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# Petrography and illite crystallinity of the Lesser Himalayan metasediments, Gorkha Narayangarh section, central Nepal

*Kabi Raj Paudyal, Tara Pokharel and Lalu Prasad Paudel

*Central Department of Geology, Tribhuvan University, Kathmandu, Nepal*

## ABSTRACT

Geological study was carried out in the Lesser Himalaya from Gorkha-Narayangarh section of central Nepal aiming to assess the metamorphism of the area. The area consists of the Kunchha Formation, Fagfog Quartzite, Dandagaon Phyllites, Nourpul Formation, Dhading Dolomite, Benighat Slate and the Robang Formation of the Nawakot Complex. Systematic study on petrography and illite crystallinity was performed in the samples representing all types of lithology and formations. Both petrography and illite crystallinity show that the rocks south of Anbu Khaireni belong to chlorite zone. Biotite and garnet zones are observed only in the north of Anbu Khaireni. The metamorphic zones are inverted as in the other parts of the Lesser Himalaya.

## INTRODUCTION

The study area lies at about 90 km west of Kathmandu (Fig. 1). The area exposes a wide section of the Lesser Himalayan low-grade metasediments along the motor road from Gorkha to Narayangarh.

Tectonically this is a fold-and-thrust belt with complex structures. Medlicott (1875), Auden (1935) and Hagen (1969) presented regional geological framework of central Nepal and introduced nappe concept. Hashimoto et al. (1973) carried out detailed geology and petrology of the area and stressed on post-folding metamorphism. They noticed isograds cutting through geological and structural boundaries. Le Fort (1975), Colchen et al. (1980; 1986) and Pêcher (1977, 1989) carried out geological mapping and petrological study of the Annapurna Range and published a number of papers related to the tectonics and metamorphism. They explained about the occurrence of inverted metamorphism in the Main Central Thrust zone (MCT zone) and in the Higher Himalaya. Stöcklin and Bhattarai (1977) and Stöcklin (1980) carried out a comprehensive geological mapping of the central Nepal Lesser Himalaya and Kathmandu Nappe. Their stratigraphy classification for central Nepal Lesser Himalaya and Kathmandu Nappe has been still widely adopted. They divided the rocks of this region into the Kathmandu Complex (crystalline rocks of the Kathmandu Nappe) and the Nawakot Complex (Lesser Himalayan metasediments). Dhital (1995) prepared geological map of Gorkha–Ampipal area and showed that the metamorphic isograds follow the thrust boundaries.

Previous workers in the area have focused on the tectonics and stratigraphy only. Metamorphic petrological studies in the area are limited only to the medium- to high-grade (higher than biotite zone) rocks. Although the low-grade metamorphic zone covers two third part of the Lesser Himalaya, petrological studies in this part of the area are still lacking. This paper deals with the petrographic characteristics and illite crystallinity of low-grade metasediments along the Gorkha-Naryangarh section to assess the metamorphism of the area. The metamorphic implications of the obtained result have been discussed.

## GEOLOGICAL SETTING

The area is covered by the rocks of the Nawakot Complex (Stöcklin 1980). The northern belt is covered by the Kunchha Formation, Fagfog Quartzite,

*Corresponding author:

E-mail address: Paudyalkabiraj@yahoo.com

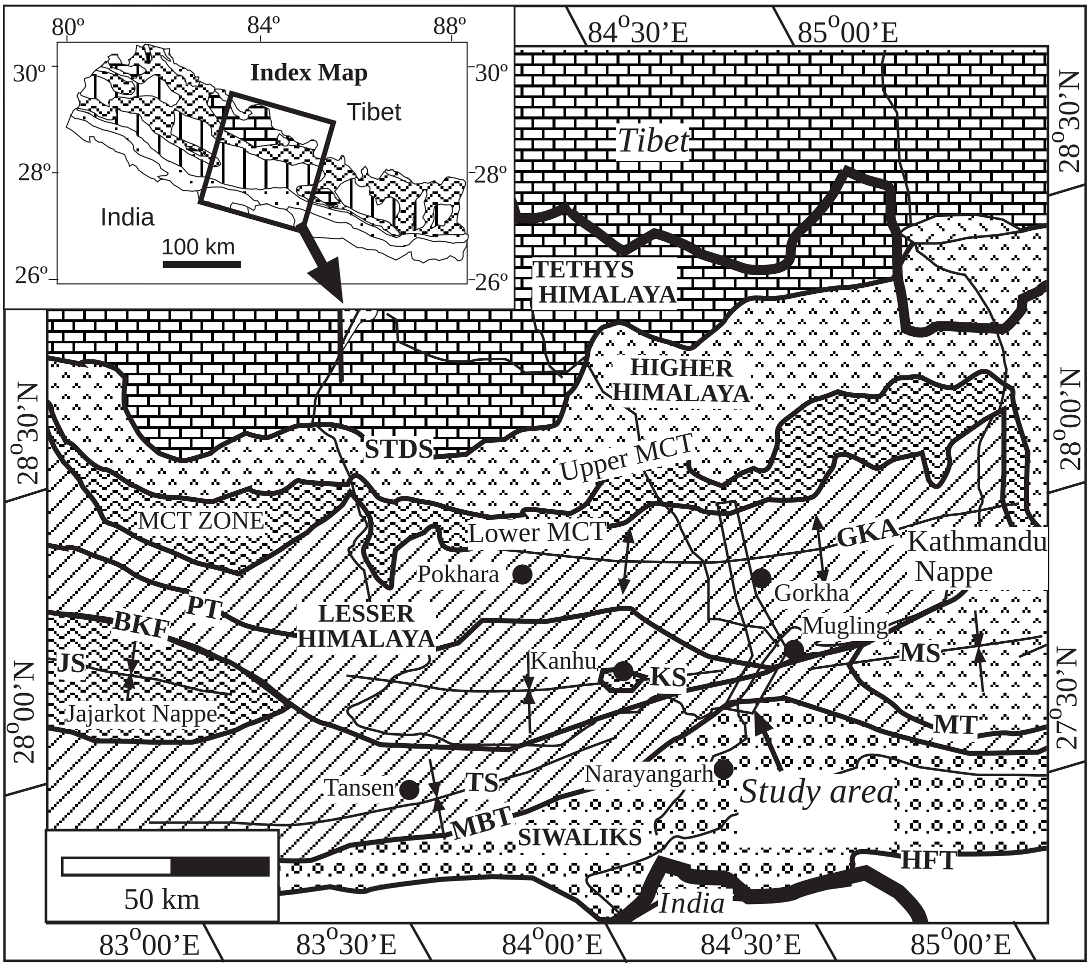


Fig. 1 Tectonic map of central Nepal showing the location of the study area (modified after Paudel and Arita, 2000). HFT: Himalayan Frontal Thrust; MBT: Main Boundary Thrust; MCT: Main Central Thrust; MT: Mahabharat Thrust; STDS: South Tibetan Detachment System; BKF: Bari Gad-Kali Gandaki Fault; PT: Phalebas Thrust; GKA: Gorkha Kunchha Anticlinorium; KS: Kanhu Synclinorium; MS: Mahabharat Synclinorium; JS: Jajarkot Synclinorium; TS: Tansen Synclinorium.

Dandagaon Phyllite, Nourpul Formation and the Dhading Dolomite of the Lower Nawakot Group (Fig. 2 and 3). The Kunchha Formation is well distributed around Mugling, Anbu Khaireni and Gorkha areas. It consists of monotonous, flysh-like alternation of sandy phyllite, phyllitic quartzite and purely argillaceous soapy phyllite. Especially noteworthy feature of the Kunchha Formation is a strong lineation, predominantly in N or NNE direction. The Fagfog Quartzite consists of white, fine- to thick-bedded quartzite. Thin layers of grey phyllite are rarely intercalated with the competent beds of quartzite. The Dandagaon Phyllite consists of dark grey quartzitic phyllite, thin bands of quartzite, dolomite and calcareous phyllite. The Nourpul Formation is divided into the Purebensi Quartzite, Amdanda Phyllite and the Labdi Khola carbonates (Paudyal and Paudel, 2011). It is made up of quartzite, laminated phyllite, dolomite and calcareous phyllite respectively from bottom to top. The Dhading Dolomite is a ridge forming unit consisting mainly of grey, medium-to thick-bedded siliceous dolomite with columnar stromatolites.

The southern part of the study area consists of the Nourpul and Dhading Dolomite of the Lower Nawakot Group and the Benighat Slate and Robang Formations of the Upper Nawakot Group. The Nourpul Formation is exposed at two places, one near Dasdhunga just above the Main Boundary Thrust and the other near Ghumaune. The Benighat Slate is composed of black carbonaceous phyllite with thin bands of silicious dolomite. The Robang Formation is composed of grey phyllite, dirty quartzite, grey metasandstone and metabasites (greenschist).

Two major thrusts pass through the area: one north of Dasdhunga and the other south of Jalbire (Fig.1). Both the thrusts bring the Nourpul Formation above the Robang Formation (near Dasdhunga) and the Benighat Slate (at Ghumaune). Besides this there are several anticlines and synclines. One of the major syncline is the Jalbire Syncline which is the western closure of the Mahabharat Synclinorium (Stöcklin, 1980). Foliation, usually parallel to bedding, is well-developed in the pelitic rocks of all formations. Foliation oblique to bedding is observed only in the Benighat Slate. The Kunchha Formation often shows crenulation cleavages. Open and closed, asymmetrical and isoclinal folds are frequently found in all types of rocks of different formations.

## PETROGRAPHY

Thin sections of altogether 15 samples representing different lithology and formations were prepared for petrographic study to know the texture, structures and mineral parageneses under the petrographic microscope. Representing samples of rocks like slate, phyllite, schist, quartzite, dolomite and metabasic were collected from all the formations of the study area. Thin sections of some of the representing samples were studied under the petrographic microscope. A brief petrographic description and photomicrographs are presented in the following sections.

### Kunchha Formation

#### Metasandstone (DM38-45, L13-13)

Sample No. DM38-45 was taken from approximately 0.5 km southeast of Mugling (Fig. 2). This is blue-grey, and medium-bedded in outcrops. It consists of the assemblage sericite+chlorite+plagioclase+quartz+calcite. Quartz and calcite are the dominant minerals. The mineral grains are medium- to coarse-grained (maximum size of quartz: 0.25 mm, calcite: 0.37 mm, plagioclase feldspar: 0.35 mm) and subhedral to anhedral. Foliation (S1) is clearly defined by the preferred orientation of the platy minerals. Suture contact among quartz grains and deformational bands are prominent in the quartz grains. A modal composition is visually estimated as quartz ≈40%, calcite ≈40%, sericite ≈10%, plagioclase feldspar ≈5% and opaque minerals ≈4% (Fig. 4a).

Sample No. L13-13 was taken from approximately 2 km north from the confluence of the Daraudi and the Marsyandi Rivers (Fig. 3). It is composed of the assemblages muscovite+chlorite+plagioclase+quartz. The size of quartz grains ranges from 0.08 to 0.25 mm, plagioclase grain ranges from 0.06 to 0.2 mm and muscovite/chlorite ranges up to 0.1 to 0.4 mm. Most quartz grains show indented contacts. Recrystallized quartz grains and deformational quartz bands are abundant. Detrital muscovite grains are also observed.

#### Chlorite Phyllite (L7-6)

Sample No. L7-6 taken from approximately 1 km from Mugling towards Anbu Khaireni along the Gorkha–Narayangarh road section is grey, thinly foliated soapy phyllite. Mineral composition is muscovite+chlorite+quartz. It consists of 40% muscovite, 20% chlorite, 15% quartz, and 25% others. Foliation (S1) is clearly indicated by platy minerals.

#### Biotite phyllite (L18-16, DM406-51A, DM416-52)

Sample No. L18-16 was taken from about 6 km north of Anbu Khaireni. It is grey, green-grey, and medium-grained and show strong stretching lineation and crenulation cleavage. The mineral assemblage is biotite+muscovite+chlorite+albite+quartz (+tourmaline+magnetite+opaques). Modal composition is 55% quartz, 20% biotite, 10% muscovite, 10% albite and 10% others. The grain size ranges from 0.2 mm to 1.20 mm. Quartz is present as detrital grains as well as recrystallized mass. Detrital quartz is also strongly deformed showing wavy extinction. Pressure solution activity is indicated by indented contact of quartz grains (Fig. 4a).

Sample No. DM406-51A was taken from the right bank of Ludi Khola, SE of Gorkha (Fig. 3). This is also a grey, lineated and crenulated gritty phyllite. It contains the assemblage, i.e., biotite+muscovite+chlorite+albite+orthoclase+tourmaline+opaques. The composition is 35% quartz, 20% albite, 35% muscovite, 15% alkali feldspar, 10% biotite and 5% others. Grain size ranges from 0.5 to 1.5 mm. Quartz shows strong wavy extinction. Asymmetric pressure shadows are developed around quartz porphyroclasts. Some quartz clasts also show core-and-mantle structure. Some quartz grains recrystallized into polygonal aggregates. Recrystallization of silica matrix into sub-polygonal

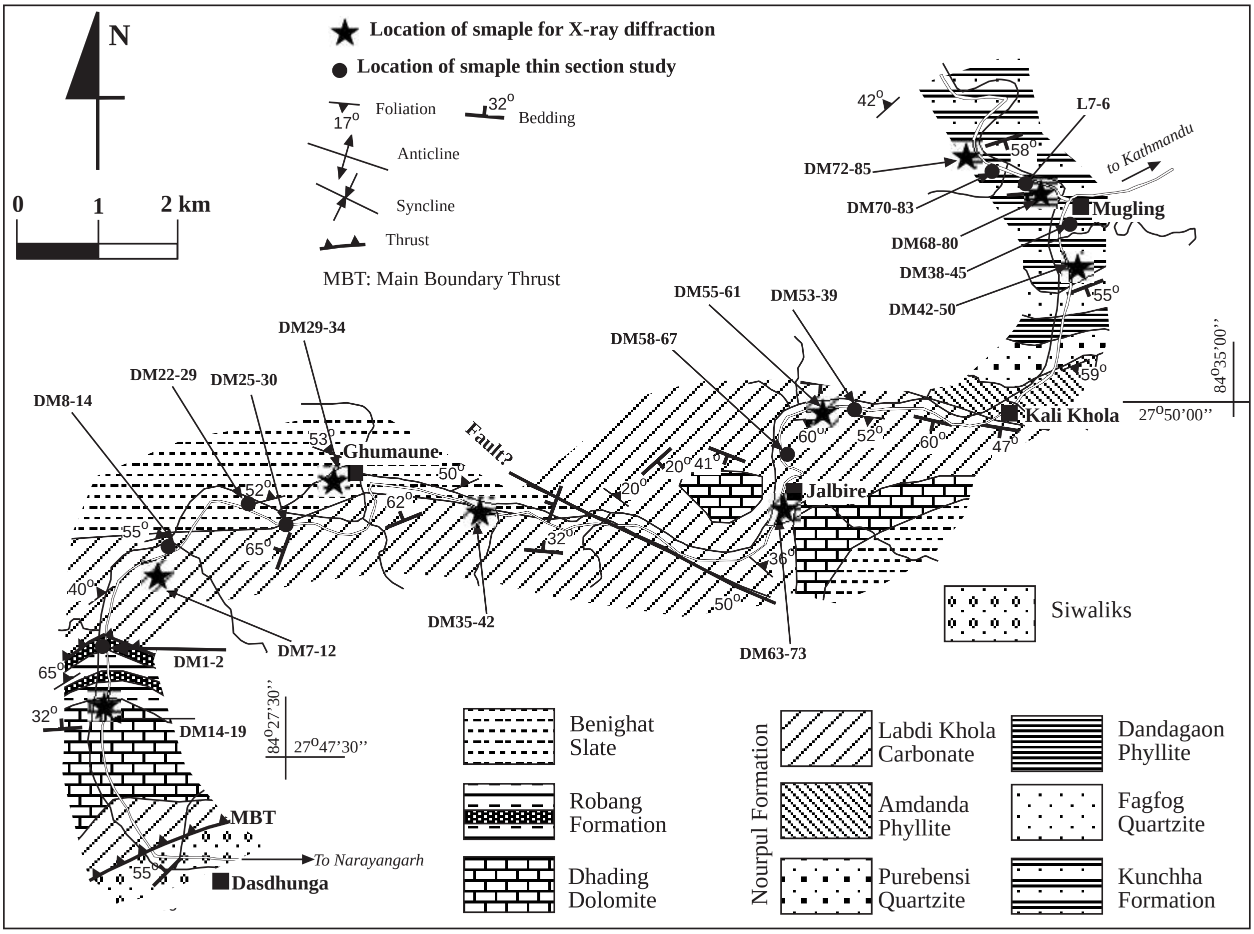


Fig. 2 Geological route map along the road from Dasdhunga to Mugling showing the sample sites.

quartz is also observed. Biotite occurs as fine-grained platy matrix oriented parallel to the foliation (Fig. 4b). Muscovite occurs both as large detrital grains (up to 0.6 mm length) as well as recrystallized matrix. Gritty phyllite from the right bank of the Daraudi River (DM416-52, Fig. 3) also contains the assemblage biotite+muscovite+chlorite+albite+orthoclase +tourmaline+opaques. However, it is more coarse-grained (grain size reaches up to 2 mm).

### Garnet-schist (DM 419-55b)

The sample of psammitic schist with garnet+biotite+muscovite+chlorite+albite+quartz assemblage was taken from Chhoprak (Fig. 3). The sample is medium to coarse-grained and parallel arrangement of biotite, muscovite and elongated grains of quartz define foliation. In thin section, the schist shows in-equigranular (grain size: 0.003–2.5 mm), grano-blastic texture. Some biotite grains have altered to chlorite. Few quartz grains show growth texture by clear margins formed due to late crystallization process. Two sets of foliation are defined by the preferred orientation of mica-minerals. Garnets are euhedral in shape and maximum size is up to 5 mm. The margins of garnet overgrown across the foliation indicate growth after deformation (Fig. 4c).

## Fagfog Quartzite

### White quartzite (DM80-96)

The sample of white quartzite was taken from the Mugling–Anbu Khaireni road section of the Gorkha–Narayangarh Highway (Fig. 3). The outcrop consists of thick-bedded, white quartzite. Under the microscope it consists of dominantly quartz and plagioclase with sericite and magnetite in minor amount. The grains are coarse (maximum diameter of quartz grain is 0.15 mm) and anhedral and show granoblastic mosaic texture. Contact between adjacent quartz grains is sutured (Fig. 4d). Deformational bands are frequent. A few polygonal aggregates of quartz are also seen in this thin section. A modal composition

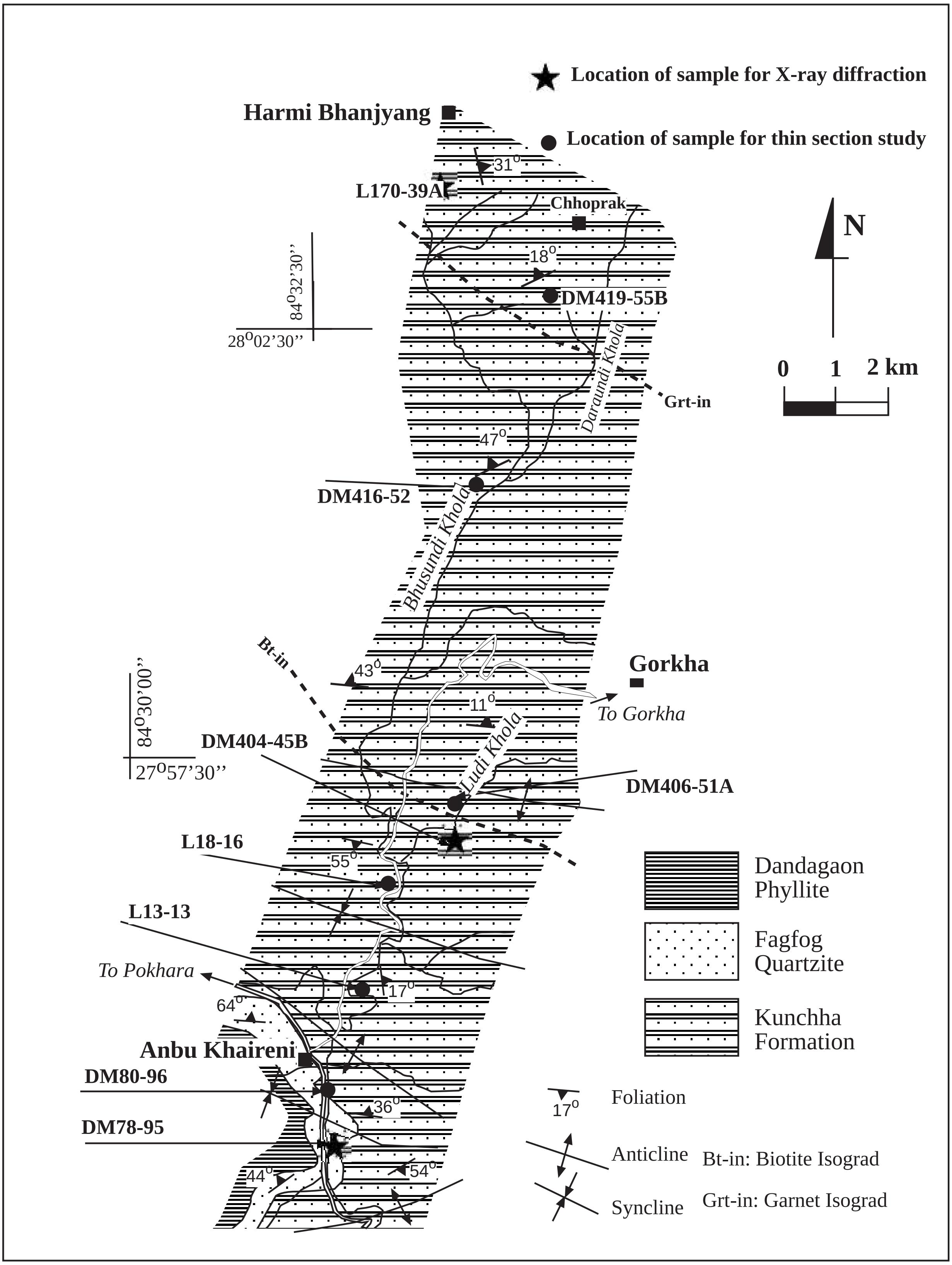


Fig. 3 Geological route map between Anbu Khaireni and Harmi Bhanjyang showing the sample sites. Biotie and garnet isograds are marked.

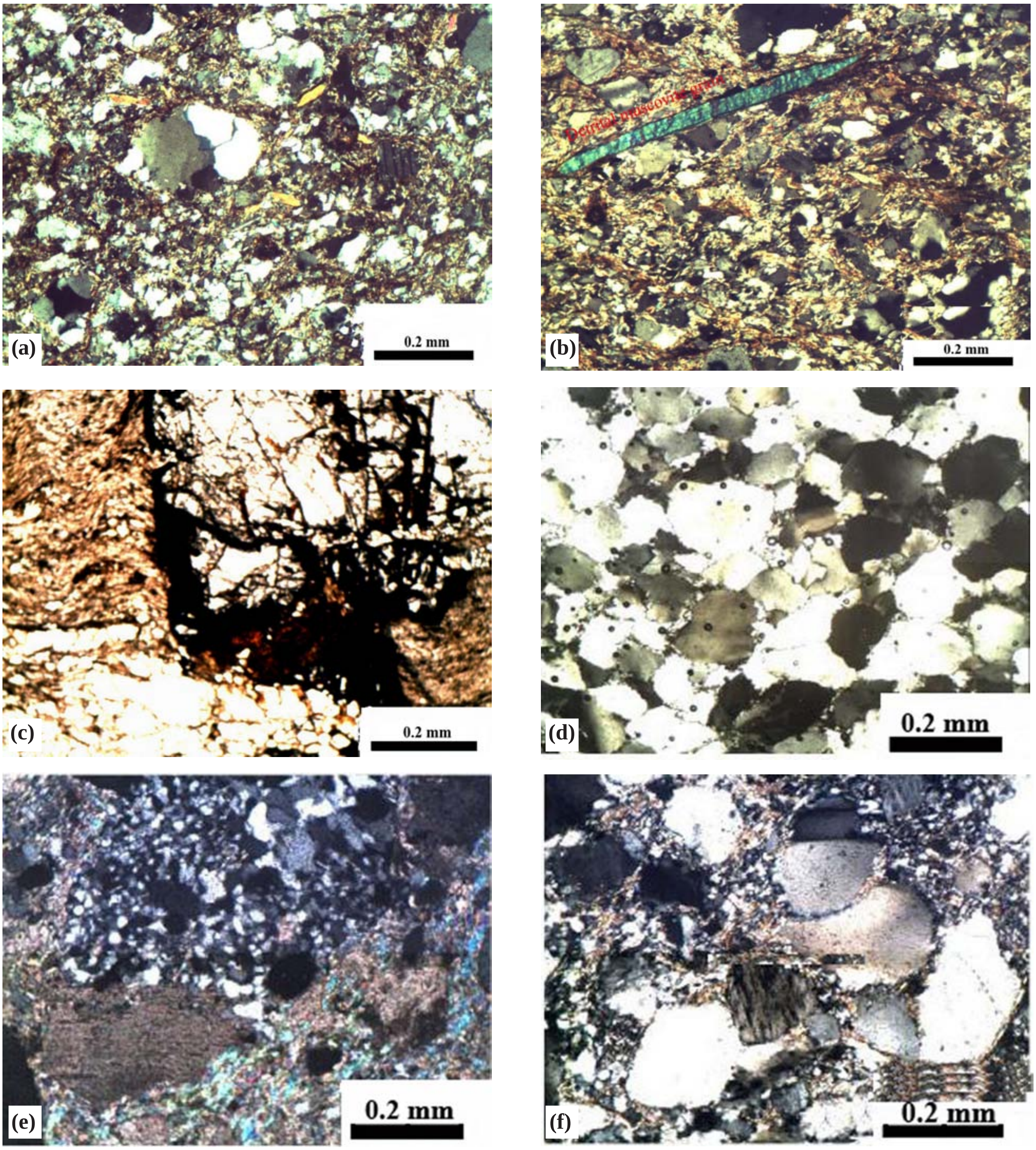


Fig. 4 (a) Photomicrograph of biotite phyllite (L18-16) from the Kunchha Formation showing indented contact between adjacent quartz grains. (b) Photomicrograph showing detrital grain of muscovite in gritty phyllite of the Kuncha Formation at Ludi Khola section (DM406-51a). (c) Photomicrograph showing the garnet porphyroblasts in the schist of Kunchha Formation (DM 419-55b). Note the overgrowth of garnet across the foliation. (d) Photomicrograph showing suture contact and deformation bands in quartz grain of the Fagfog Quartzite (DM80-96). (e) Photomicrograph showing lithic fragment in quartzite of the Nourpul Formation (DM58-67). (e) Photomicrograph showing indented contact in quartz grains in metasandstone of the Nourpul Formation (DM53-57). Qtz: Quartz, Pl: Plagioclase, Bt: Biotite, Ms: Muscovite.

is visually estimated as 95% quartz and 5% others.

## Nourpul Formation

### Calcareous phyllite (DM8-14)

The sample was taken from approximately 1 km southeast from Ghumaune (Fig. 2). It consists of the assemblage muscovite+chlorite+calcite+quartz+albite +orthoclase.The grain size of grains is usually less than 0.075 mm. However detrital muscovite grains sometimes reach up to 0.19 mm along long axis. Scales of carbonaceous materials form isoclinal folds. Foliation (S1) is determined by the elongated grains of muscovite and chlorite. A modal composition is visually estimated as quartz ≈60%, calcite ≈20%, sericite≈10% and others ≈10%.

### Calcareous quartzite (DM25-30, DM58-67)

Sample No. DM25-30 was taken from Seti Dovan, south of Ghumaune (Fig. 2). In thin section it consists of mineral assemblage muscovite+calcite+albite+orthoclase+quartz. Modal compostion is 80% quartz, 10% feldspar, 3% calcite, 2% mica and 2% others (zircon, hematite, opaque). Foliation is defined by muscovite. Several quartz veins cross-cutting the quartz grains and foliation are observed in thin section.

Sample No. DM58-67 was taken from near Jalbire (Fig. 2). It consists of the assemblage muscovite+chlorite+albite+quartz. Lithic fragments (1 mm) and quartz clasts are common in this rock (Fig. 4e). Grain size is bimodal. Foliation is defined by the parallel arrangements of fine-grained muscovite and chlorite in the matrix. The modal composition shows 60% quartz, 15% muscovite, 10% lithic fragments, 5% feldspar, 10% others.

### Metasandstone (DM53-39)

This sample was taken from approximately 3 km north of Jalbire (Fig. 2). It consists of predominantly quartz, subordinately muscovite, sericite and alkali feldspar (microcline) and calcite as minor amounts. Deformation bands of quartz grains with both indented and suture contacts (Fig. 4f). Quartz grains are mostly surrounded by sericite and mica. Foliation (S2) is oblique to foliation (S1). A modal composition is visually estimated as quartz ~85%, (platy minerals like muscovite and sericite) ~10%, opaque ~2%, alkali feldspar ~2% and calcite ~1%.

## Benighat Slates

### Black slate (DM22-29)

This sample was brought from approximately 3 km south of Ghumaune. It consists of predominantly quartz and graphitic materials and mica, plagioclase feldspar, calcite, hematite and lithic fragments as minor amounts. The rock is very fine-grained. Alternating bands of white (quartz, feldspar) and dark (graphite) minerals define the foliation. A modal composition is visually estimated as quartz ~50%, back graphitic minerals~20%, others (mica ~5%, calcite ~10%, alkali feldspar ~5%, opaque minerals, hematite and lithic fragments~10%).

**Robang Formation**

### Metabasite (DM1-2)

The sample was taken approximately 4 km north of Dasdhunga. They are medium-to coarse-grained with bimodal grain size, i.e., porphyroclasts embedded in matrix. In thin section, the metabasite show actinolite+chlorite+epidote+calcite+albite. Size of actinolite reaches up to 1.0 mm and is subhedral in shape. Blue-green and sometimes pale-brown relict of hornblende grains commonly occurs as phenocrysts (>3 mm). The phenocrysts are characterized by acicular actinolite growth around the rims. The preferred orientation of actinolite and chlorite define foliation.

**Illite crystallinity**

Crystallinity of illite in pelitic rocks usually signifies the degree of ordering of crystal lattice of these minerals (Kübler, 1967). The crystallinity of illite increases with increasing metamorphic grade. Systematic changes in the shape of peaks of these minerals on X-ray diffractograms serve as an indirect measure of the change in crystallinity. In the present study Illite Crystallinity (IC) was measured using the D8 Advance X-ray Diffractometer at the Central Department of Geology, Tribhuvan University. On the basis of the illite crystallinity data, the metamorphic grade and temperature condition of low grade metamorphic rocks were interpreted.

Systematic changes in the shape of 10Å (001) illite peak on X-ray diffractograms serve as an indirect measure of the change in IC (Weaver, 1960). There are several methods used to quantify the shape of the 10Å illite peak (Frey, 1987), the most commonly used one is Kübler Index (KI). The KI is measured as the peak width at half height of the 10Å X-ray diffraction peak of illite above the background. The KI decreases with increasing IC (Kübler, 1967). On the basis of IC, low-grade metamorphism can be divided into the diagenetic zone (>0.42 $\Delta$°2θ), anchizone (0.25–0.42 $\Delta$°2θ) and epizone (<0.25$\Delta$°2θ), which are roughly equivalent to the zeolite facies, prehnite-pumpellyite facies and greenschist facies of metamorphism (Warr and Rice, 1994).

## SAMPLE PREPARATION TECHNIQUES

Pelitic rock samples were collected from the study area. Among them thirteen representative rock samples were selected for IC analysis. During the sampling, very fine-grained rocks of similar lithology (mainly pelitic rocks) lacking of detrital grains, with well-developed foliation with shining surfaces and containing abundant phyllosilicates were collected as far as possible. Such selective sampling helped to reduce the inter- and intra-sample variation.

The standard laboratory procedure outlined by the IGCP 294 Working Group (Kisch, 1991) was used for the sample preparation. The detailed procedures are given in Paudel and Arita (2000) and Pokharel (2010). X-ray diffraction was carried out on <2 μm fraction of the sample. The diffractometer setting was constant for all samples (Advanced D8 diffractometer, Cu cathode, Ni filter, 40 kV tube Voltage, 30 mA current, time constant =2 second, scatter silt =1°, receiving silt =0.2 mm, divergence silt =1°). The KI was measured both manually and by using computer.

## RESULT

The KI values for 12 samples from the area are given in Table 1. The average KI values in the samples from the Kunchha Formation ranges from 0.11 to 0.129 $\Delta$°2θ. The KI values for the Nourpul Formation range from 0.121 to 0.143 $\Delta$°2θ. The KI value for the Dhading Dolomite is 0.123 $\Delta$°2θ, for Benighat Slate is 0.123 $\Delta$°2θ and for the Robang Formation is 0.127 $\Delta$°2θ. The data show that the Lesser Himalaya is in the epizonal metamorphic condition.

## DISCUSSIONS ON METAMORPHIC IMPLICATION

On the basis of petrography, the Gorkha-Narayangarh section of the Lesser Himalaya can be divided into three metamorphic zones namely chlorite, biotite and garnet zones (Fig. 2 and 3). Most of the area belongs to the chlorite zone. Common mineral assemblages in the pelitic rocks of this zone are muscovite+chlorite+albite+quartz. Degree of deformation and recrystallization is different in the southern part (south of Mugling) and northern part (north of Mugling) of the chlorite zone. In the southern part, sedimentary layering and detrital minerals are still well-preserved. Contact between quartz grains is tangential or slightly indented. Foliation is well-developed only in the pelitic rocks. In the northern part around Mugling and Anbu Khaireni, rocks are more coarse-grained, deformation is more intense as shown by the sutured contacts between the quartz grains. Foliation is well-developed both in the

Table 1: Illite Crystallinity (Kuble Index) of selected samples from the Dashdhunga to Harmi Bhanjyang.

| S. No. | Sample | Formation | Kubler Index ( $\Delta$°2θ) | | | Metamorphic zone |
|---|---|---|---|---|---|---|
| | | | Calculation by using software | Manual calculation | Average | |
| 1 | DM7-12 | Robang | 0.129 | 0.124 | 0.127 | Epizone |
| 3 | DM29-34 | Benighat | 0.122 | 0.124 | 0.123 | Epizone |
| 2 | DM14-19 | Dhading | 0.122 | 0.124 | 0.123 | Epizone |
| 4 | DM35-42 | Nourpul | 0.145 | 0.141 | 0.143 | Epizone |
| 6 | DM63-73 | Nourpul | 0.132 | 0.136 | 0.134 | Epizone |
| 5 | DM55-61 | Nourpul | 0.121 | 0.120 | 0.121 | Epizone |
| 7 | DM42-50 | Kunchha | 0.119 | 0.114 | 0.117 | Epizone |
| 8 | DM68-80 | Kunchha | 0.128 | 0.132 | 0.130 | Epizone |
| 9 | DM72-85 | Kunchha | 0.119 | 0.124 | 0.122 | Epizone |
| 10 | DM78-95 | Kunchha | 0.108 | 0.115 | 0.112 | Epizone |
| 11 | DM404-45B | Kunchha | 0.150 | 0.108 | 0.129 | Epizone |
| 12 | L170-39A | Kunchha | 0.113 | 0.108 | 0.111 | Epizone |

psammitic and pelitic rocks. This area is also marked by the development of strong stretching lineation.

Biotite isograd passes about 10 km north of Anbu Khaireni (Fig. 3). Biotite flakes are observed in the phyllite of the Kunchha Formation both in hand specimens and thin sections. Common mineral assemblages in the metapelite of the biotite zone are biotite+muscovite+chlorite+albite+quartz. Detrital minerals like quartz, K-feldspar, tourmaline and muscovite are still recognizable in the biotite zone. However, the quartz grains show core-and-mantle structure, indented and sutured contacts and grain size of the recrystallized grains is rather large. The garnet isograd passes from south of Chhoprak (Fig. 3). Tiny garnet porphyroblasts are observed in schist and metasandstone with naked eyes too. The common mineral assemblage of the garnet zone is garnet+biotite+muscovite+chlorite+albite+quartz.

Illite crystallinity indicates an epizonal condition of low-grade metamorphism in the whole sequence. There is no systematic variation of IC among different formations. Minimum value is given by the sample from the garnet zone. The presence of actinolite in metabasite indicates greenschist facies condition.

North of Anbu Khaireni, metamorphic grade increases northward regardless of the stratigraphic position. The isograds do not follow the lithological boundaries. This increase of metamorphic grade towards the MCT zone indicates presence of inverted metamorphism in the area.

## CONCLUSIONS

The study area consists of the Kunchha Formation, Fagfog Quartzite, Dandagaon Phyllites, Nourpul Formation, Dhading Dolomite, Benighat Slates and the Robang Formation of the Nawakot Complex. Petrographic study shows that the area can be divided into three metamorphic zones namely the chlorite zone, biotite zone and the garnet zone. Most of the area belongs to the chlorite zone. Biotite and garnet zones are limited to a narrow belt north of Anbu Khaireni. Illite crystallinity is $<0.25\ \Delta°2\theta$ showing an epizonal condition of metamorphism. Deformation and recrystallization patterns in quartz grains indicate a northward increase of intensity of deformation. The metamorphic zones are inverted as in the other parts of the Lesser Himalaya.

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