quartzite. This unit is overlain by a thrust in the northern part i.e. the MCT. The lower part of this unit consists of well-foliated, garnet-schist with small bands of white, medium-grained quartzite. The middle part of this unit comprises of light-grey to white, medium to thick beds of quartzite with intercalations of thin bands of garnet-schist. The upper part of this unit consists of intercalation of pelitic-schist and psammatic-schist with minor amounts of milky-white quartzite. Similarly, quartzite proportion decreases while heading towards the north with the increment of garnet grains ranging in size variations about 2 to 5 mm in diameter.

GEOLOGICAL STRUCTURES

All the structures observed and interpreted in the study are secondary structures resulted from deformation which are developed by the tectonic activities. The MCT is marked by the distinct change in lithology i.e. garnet-schist and quartzite to gneiss and metamorphic grade from garnet-grade to kyanite-grade and thick ductile zone lying below the kyanite-grade. In addition to this, other related features like abundant quartz veins, drag folds, micro-structures, presence of hot springs, etc. are indicators of the MCT. Similarly, the Bahundanda Thrust is also observed trending east-west along Bahundanda, Dindin, that brought the older rocks successio on top of the younger rocks succession. The Bahundanda Thrust is distinguished on the basis of lithological variation, deformation of rocks and abundant debris flow around this area. In the study area, there exist a large number of meso-scale folds in many rock types of different rock succession units. The isoclinal folds in calcareous bed, schist and gneiss are trending north-south direction. Folds in the MCT zone are mostly E-W trending while the shear-sense indicators show top-to-south movement.

METAMORPHISM

The present study area has undergone poly-phase metamorphism, 3- sets of foliation shown by cross- cutting relations of biotite grains define at least three phases of crystal growth (Fig. 4) i.e. the Higher Himalaya has undergone regional high pressure/ high temperature kyanite- grade pro-grade regional metamorphism (M1). This is probably coincident with the development of first set of foliation most probably related to the pre- MCT deformation. It is followed by the M2 related to large scale thrusting and shearing probably due to the activity of the MCT indicated by rotated garnet grains overprinted by the retrograde biotite to chlorite grade of metamorphism (M3) during upheaval (Fig. 5). Lesser Himalaya has also experienced a pro-grade regional metamorphism (M0) due to the burial of the overlying rocks, second phase of pro-grade inverted metamorphism which is syn- to post- tectonic (M1). A later phase of retrograde metamorphism (M3) is shown by the retrograde alteration of garnet to biotite along the rims of garnet porphyroblast (Fig. 6).

Micro-structures

In the study area, paramount number of micro-structure indicators are present form various localities in sample specimens. Micro-structures are the common features that indicate deformation and the metamorphic history through the observations in the thin-sections. From the quartz grain micro-structures, it can be confirmed that the quartz grains have undergone intense deformation during thrust sheet propagation and dynamic re-crystallization direction is top towards south. Quartz grains of the study area have polygonal to amoeboid contact barely showing the evidence of polygonization. The quartz grains are extended in the direction of foliation forming ribbons of quartz with sweeping undulatory extinction (Fig. 7). Similarly, ribbon shaped quartz and triple junction indicate high grade metamorphism of rocks (Fig 8). Quartzite shows triple junctions and an indented contact that denotes the state of textural equilibrium. Also, porphyroblast having inclusion of sigmoidal poikiloblast on trail indicates syn-tectonic origin of porphyroblast (Fig. 9). The shear sense indicators like shear band cleavage, mica-fish indicate top towards south sense of shear developed during thrust sheet propagation.

DISCUSSION

The Higher Himalayan rocks are represented by thick bedded gneiss with occasional bands of schist of the Higher Himalayan sequence. The size of the kyanite increases toward the north up to few kilometers, ranging in size from 20 mm to 100 mm in length. It can be correlated with the Formation I of Le Fort (1975). The Lesser Himalayan sequence, Benighat Slate, the Malekhu Formation and the Robang Formation are equivalent of the rock units of the Nawakot Group but they are metamorphosed to high-grade as compared to type locality in Central Nepal. The Benighat Slate comprises dark-grey, medium- to fine-grained schist. Similarly, grey, medium-grained, thinly-bedded meta-sandstone is occasionally observed within the succession. It can be correlated with the graphitic schist and garnet schist of Dhital (2015). The Malekhu Formation with massive beds of creamy-white-to grey, silicious dolomitic-marble with parting of phyllite including intercalation of schist.

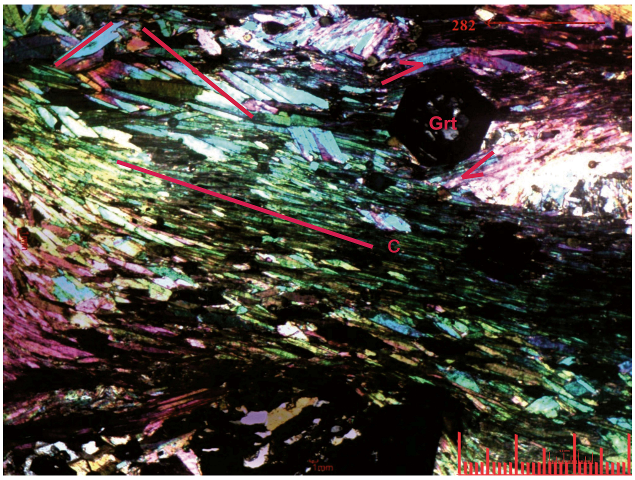

Fig. 4: Photomicrograph showing 3-sets of cleavage in gneiss of the Higher Himalayan sequence

Fig. 5: Presence of biotite in rims of garnet in gneiss of the Higher Himalaya

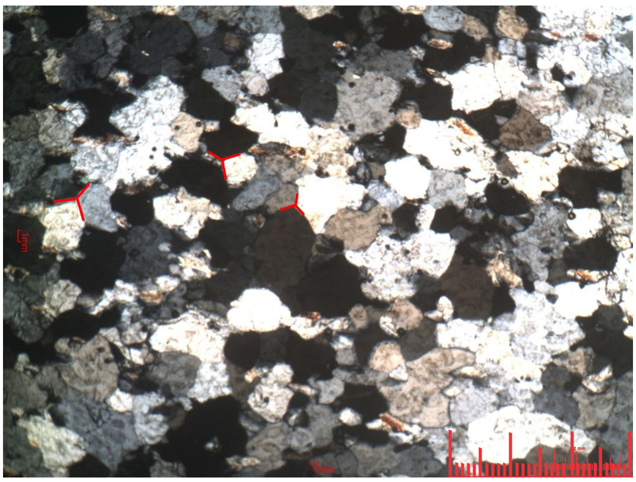

Fig. 6: Photomicrograph showing triple junction and indented contact from quartzite

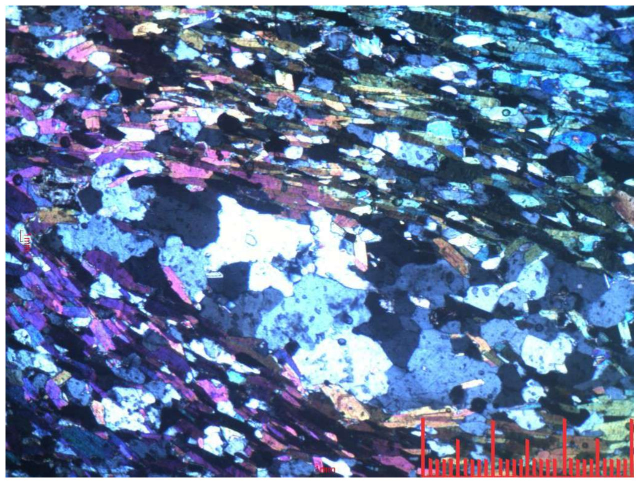

Fig. 7: Photomicrograph of schist showing polygonized quartz clast

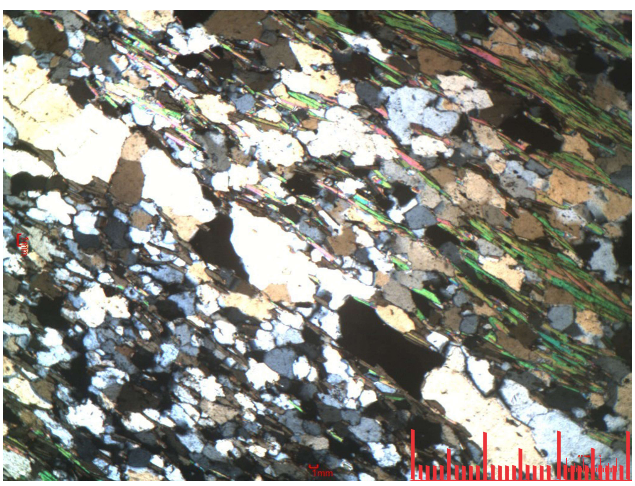

Fig. 8: Photomicrograph of sample with ribbon shaped quartz from calc-schist

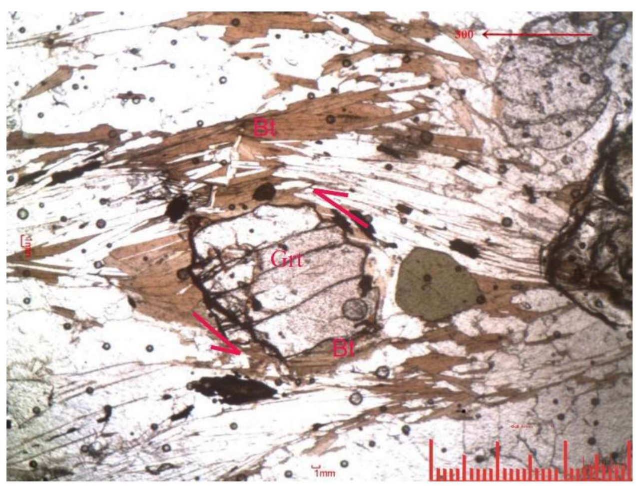

Fig. 9: Garnet porphyroblast with sigmoidal inclusion trail indicating shear sense and syntectonic origin (rock type: schist)

This unit is overlain by highly deformed garnet-schist and quartzite. It can be correlated to the Malekhu Limestone of Stöcklin (1980) in Central Nepal. The Robang Formation with fine- to medium-grained, well-foliated garnet-schist with partings of milky-white fine-grained quartzite. This unit is overlain by a thrust in the northern part i.e. Main Central Thrust. Similarly, the MCT is marked by the distinct change in lithology i.e. garnet-schist and quartzite to gneiss and metamorphic grade from garnet-grade to kyanite grade and thick ductile zone lying below the kyanite-grade. Similarly, the BT trends east-west direction.

From the quartz grain micro-structures, it can be confirmed that intense deformation has occurred during thrust sheet propagation with dynamic re-crystallization direction top towards south. Similarly, high grade metamorphism has underwent with syntectonic deformation and south sense of shear has developed during thrust sheet propagation.

CONCLUSIONS

Following conclusions are drawn after the present work:

1. Rock successions of two tectonic units i.e. the Higher Himalaya in the north and the Lesser Himalaya in the south as separated by the MCT, are mapped in scale 1:25,000. The Higher Himalaya consists of garnet-kyanite paragneiss (mapped as the Formation I), and the Lesser Himalaya consists of the Benighat Slate, the Malekhu Formation and the Robang Formation.

2. The rocks of the Benighat Slate in this area are in the grade of garnet-schist. Similarly, the rocks of the Malekhu Formation and the Robang Formation have higher crystallinity than those described in the central Nepal.

3. Inverted metamorphism in the MCT zone is distinct as in the other sections of the Himalayas. The rocks of the Lesser Himalaya and the Higher Himalaya have metamorphosed respectively up to garnet grade and kyanite grade. Different types of meso-scale and micro-scale structures show top to the south sense of shear along the MCT zone.

The study area has under gone poly-metamorphism with dynamic and static crystallization of minerals. Metamorphic events such as pre-MCT and post-MCT are well-recorded in the rocks. Quartz grain micro-structures (polygonization an rotation of quartz), garnet porphyroblast indicate dominant dynamic recrystallization in the footwall of the MCT zone indicating the ductile shearing along the MCT. The dynamic re-crystallization direction is top towards south sense of shear. Recrystallized quartz grains show undulose extinction and mica grains are imbedded in them. This indicates the recrystallization in the static condition.

4. The isoclinal folds observed in the rocks of the Lesser Himalaya shows north-south trends while the folds in the MCT zone are mostly E-W trending.

5. The Bahundanda Thrust, a new thrust, trending east-west, that has brought the older rocks succession on top of the younger rock succession, was mapped. The Thrust was distinguished on the basis of lithological variation, deformation of rocks and abundant debris flow around this area.

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