GEOLOGICAL STUDY OF THE MARDI RIVER SECTION FROM UPALLO DIP TO RAMCHE, LESSER HIMALAYA, WESTERN NEPAL

A Dissertation Submitted to the

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In Partial Fulfillment of the Requirement for the Award of Degree of
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RECOMMENDATION

This is to certify that Amit Neupane has completed this dissertation work entitled **"GEOLOGICAL STUDY OF THE MARDI RIVER SECTION FROM UPALLO DIP TO RAMCHE, LESSER HIMALAYA, WESTERN NEPAL"** as a partial fulfillment of the requirement of M. Sc. degree in Geology under my supervision. To my knowledge this work has not been submitted for any other degree.

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ABSTRACT

Geological mapping and petrographic study were carried out along the Mardi River from the Dip to Ramche. The area is covered by the rocks of the Lesser Himalaya in the south and the Higher Himalaya in the north separated by the Main Central Thrust (MCT).

The Kuncha Formation consists of chlorite-phyllite and metasandstone, which is underlain by the Fagfog Quartzite. The Fagfog Quartzite consists of white quartzite and two band of amphibolite intrusion, above this lies the Marble and Schist having medium grained garnet. The Black Schist and Quartzite lies over the Marble and Schist. All these terminate over the garnet and kyanite bearing schist and gneiss namely the Kyanite banded Gneiss. The lower boundary of the formation is supposed to be the Main Central Thrust (MCT). Hence in the area the Lesser Himalaya contains four units and the Higher Himalaya contains one unit.

The biotite grade zone starts from the Dip, lowest part of the area which is underlain by the garnet zone. The garnet grade zone starts from the Saiti Ghatta Khola and terminates in the MCT, from that kyanite grade zone is initialized.

The foliation in the area mostly dips towards NE except in the areas of local folding. Foliation is less prominent and usually parallel and sub parallel to the bedding. The area contains folds, thrust, stretching lineation and boudinage in the lesser Himalaya rocks.

From the petrographic study, it is depicted that the metamorphism in the area is the inverse prograde type. The higher grade metamorphic mineral is found stratigraphically high.

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Chapter One

Introduction

1.1 Introduction

The general geological mapping and the petrographical study of the rocks were carried out for the Mardi River area west central Nepal observing the Lesser Himalayan rocks and the Higher Himalayan Rocks. The thesis was the outcome of 35 days of field work during the month of March 2013 followed by 45 days of laboratory work for the petrographic study and about 3 months of the desk study. During the desk study, various literatures related to the geological mapping of adjacent areas, general geology of Nepal Himalaya and publications of Department of Mines and Geology, Central Department of Geology etc. were reviewed.

Study area lies tectonically in the Lesser and Higher Himalayan regions. Main Central Thrust (MCT) is the main tectonic structure in the area. It divides the whole rock units into the Lesser Himalaya underlain by the Higher Himalaya. Both rock units are subdivided into smaller units. The criterion of the division is lithological or structural. Because there is the movement of one rock unit over the other along the tectonic boundary like MCT, tectono-lithostratigraphy is proposed.

1.2 Location

The study area lies in North-West from the Pokhara, Kaski District of Western Nepal (Figure 1). The area lies in between latitudes 28°25'00" N to 28°15'00" N and longitudes 83°50'00" E to 84°00'00" E. It is about 250 km far from the Kathmandu by bus.

1.3 Topography and drainage

Steep and rugged topography are very common. The altitude ranges from 1000 m at dam site of the Seti Hydropower to 3800 m at the Annapurna Range.

The area is intricately dissected and drained by the network of steep gradient (>35° north part of the Mardi Khola) streams. The streams in the southern slope join the Mardi Khola, a major stream which flows north-south and confluences the Idi Khola downstream. The Resuka Khola, Bhajin Khola, Saiti Khola, Pau Khola, Kuiban Khola and Pati Khola are few principal feeders of the Mardi Khola. The Drainage pattern in the area is dendritic (Figure 2).

1.4 Objectives

The objectives of the study are:

- To prepare the geological map and cross-section of the area in 1:25,000 scale.
- To carry out the petrographic study of the rocks from the area and
- To find out the metamorphic grade and metamorphic zone of the area.

1.5 Limitations

The limitations of the present study are as follows:

- Some outcrops are inaccessiable due to steep cliffs.
- The criterion to define the individual rock unit is only lithological.
- It is difficult to establish true stratigraphy due to metamorphism and deformation.
- There is a limited time frame of the university to complete the dissertation.

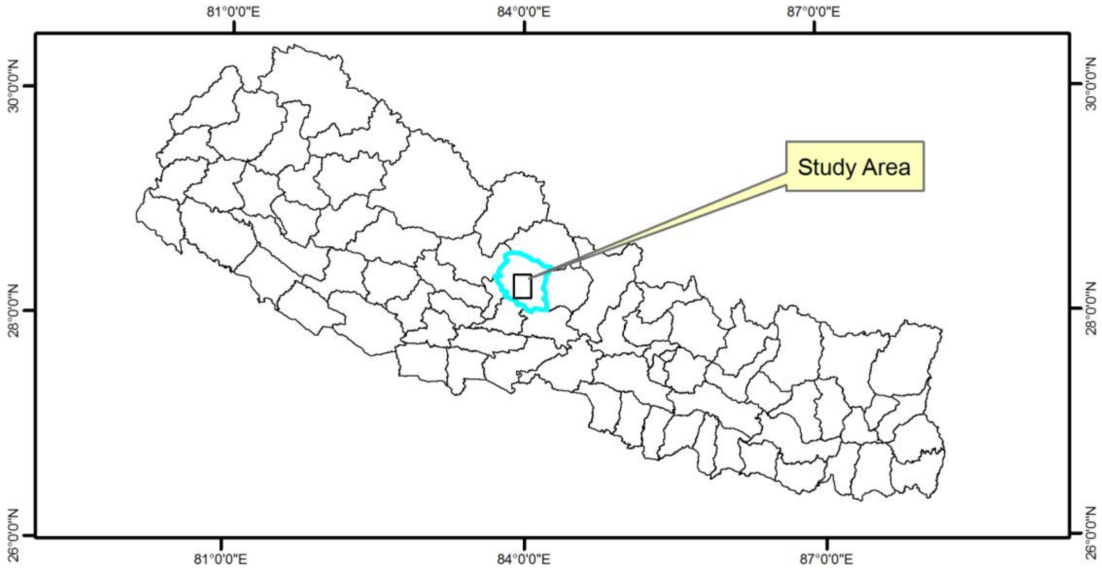


Figure 1 Location map of study area

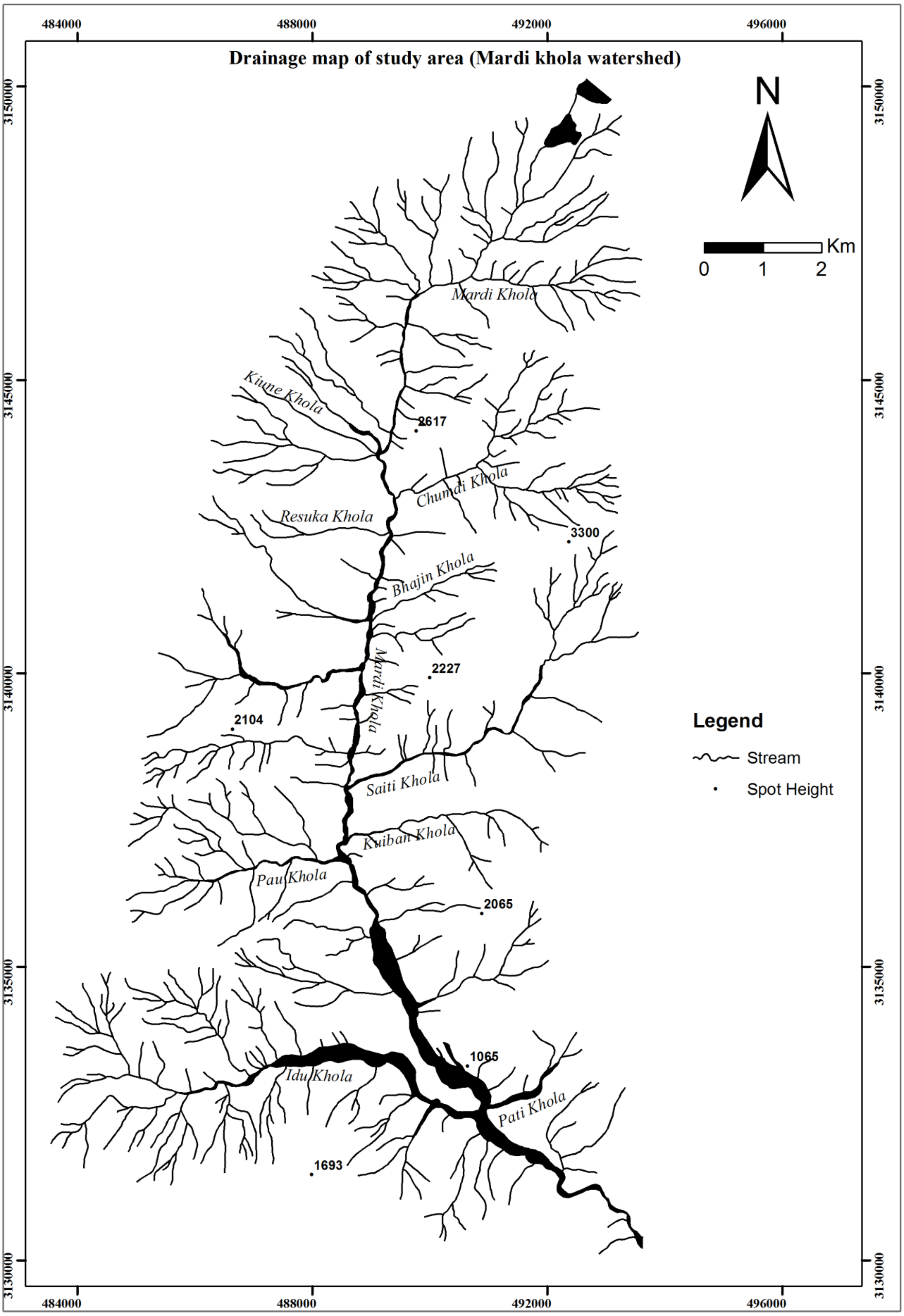


Figure 2 Drainage map of study area

Chapter Two

Literature Review

Hagen (1959) has reconnaissance survey of 9 years covering virtually the whole country (Nepal) brought forward the nappe concept in the Nepal Himalaya. The concept and his work was a breakthrough for the geological studies in the Nepal Himalaya as well as in the entries Himalaya. He reported the Nawakot Nappe made up of low grade metamorphic rocks of the Kathmandu Nappe.

Stöcklin and Bhattarai (1980) carried out a comprehensive geological mapping in central Nepal. They divided the rocks of this region into two complexes- the crystalline, high grade metasedimentary Kathmandu Complex, and beneath it the non-crystalline, low grade metasedimentary Nawakot Complex.

Colchen *et al.* (1986) carried out the mapping of Annapurna-Manaslu-Ganesh Himal area. The map has been further modified by Rai (2001). According to them, the Higher Himalaya succession is made up of medium to high grade metamorphic rocks such as sillimanite schist and gneiss, kyanite schist and gneiss whereas the Lesser Himalayan sequence contains essentially phyllite, quartzite and graphitic schist. They delineated the MCT between Ganesh Himal and the Kaligandaki River.

Inger *et al.* (1992) prepared a geological map of the area along Langtang valley and adjacent parts. They studied petrography and mineral chemistry as well as geothermobarometry for quantitative P-T determined of the Higher Himalayan crystalline sequence of the area. They also dated the rock for Langtang section through Rb-Sr method, applied for the whole rock as well as to mica. They also studied the polyphase metamorphism. They concluded that early Barrovian metamorphism happened in the area prior to 34 Ma in the early stages of the Himalayan Orogeny, followed by second metamorphic event resulted in the sillimanite grade metamorphism between 20 and 17 Ma. But their study provides, as they stated, no evidence for a genetic link between thrust faulting and inverse metamorphism.

Rai (1998; 2001) prepared a geological map of the central Nepal including Syaphrubensi area. Rai (2001) carried out 40Ar/39Ar and U-Pb dating. From the 40Ar/39Ar dating on muscovite indicate the cooling age of the Gosainkund Crystalline Nappe to be 16 to 5 Ma. He also prepared the metamorphic zonation map in the central Nepal including Gosainkund and Dhunche areas, on the left bank of the Trishuli River.

Macfarlane *et al.* (1992) prepared a geological map around Syabrubesi and also studied the deformation history along with major thrusting events with 40Ar/39Ar dating. This is the first major geological work in the area. They divided the rocks into three units namely, Lesser Himalyan Sequence, Main Central Thrust (MCT) zone and Greater Himalayan Sequence. They identified a duplex structure in the MCT zone. They further mentioned that the MCT in the Langtang region had at least two major periods movements- an early ductile phase and a later brittle phase.

Parrish and Hodges (1996) carried out U-Pb and Sm-Nd isotopic studies of the samples from the Langtang Area. They also dated the ages of detrital zircons of the Higher Himalayan rock. They found that the Greater Himalayan sequence had a sedimentary provenance that included a major source of 0.8-1 Ga zircons, implying a Late Proterozoic age. According to them the Lesser and Greater Himalayan sequence in the Langtang Area are correlated to the Lower and the Upper parts of the Vindhyan Supergroup of India. They do not support the logic of Pre-Himalayan metamorphism because the area contains sufficient metamorphic zircon and monazite.

Fraser *et al.* (2000) applied the recently developed ΔPT approach to make the absolute pressure and tempature calculations, across Langtang valley section of the Higher Himalayas and within the hanging wall of the MCT, which significantly assisted the 'inverted' metamorphism gradients in the Himalaya. They also studied the petrography. Intragrain garnet compositional variation had been documented via semi-quantitative x-ray maps. They distinguished previously unrecognized details in the preserved pressure array from the Langtang region which indicate post-metamorphic structural disruption of the High Himalayan Crystalline sequence. They identified the inverted metamorphic temperature in both the hanging wall and foot wall of the MCT.

Takagi *et al.* (2003) discussed about the kinematic history of the MCT zone in the Langtang area. They divided the MCT zone into Lower, Middle and Upper units. They described for the first time evidence for a northeastward brittle extensional movement of the MCT zone overprinting the southward ductile thrust movement. The study further concluded that the extensional shear movement in the Lower Unit took place after the major thrust movement in the MCT zone as a negative inversion. The Middle Units gives the dextral-thrust oblique sense of shear. The Upper Units commonly shows a thrust, in the authors' word, top-to-the-west sense of movement.

Paudel (2011) The Lesser Himalaya in central Nepal comprises low- to medium-grade metasedimentary rocks. Metamorphic studies show that they have experienced at least two metamorphic events (M1 and M2). However, exact timing of metamorphism is still controversial. In the study K-Ar dating of white micas in shales, slates, phyllites, schists and gneisses from the Tansen-Pokhara section was carried out to understand the timing of metamorphism. The muscovite in gneiss from the MCT zone shows an age of about 1255 Ma representing the age of crystallization of parent granite. Detrital mica from the Bhainskati Formation gives an age of about 2441 Ma. Probably this is the age of crystallization of muscovite in its provenance. The recrystallized white micas from slate and phyllite show older ages (Early Paleozoic) in the southern part (279 to 458 Ma). Most probably this represents the timing of M1. Age become gradually younger towards the north due to the mixing of older (M1 related) and younger (M2 related) white micas. Youngest age (10 Ma) was measured from the sample just below the Upper MCT. This age may be related to the M2 which was due to the Late Miocene-Pleistocene reactivation of the Upper MCT.

Kohn *et al.* (2005) worked in this area to find out the ages of the Higher Himalayan rocks as well as the chronology of the Himalayan metamorphic core. They mapped the monazite grains chemically from the Higher Himalayan gneiss (in Langtang valley) and then dated *in situ* via Th-Pb ion-microprobe analysis. They delineated a thrust namely, Langtang Thrust through Ghodatabela area and Ramgarh Thrust through the age and chemistry of the monazite grains in rock which revealed at least five generations of monazite ranging from 9 to >300 Ma which ultimately associated with the thermal evolution of the rocks.

Chapter Three

Material and Methods

3.1 Materials

Various field materials were used for the field work. Some of the important field materials/equipments used in the field are described below:

- **Brunton Compass**

Brunton compass was used to measure attitude of bedding, foliation, lineation, cleavage and hinge line of fold.

- **Geological Hammer**

It was used for the sampling of hand specimen of the rocks and resized in desired orientation.

- **Toposheet**

In the field, toposheet was used for plotting the location point and attitude of the bed rocks. Toposheet used in the field was topo no. 2883_12 which was at the scale of 1:50,000 but for the field work, it was enlarged in the scale of 1:25,000.

- **Measuring tape**

It is used for the measuring the thickness of the beds and the dimensions of the outcrops.

- **Dil. HCl**

For the field work, dil. HCl was used of concentration of 1:10 for determining the carbonate rocks in the field.

- **Diary and other stationary**

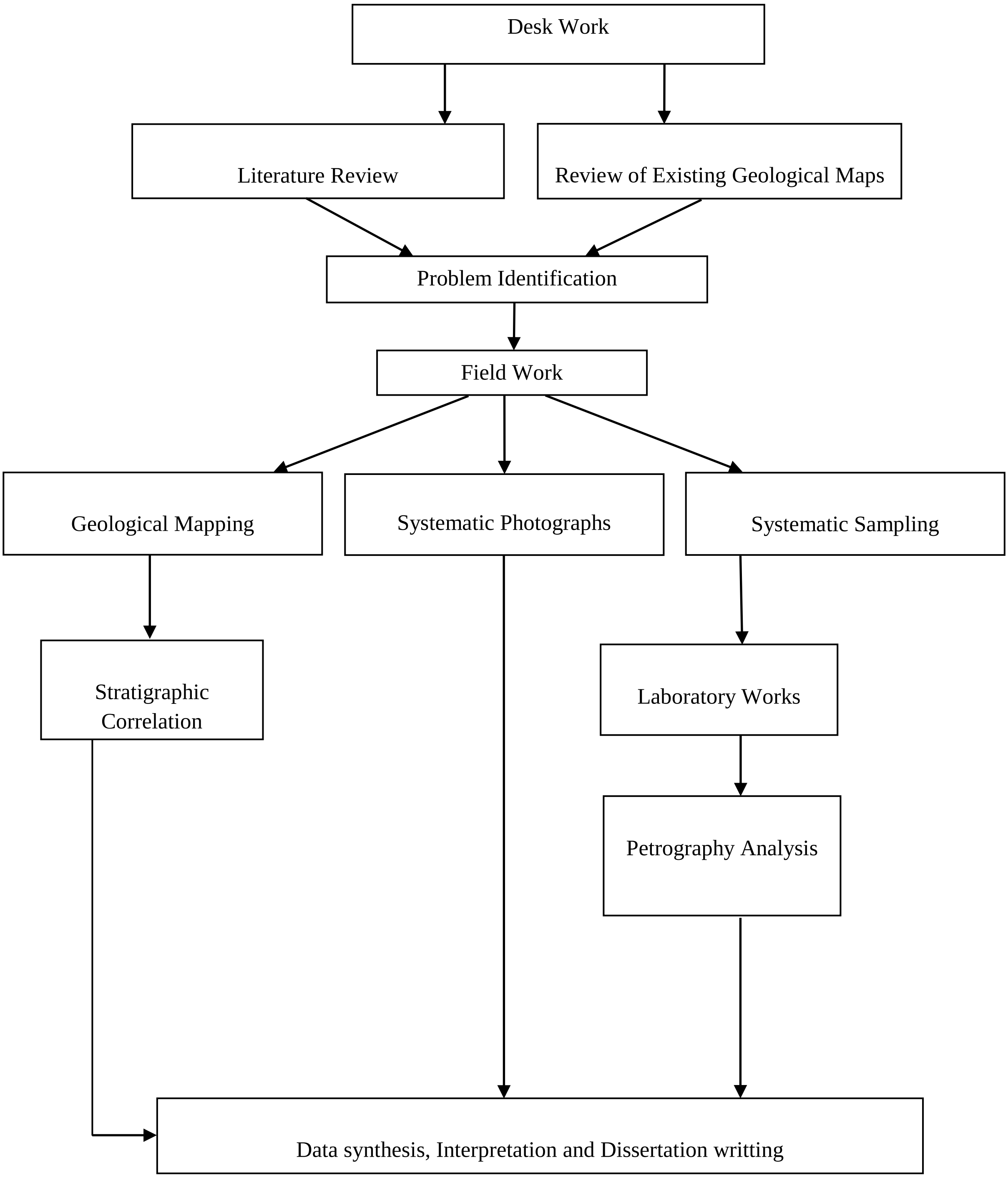
Various stationary materials were used for plotting the attitude in the toposheet and location points. Also used for the writing outcrops description and making sketch of it, in the dairy.

- **Sample bags**

Sample bags were used for keeping the hand samples safely.

3.2 Methods

During the field studies following methods were carried out:



3.2.1 Desk Study

During desk study period, earlier research publications and documents related to Google Earth images of the area, geological maps and other relevant documents were reviewed. Relevant Journals, articles, books and internet sites were searched and collected and discussion was made with the thesis supervisor and other related experts of geology.

Research papers and documents were acquired from Department of Mines and Geology; Government of Nepal, Department of Topographical Survey; Government of Nepal, Central Library of Tribhuvan University, Central Department of Geology; Tribhuvan University, etc. The main literatures studied belong to Geology of Nepal and Its adjacent region, Stratigraphy of Central Nepal Lesser Himalaya by Stöcklin and Bhattarai (1977); Stratigraphy of Central West Nepal Lesser Himalaya including Kaligandaki Supergroup by Sakai (1983; 1985); Journals of Stratigraphic Association of Nepal (SAN), unpublished report and thesis of present study area from Central Library and Library of Central Department of Geology.

3.2.2 Geological mapping

The field study was focused on mapping of the Lesser Himalaya and Higher Himalayan rocks of the Mardi River. The geological mapping was carried out essentially by the Brunton Compass traverse along ridges, rivers, trails and roads. Geological map of the area was prepared using 1:50,000 topographic map and 1:25,000 topographic maps produced by Department of Topographical Survey, Government of Nepal.

3.2.3 Systematic Sampling

Various rock samples were collected from the field for the petrographic study. Samples were numbered according to the location in the topomap taken to the field.

3.2.4 Outcrop description and Sketching

Dip-slope, counter dip slope, dipping of beds and lithology of rock were recorded. Sketch was made on the left page of the diary with appropriate scale. Outcrop description was done on the right page of the diary which mainly includes lithology of rock type of the outcrop, color of rock, grain size variation, bedding type, any geological structures and finally attitude of beddings.

3.2.5 Photographs

Photographs of outcrops and observed structure in the field were taken. In photographs time was leveled in the bottom right corner. Also in the lab, photographs of thin sections of samples were taken. Photo Nos. were recorded in the field dairy with description and facing direction of Camera.

3.2.6 Laboratory study

Lab work was carried out to prepare the thin sections of some rock samples. Lab work was done in the petrographic laboratory of the Central Department of Geology, Tribhuvan University, Kirtipur.

a. Preparation of Thin Section

The thin sections of each sample were made in the lab and studied under microscope to find out the chemical composition and percentage and the photomicrographs were taken. It also helps to find the metamorphic grade of rock.

Preparation of thin section includes several steps which are as described below:

Step 1: Preparation of glass slide

The glass slides used for sticking rock should be flat. Otherwise the rock section will not end up with a constant thickness. Usually, the glass slides available in the market are not flat and two sides are not parallel. Therefore, first and most important step of preparing thin section is to make the glass slide flat. It was done by polishing the slide on the glass slab with 600# grit. This process also roughened the surface of the glass slide so the epoxy bonded well.

Step 2: Marking on the rock

The rock samples which were to be cut should be marked. This is important especially when the rock has fabric. We must cut the rock perpendicular to a planar fabric (foliation or bedding) and parallel to a linear fabric. Make a line by a permanent pen.

Step 3: Preparation of a rock chip from sample

Rock chips slightly smaller than the size of the glass slides were prepared. Normal size of thin section chip is about 3.5 cm x 2.5 cm x 1-5 cm. Both big and small rock cutting machines were used for making chip for thin section.

Step 4: Polishing the chip

After cutting the chip, the side which has to be glued on the glass slide was polished to remove the marks from the saw blade. First polished with 400# powder on the grinding wheel to remove the saw marks, then it was polished with 600#, 800# and 1000# powders respectively to make the surface shining.

Step 5: Mounting sample on the glass slide.

I. Hot plate was turn on and temperature was set at 110-120°C.

II. The sample was set on the hot plate for at least 10-15 minutes (longer if the sample is porous or soft) for completely drying before coming into contact with epoxy.

III. When the sample was completely dried, it was removed from the hot plate and was set in front of own self with the face mounted pointed up.

IV. A small drop of epoxy was placed on the surface of the sample and the glass slide prepared earlier was pressed onto the surface of the sample. Air bubbles were removed, and/or added an additional epoxy before the epoxy began to harden.

V. To remove air bubbles, a popsicle stick was placed on the glass and was slowly and carefully "chased" the air bubbles to bring to the edge of the sample by drawing another popsicle stick from the middle of the sample to the edge.

VI. Once there were no more bubbles and the glass was properly centered, the sample was turned over and set back on the hot plate to cure with the glass slide down.

VII. Epoxy was allowed to cure for approximately 45 minutes, and then it was let cool off the hot plate for a while (time varies depending on the sample) before handling it further. The slide was kept overnight for proper hardening of the epoxy before further processing.

Step 6: Cutting of thin section

This step is to trim as much of the sample as possible with the fine cut-off saw. The thickness of the section can be adjusted with the help of screw.

Step 7: Hand grinding and polishing

I. On a flat piece of glass plate, slurry was made with about a teaspoon of 400# grit of SiC. The sectioned rock side was put down into the slurry and, while pressing on it with our fingers, the section was moved in circles or Figureure-8's to grind away the thickest parts. The places where pressed the hardest would be the areas that would grind away the fastest. The section was rinse with water and checked its thickness at frequent intervals. The thick parts of the section was always tried to grind and was made an even thickness. The job was continued until the saw marks were removed and the surface was flat enough. The glass plate was then washed.

II. New slurry was made on the clean glass with 600# grit of SiC. The section was polished with the method as described previously and continued until the section had reached a constant thickness and quartz and feldspar had 1st order yellow or yellow-orange interference colors.

III. The glass plate was washed.

IV. New slurry was on the clean glass with 1000# grit of SiC. The section was grinded away until it had an even thickness and quartz and feldspar have no more than 1st order grey interference colors. The thickness was checked frequently while grinding.

Impregnation Methods

Specimens that are very fragile, e.g., loosely cemented sandstone, mica-rich schist and any other weathered rocks cannot be sectioned in the normal way. They tend to break into pieces but often only when the slice has been ground down to thicknesses approaching 40 or 50 microns. Rocks like mudstones crumble to pieces at the first cutting stage and these specimens require different treatment. The normal method for dealing with specimens which are too fragile for normal sectioning techniques is to harden the specimen by impregnation.

The specimen was cut and rough grinded to produce a slice, often thicker than normal. The slice was placed on a hot plate to dry it. The epoxy resin was put to the surface and allowed it to soak into the slice. The epoxy would penetrate through the pores of the specimen. The depth of penetration of the hardening medium depends on the porosity of the hardener. Generally depth of penetration should be more than 2 mm for making thin section.

Where simpler surface methods were inadequate, the technique of thorough impregnation was used. The impregnating medium was required to penetrate right through the specimen; all the voids and cavities were filled within the body of the specimen. It was carried out by immersing the specimen in the epoxy resin for several hours.

Friable or porous samples were prepared by first cutting them into pieces about the size of a thin section chip (about 3.5 cm x 2.5 cm x 1.5 cm). Most friable samples contained excess water in between grains, adsorbed on days and elsewhere. The excess water was dried off by heating the samples on a 100°C on hot plate for 30 minutes or more. Enough epoxy for the sample was mixed. The samples were put in cups or dishes and was confirmed that they were completely covered with epoxy. When finished, the samples were taken out from their epoxy bath.

b. Petrographic Study

The thin sections prepared were studied under petrological microscopes to assess the mineral associations and texture.

3.2.7 Report Preparation

After the completion of field work and laboratory works, the primary data were compiled analyzed for the report writing. The thesis was prepared including all the primary and secondary data. Necessary discussion was made with supervisor and related experts. Finally the M.Sc. thesis was prepared and submitted to the Central Department of Geology, Kirtipur.

Chapter Four

Result

4.1 Lithostratigraphy

The main tectonic structure in the area is Main Central Thrust (MCT) which divides the whole rock units of ths study area into the Lesser Himalaya that underline by the Higher Himalaya. Lithological or structural criterion is adopted for the division in the study area. The lithostratigraphic division is given in table 1 and the geological map and its cross section of the area is in Annex 1. For many cases, the rock unit corresponds to the mineral isograds. As far as practicable the name of the rock units are adopted from the previous works.

The area has two major tectonic units *viz.* Lesser Himalaya unit in the south and Higher Himalaya unit in the north, separated by the MCT. The Generalized Lithostratigraphic sections are shown in Table 1.

Table 1 Lithostratigraphic of present study

Tectonic Units	Lithostratigraphic unit	Description of Lithology	Approx. Thickness (m)
Lesser Himalayan Unit	Black Schist and Quartzite	thinly laminated, black coloured schist with garnet containing medium bedded, greyish white coloured quartzite	800+
	Marble and Schist	Medium bedded, medium grained, light grey dolomitic marble with intercalation of thinly laminated, fine grained, grey coloured schist with garnet	700+
	Fagfog Quartzite	Medium bedded, medium grained, yellowish to white coloured Quartzite	140
	Kuncha Formation	Greenish gray, fine grained Phyllite and greenish gray, fine to medium grained, medium to thick bedded metasandstone and augen gneiss	+300
………………………………………..**MCT**..			
Higher Himalayan Unit	Kyanite banded Gneiss	Green schist and garnet bearing augen gneiss and well foliated dark and light banded gneiss	200+

The lithological descriptions of all the units are given in the following sections.

4.1.1 Higher Himalayan units

Kyanite banded Gneiss of the Higher Himalayan units was exposed in the study area which described below:

4.1.1.1 Kyanite banded Gneiss

This unit embraces all the terminations of the Lesser Himalayan formations. Kyanite banded Gneiss is well exposed around Ramche Village (Md 1; Figure 3). It is composed of well foliated dark and light banded gneiss.

This rock unit abruptly lies over the Lesser Himalaya unit which is exposed around Ghipli Village (Md 2-6; Figure 4). This sequence consists of green schist and garnet bearing augen gneiss. The thickness is about 800 m.

4.1.2 Lesser Himalayan units

In the study area, the Lesser Himalayan units were classified into four rock units which are describe below:

4.1.2.1 Kuncha Formation

Kuncha Formation is the oldest formation in the Lesser Himalaya of Nepal and comprised by Pre-Cambrian rocks. In the study area, the Kuncha Formation is observed from Upallo Dip through Hemja along road at the left bank of the Seti River. Also on the both banks of the Mardi Khola, it is exposed around Dadagau, Gairegau, Charyam, Anante Thati, Khoramukh, Phalamkhani, Humdi and Lumre areas.

It consists of greenish gray, fine grained Phyllite and also greenish gray, fine to medium grained, medium to thick bedded metasandstone (Figure 5). The thickness of this formation is more than 300 m.

Northwest of Khoramukh (Md 47) and in Humdi (Md 30-31), granitic gneiss (Figure 6) is observed within the Kuncha Formation which is similar in composition and texture with the Ulleri Augen Gneiss of Le Fort (1975). The thickness of the gneiss is more than 500 m in the Khanigau area which is pinched out in the Humdi area (thickness is about 100 m).

4.1.2.2 Fagfog Quartzite

Fagfog Quartzite unit is exposed at the confluence of the Pau Khola and Mardi Khola, at the left bank of the Mardi Khola below suspension bridge (Md 21) and even at the left bank of the Pau Khola (Md 22; Figure 7). It composed of medium bedded, medium grained, yellowish to white coloured Quartzite. The bedding is gentle dipping. The thickness is about 300 m.

North of Anante Thati (Md 32-33) and at the left bank of the Mardi Khola near Lumre (Md 23-25), the metabasic rock (amphibolite) (Figure 8) is intruded at the contact between the metasediments of the Kuncha Formation and the Fagfog Quartzite. The thickness of the amphibolite is about 100 m.

At the right bank of the Mardi Khola, southeast of Ghalel (Md 18-19), the metabasic rock (amphibolite) (Figure 9) is intruded at the contact of the Fagfog Quartzite and Marble and Schist. The thickness of the amphibolite is about 140 m.

4.1.2.3 Marble and Schist

Marble and Schist unit overlying the Fagfog Quartzite i.e. Dadagaon Phyllite, Nourpul Formation and Dhading Dolomite are highly metamorphosed and sheared. Therefore, it is very difficult to separate them. These rocks have been mapped as the Marble and Schist unit. They are (Md 11-19; Figure 10) composed of medium bedded, medium grained, light grey dolomitic marble with intercalation of thinly laminated, fine grained, grey coloured schist with garnet (Md 14). The thickness of the formation is more than 700 m.

4.1.2.4 Black Schist and Quartzite

Black Schist and Quartzite unit is exposed in the Girim and Sidhin Village (Md 7-10; Figure 11) which is composed of thinly laminated, black coloured schist with garnet containing medium bedded, greyish white coloured quartzite. The thickness of the formation is more than 800 m.

4.1.3 Lithostratigraphic comparision between the present study and previous works

The Kuncha Formation of the present study and Stöcklin (1980) are similar to the Kuncha Formation.

The Fagfog Quartzite of present study and Stöcklin (1980) are similar to the Fagfog Quartzite.

The Dandagaon Phyllite, the Nourpul Formation and the Dhading Dolomite of Stöcklin (1980) are similar with the single Marble and Schist unit because they are not distinctly separated with eachother.

The Benighat Slate of Stöcklin (1980) can be compared with the Black Schist and Quartzite.

The Formation I of Higher Himalaya of Le Fort (1975) is seen in the study area namely Kyanite banded Gneiss.

The comparison of lithostratigraphic units of the present study with that of the above mentioned authors is summarized in Table 2.

Table 2 Correlation of Rocks of present study with Stöcklin (1980)

Central Nepal, Stöcklin, 1980		**Present Study**
Group	**Formation**	**Formation**
Upper Nawakot	Robang-Malekhu Limestone	
	Benighat Slate	Black Schist and Quartzite
Lower Nawakot	Dhading Dolomite	Marble and Schist
	Nourpul	
	Dandagaon Phyllite	
	Fagfog Quartzite	Fagfog Quartzite
	Kuncha	Kuncha

Figure 3 Banded Gneiss near Ramche (facing southwest)

Figure 4 Augen gneiss containing garnet near Ghipli (facing northeast)

Figure 5 Exposure of the Kuncha Formation at dam site of Seti HP (facing is southwest)

Figure 6 Exposure of Granitic Gneiss near Humdi (facing northeast)

Figure 7 Exposure of gentle dipping bed of the Fagfog Quartzite Formation near Lumre (facing Southwest)

Figure 8 Hand Sample of Amphibolite near Ananta Thati Village

Figure 9 Hand Sample of Amphibolite near Lumre

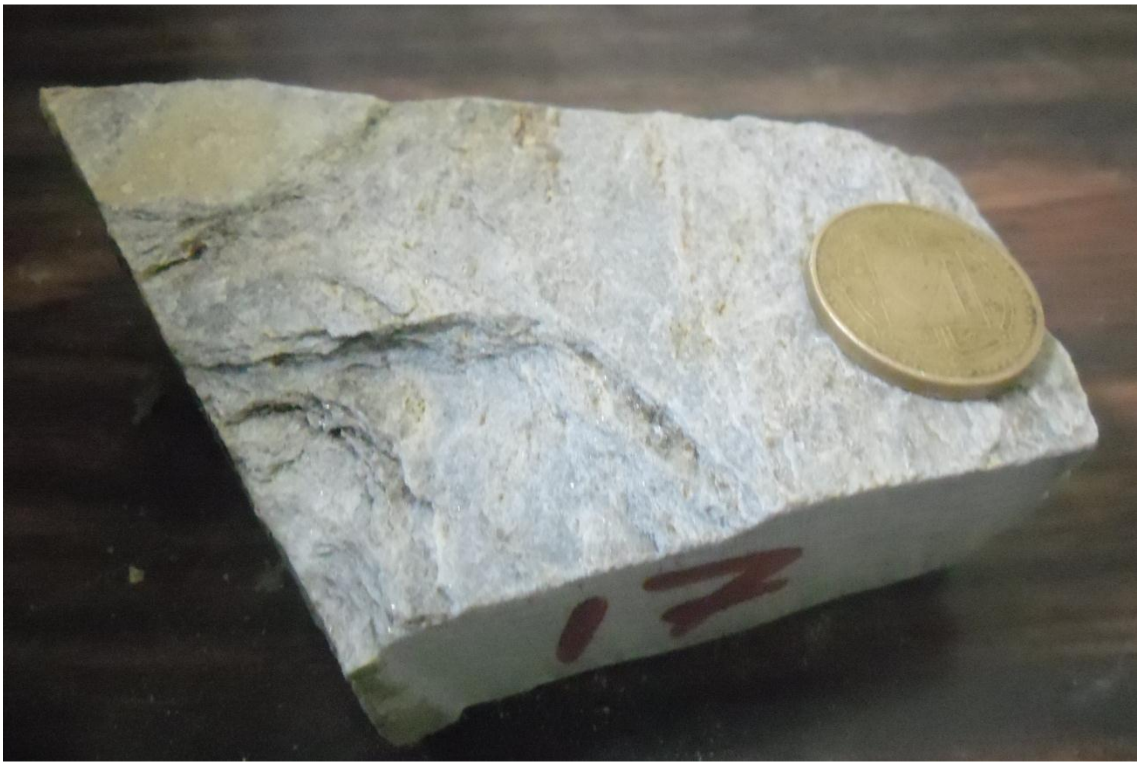


Figure 10 Hand sample of Marble and Schist

Figure 11 Interbedding of Schist and Qurtzite of Black Schist and Quartzite (facing Northwest)

4.2 Geological Structure

Since the area was composed of low to high grade metamorphic rocks, the primary structures are very rarely preserved. The secondary structures found in the area are given below:

4.2.1 Foliation

Foliation in the area is dip generally towards the north (Figure 12). The dip amount accedes 20° in most of the places, making the beds steeply dipping. The foliation in most of the places is parallel or gently inclined to the bedding.

4.2.2 Fold

Many minor folds (Figure 13) were observed, especially in the quartz veins, in the Marble and Schist near Saiti Ghatta area. Besides these, small scale folds were observed in the Kuncha Formation near Khoramukh area. The orientation of the fold axis is 330°/40°.

4.2.3 Joint

The joint is one of the most prominent and universally present in the study area. Every outcrop was jointed. The two set of the joint except the foliation were prominent.

4.2.4 Fault

The Main Central Thrust (MCT) is a regional fault (thrust) and major tectonic structure in the area dipping fairly (40°-50°) to the north which separates the low grade Lesser Himalayan rocks from the high grade Higher Himalayan rocks. The MCT can be trace throughout the study area, contact between Black Schist and Quartzite and Kyanite banded Gneiss as well as extends east to west crossing the Mardi Khola near Sidhin Village. Geomorphologically in the field, drastic change in lithology, Lesser Himalaya displays inverted metamorphism zonation, rotated and fractured garnets and highly deformed quartz veins are strong evidences for the MCT.

4.2.5 Lineation

There are many features developed due to the tectonics or mineralization. Some elongated minerals like mica show the mineral lineation in the rock. Stretching lineation was observed in the outcrop of the Fagfog Quratzite Formtion near Lwan Village (Figure 14) which orientation is 210°/70°.

4.2.6 Boudinage

Boudinage of quartz was very common in the field (Figure 15). These are formed in the tensile stress condition.

Figure 12 Foliation developed in the Black Schist and Quartzite near Sidin Village (facing northwest)

Figure 13 Fold observed in Marble and Schist near Lumre (facing northwest)

Figure 14 Streatching lineation observed in Fagfog quartzite near Lwan Village

Figure 15 Boudinage observed in Marble and Schist near Saiti Ghatta Village (facing southwest)

4.3 Petrography Study

Large number of hand samples were collected systematically representing the respective formations in the area. Out of them, only 24 were selected for the thin sections.

The index minerals, which are very important from the view point of metamorphism, when not observed in the hand specimen, observed in the thin sections along with the mineral assemblages of the rocks. According to the first appearance of the index minerals, a mineral isograd map is also prepared (Annex 2).

Brief results from the petrographic study of every sample are given below, according to Formations. The detailed description of each sample is given in (Annex 3). One important matter which must be mentioned is anything described about the petrography of the rock samples are seen on the whole thin sections but not limited to the photographs taken. The photographs are only a small part of the thin sections. The sample no. is homologous to the observation point in the field.

4.3.1 Kyanite banded Gneiss

This is from the Ramche area, on the right bank of the Mardi Khola. It contains quartz and orthoclase in equal proportion and few mica grains (Figure 16). A tentative model composition of estimation as quartz ≈ 10%, feldspar ≈ 70%, muscovite ≈ 15% and Biotite ≈ 5%. The index mineral is kyanite. One set foliation is due to parallelism of biotite. The rock is coarsed grained.

4.3.2 Kuncha Formation

Sample No. Md 56 (Metasandstone):

This is from dam site area of the Seti River and it contains quartz and feldspar in almost equal proportion and a few plagioclase (Figure 17). A tentative model composition of estimation as quartz ≈ 40%, feldspar ≈ 40%, muscovite ≈ 10%, Biotite ≈ 5% and chlorite ≈ 5%. It contains sufficient mica in the bands. Chlorite and biotite are present as index minerals. Some granoblastic and interlocking texture is observed. One set of foliation is developed due to mica band.

Sample No. Md 43 (Phyllite):

This is from the Khoramukh area. It contains quartz, orthoclase and much mica (Figure 18). It contains biotite as index mineral. The modal composition is evaluated as quartz ≈ 70%, feldspar ≈ 10%, and mica (biotite + muscovite) ≈ 15%. Granoblastic texture is commonly seen with some poikiloblastic one. The crystal shape is subhedral to euhedral. Foliation is due to the parallelism of the mica grains and some folds are observed in them.

Sample No. Md 30 and Md 47 (Augen Gneiss)

This is from the Khoramukh Village area. It contains quartz, orthoclase, muscovite and biotite. The model composition estimated as orthoclase ≈ 60%, quartz ≈ 20%, muscovite ≈ 10%, biotite ≈ 5% and plagioclase ≈ 5%. First sample contains perthite mineral grain (Figure 19) where latter sample contain plagioclase mineral grain (Figure 20). Biotite stands for the index mineral. Granoblastic and augen texture are common in the slides. Foliation is well developed due to elongated mineral crystals.

4.3.3 Fagfog Quartzite

Sample No. Md 21 (Quartzite):

This is from the Lumre area. It contains mostly quartz with a little plagioclase and mica (Figure 21). The model composition estimated as quartz ≈ 82%, potassium feldspar ≈ 9%, muscovite ≈ 1% and biotite ≈ 7%. The index mineral is biotite. The mineral are fine to medium grained. Foliation is due to parallelism of mica.

Sample No. Md 23 (Amphibolite)

This is from the Lumre area, at the left bank of the Mardi Khola. It contains Hornblende in more amount and few grains of orthoclase, quartz and mica (Figure 22). The modal composition estimated as hornblende ≈ 80%, quartz and feldspar ≈ 14% and mica ≈ 6%. Hornblende minerals have high interference color of dark green to yellow. They show a preferred orientation and define foliation.

4.3.4 Marble and Schist

Sample No. Md 17 (Marble):

This sample is from the Keshban Village. It contains about 90% calcite, few grained of quartz, orthoclase and mica (Figure 23). The model composition estimated as calcite ≈ > 68%, quartz ≈ 2% and feldspar ≈ 15% grains. The biotite is the index mineral. The calcites are coarse grained.

Sample No. Md 18 (Schist):

This is from the Kulban Village. It contains quartz, orthoclase and more mica. Some grain of plagioclase is also observed (Figure 24). The modal composition is estimated as quartz ≈ 22%, potassium feldspar ≈ 19%, muscovite ≈ 20% and biotite ≈ 33%. It contains biotite as index mineral. Granoblastic texture is commonly seen with sometimes poikiloblastic one. Foliation is due to mica band which is one set.

4.3.5 Black Schist and Quartzite

Sample No. Md 11 (Quartzite):

This is from the Kalimati area, left bank of the Mardi Khola. It contains mostly quartz and orthoclase (Figure 25) and few mica grains. The model composition estimated as quartz ≈ 87%, potassium feldspar ≈ 5%, muscovite ≈ 2% and biotite ≈ 6%. Biotite is the index mineral. The rock is medium grained. Foliation is due to elongation of mineral grains. The summary of the mineral assemblages in each rock unit is presented in table below.

Table 3 Summary of Mineral Assemblages of the individual lithostratigraphic units in the study area

Broad Tectonic Unit	Lithostratigraphic Unit	Lithology	Mineral Assemblage
Higher Himalaya	Kyanite banded Gneiss	Schist and Gneiss	**Ky+Grt+Bt+Ms+Or+Pl+Qtz**
Lesser Himalya	Black Schist and Quartzite	Schist and Quartzite	**Grt+Bt+Ms+Or+Qtz**
	Marble and Schist	Marble and Schist	**Grt+Bt+Ms+Dol+Or+Pl+Qtz**
	Fagfog Quartzite	Quartzite and Amphibolite	**Bt+Ms+Pl+Qtz and Bt+Ms+Hb+Qtz+Or**
	Kuncha Formation	Phyllite, Quartzite and Augen Gneiss	**Bt+Chl+Ms+Or+Pl+Qtz**

Qtz = Quartz, Or = Orthoclase, Pl = Plagioclase, Dol = Dolomite, Ms = Muscovite, Bt = Biotite, Grt = Garnet, Chl = Chlorite, Hb = Hornblende, Ky = Kyanite

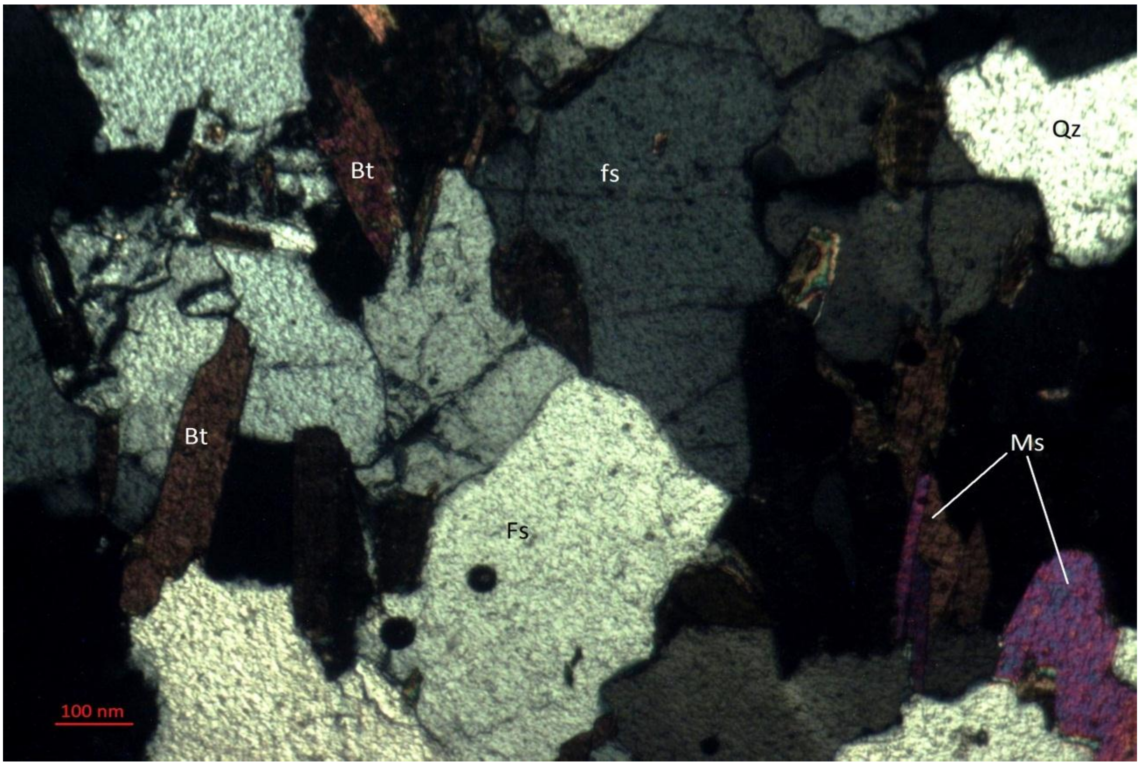


Figure 16 Photomicrograph of Banded Gneiss (Sample No. Md 1)

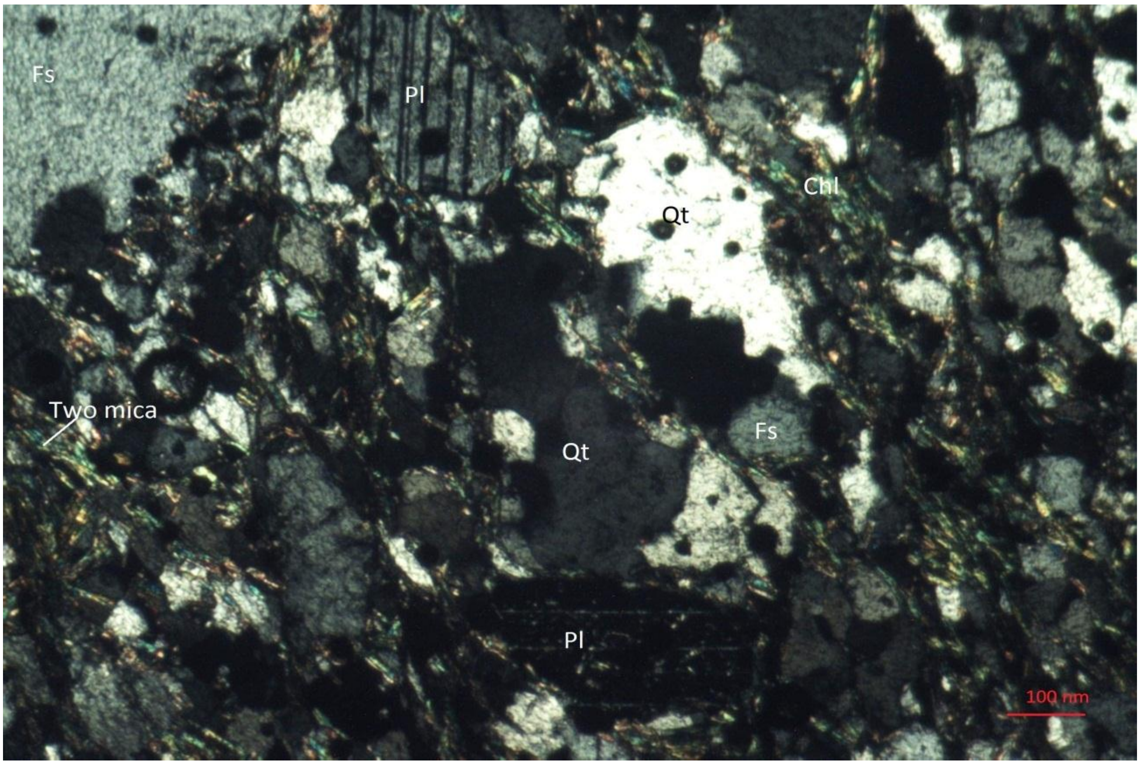


Figure 17 Photomicrograph of metasandstone of the Kuncha Formation (Sample No. Md 56)

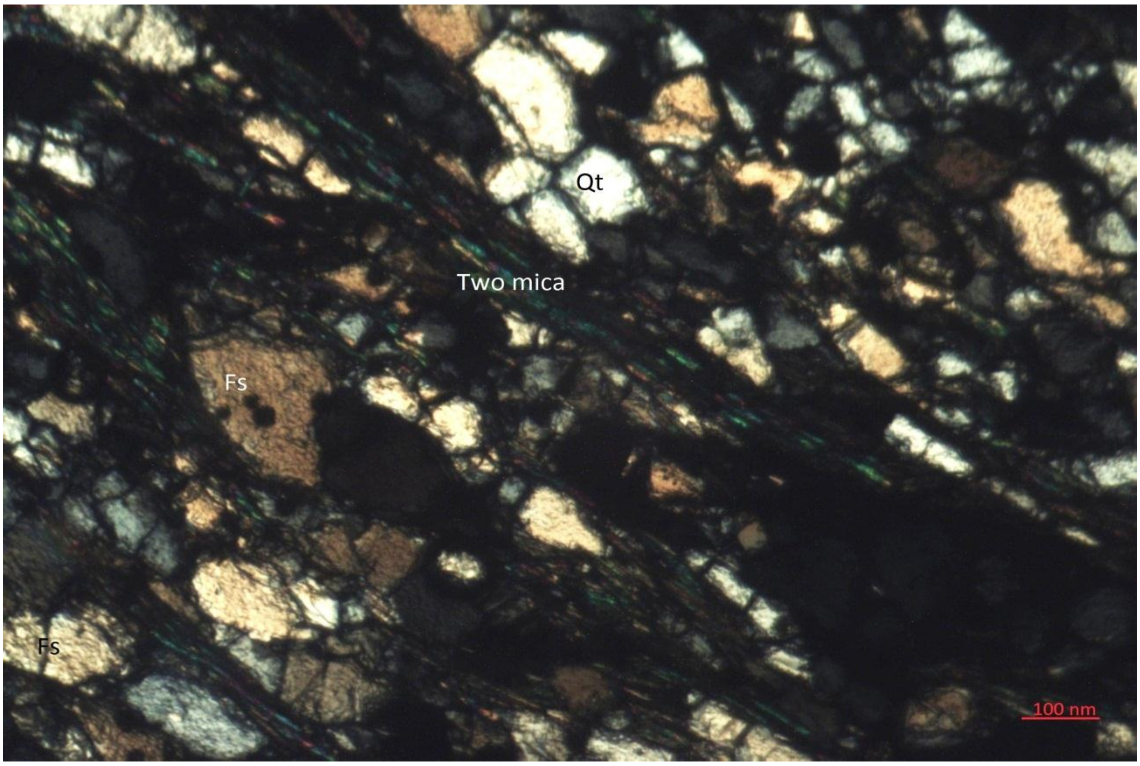


Figure 18 Photomicrograph of Phyllite of the Kuncha Formation (Sample No. Md 43)

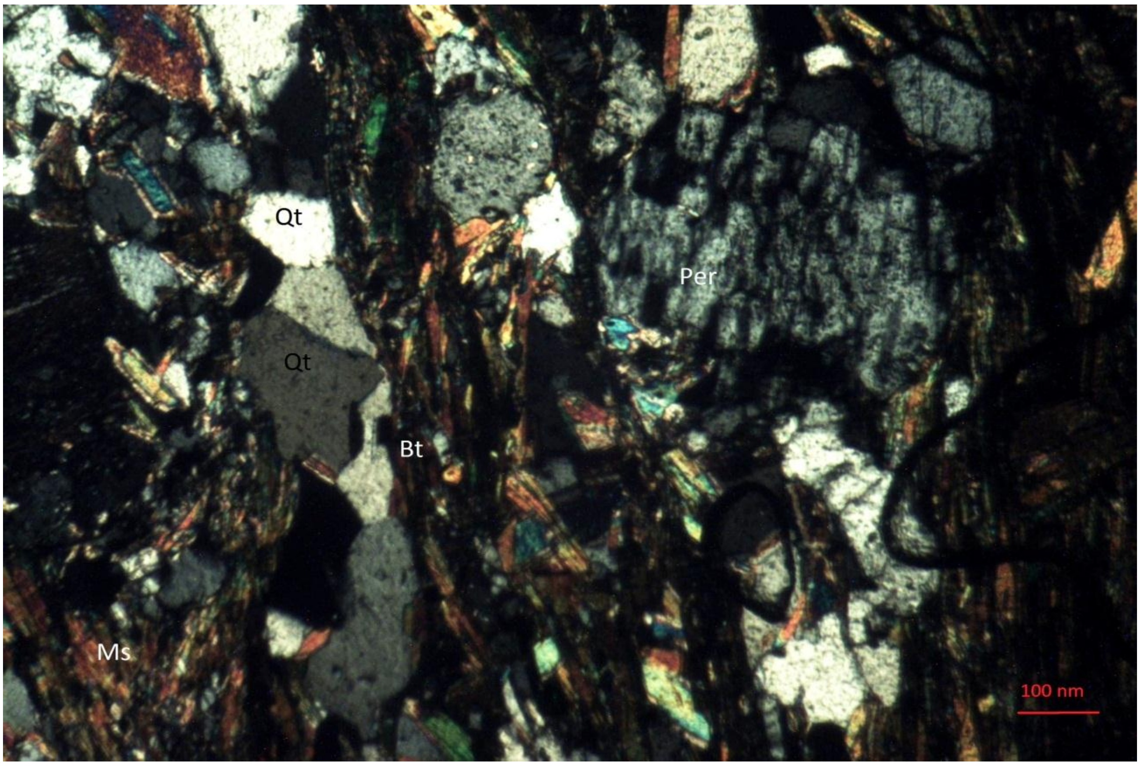


Figure 19 Photomicrograph of Augen Gneiss Associated with Kuncha Formation (Sample No. Md30)

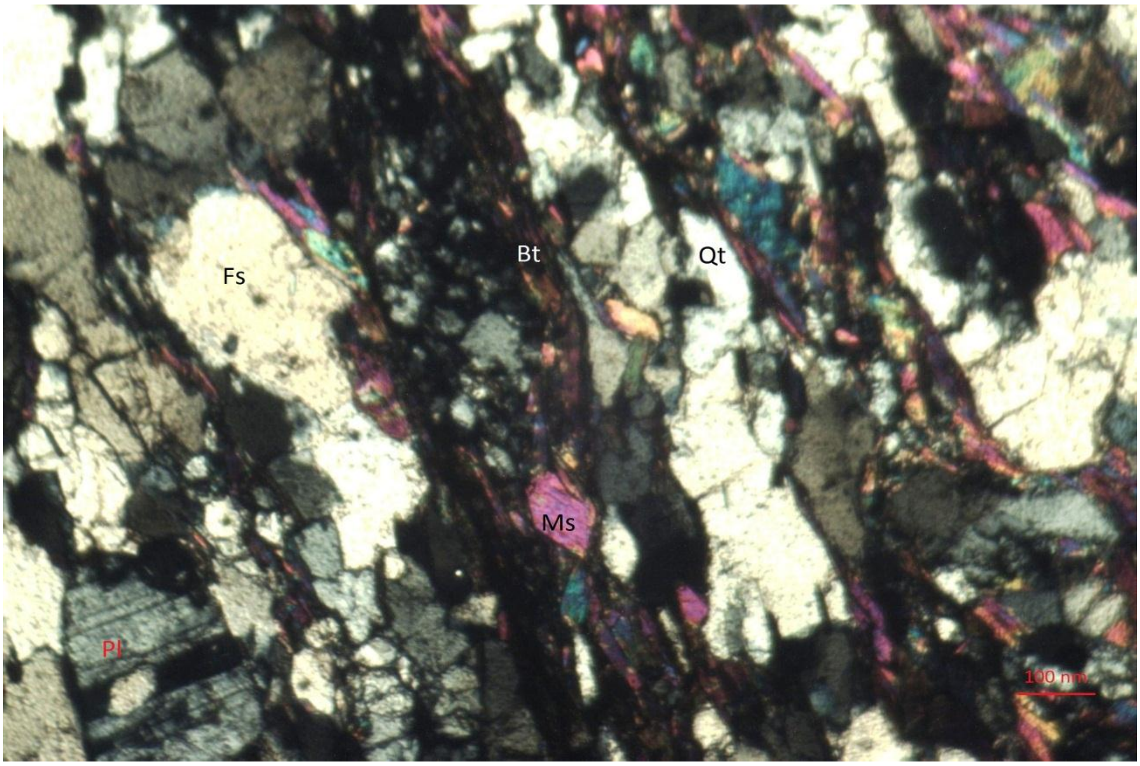


Figure 20 Photomicrograph of Augen Gneiss associated with the Kuncha Formation (Sample No. Md 47)

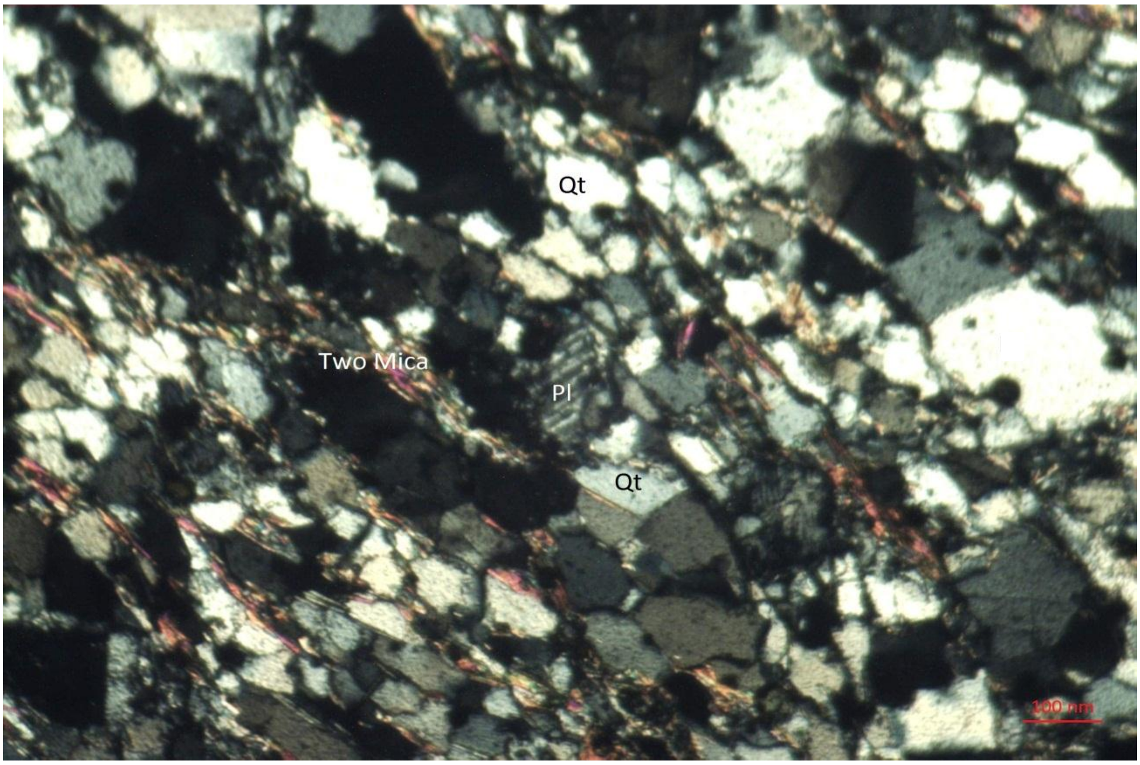


Figure 21 Photomicrograph of Quartzite of the Fagfog Formation (Sample No. Md 21)

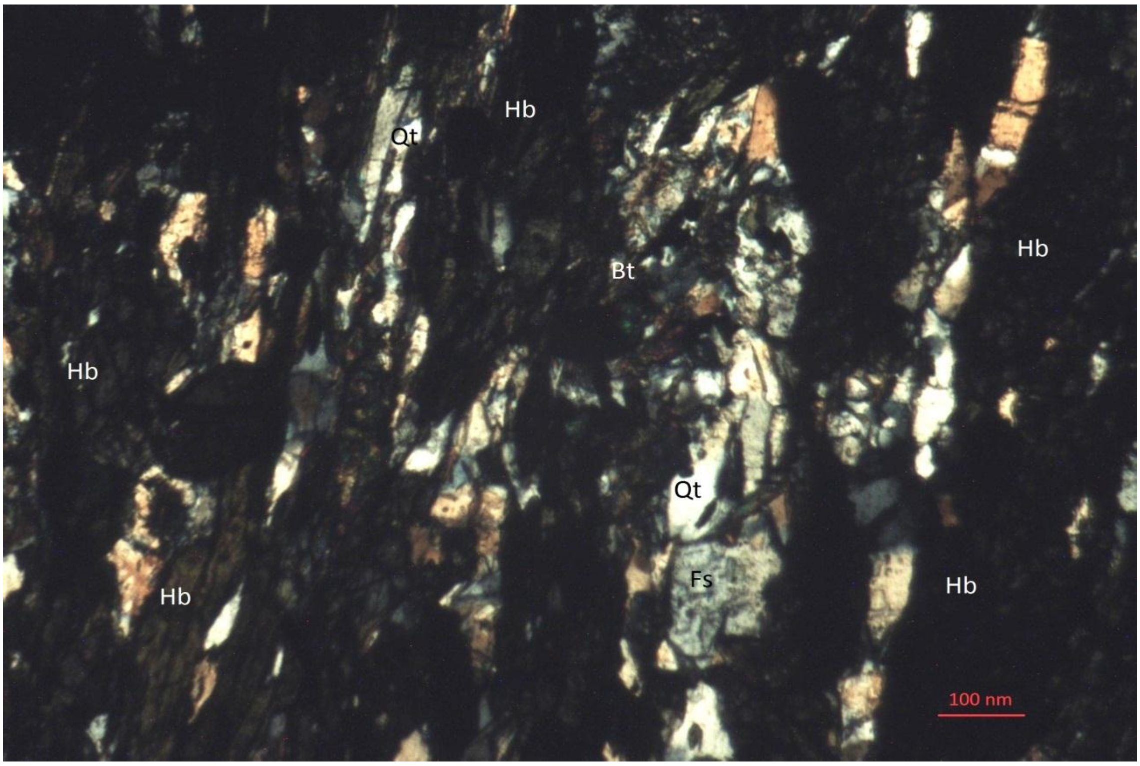


Figure 22 Photomicrograph of Amphibolite associated with the Kuncha Formation and the Fagfog Quartzite (Sample No. Md 23)

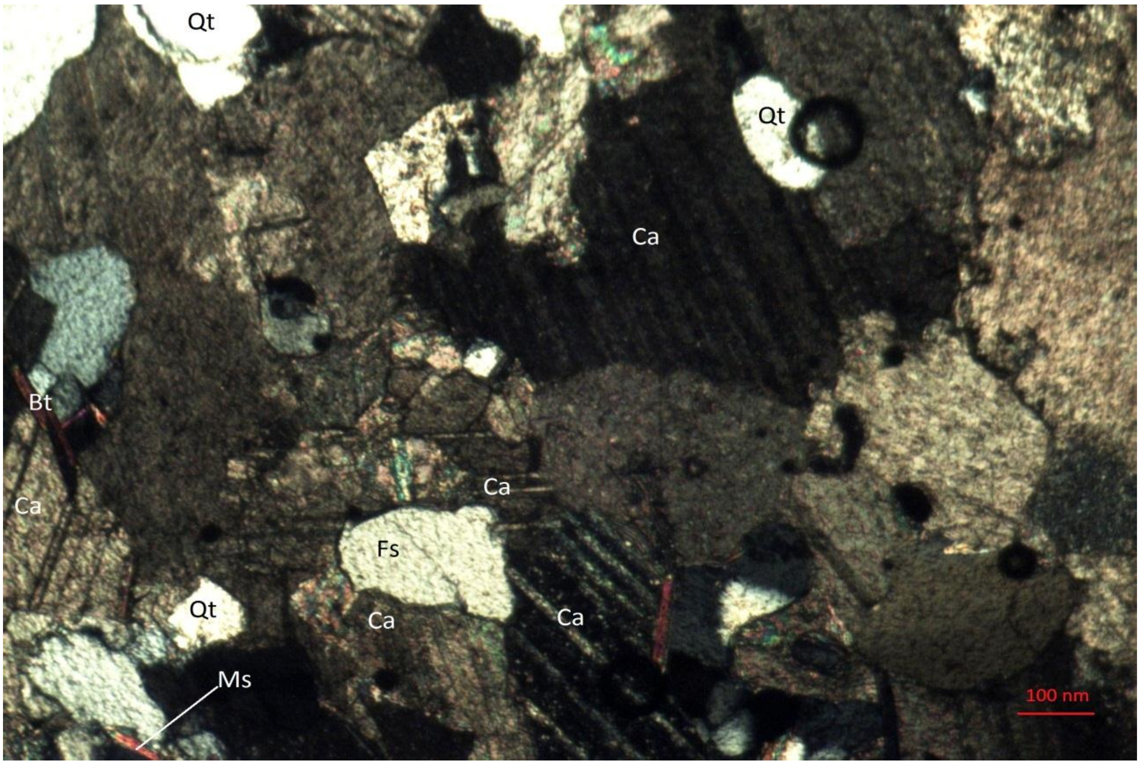


Figure 23 Photomicrograph of Dolomitic Marble (Sample No. Md 17)

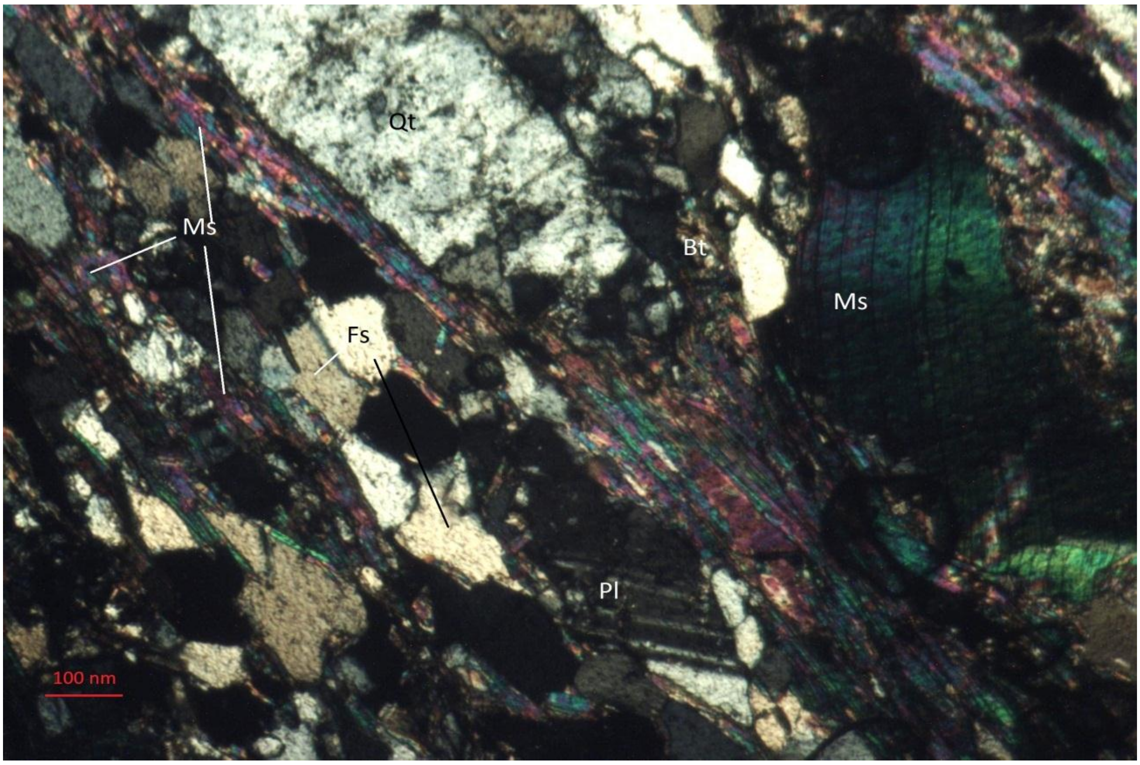


Figure 24 Photomicrograph of Schist (Sample No. Md 18)

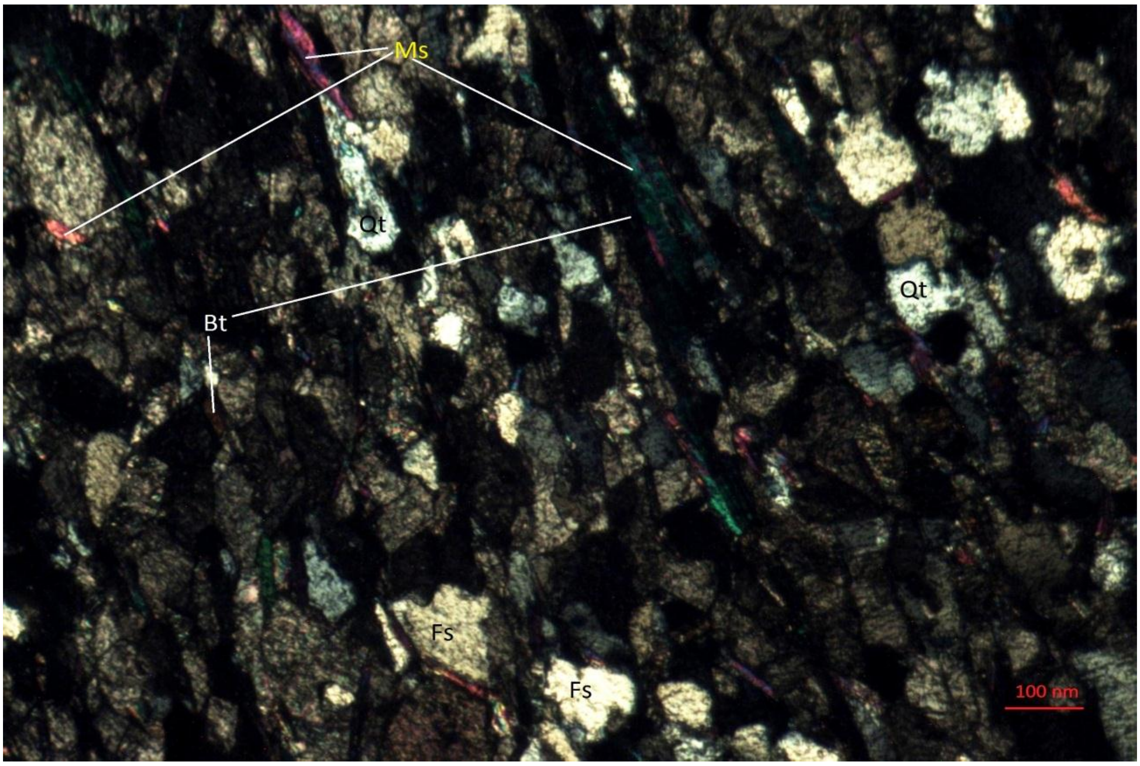


Figure 25 Photomicrograph of Quartzite (Sample No. Md 11)

Chapter Five

Discussion

5.1 Lithostratigraphy

The geological study was carried out along the Mardi Khola section from the Upallo Dip to the Ramche, Kaski District, Western Nepal, Lesser Himalaya. The rock units found in the study area are compared to the established stratigraphy of metasedimentary and sedimentary succession to the Nawakot Complex of Stöcklin and Bhattarai (1977).

The present study is aimed to carry out the detail lithostratigraphy of the area in the scale of 1:25000 and study about the structures of the area. Finally, the geological map and isograd map of the study is prepared.

The geology of the study area is compared to the established stratigraphy of the Nawakot Complex of Stöcklin and Bhattarai (1977). As the Kuncha Formation and the Fagfog Quartzite of the study which are similar to the type locality of Stöcklin and Bhattarai (1977) but ripple marks in the Fagfog area not observed in the present study. The augen gneiss rock type is similar to the Ulleri type augen gneiss Stöcklin and Bhattarai (1977) which is not extended more than around Humdi area, due to the steep slope the terminating location cannot be located. The metabasic rock (Amphibolite) intrudes into the Fagfog Quartzite and the Kuncha Formation. Locally, the Amphibolite is alternated with white quartzite belonging to the Fagfog Quartzite and carry foliation similar to the host rock.

In the studied section, the Marble and Schist is correlated with the Dandagaon Phyllite, Nourpul Formation and Dhading Dolomite of Stöcklin and Bhattarai (1977) which the lithostratigarphical boundaries of the rocks are not easily distinguishable due to high metamorphism. However, these formations consists of metasedimentary rocks namely mudstone, quartzite, dolomite and phyllite with sedimentary structures like mudcracks, ripple marks and stromatolites were preserved but in the study area, rock unit consists of Marble and Schist with garnet where sedimentary structures are not observed. But are correlated with the above mentioned formations of Stöcklin and Bhattarai (1977) because the rock type locality of the formations is not similar but their position in the stratigraphic column can be correlated stratigraphically.

The Black Schist and Quartzite rock unit is compared with the Benighat Slate of Stöcklin and Bhattarai (1977). The rock type according to the Stöcklin and Bhattarai (1977) in this formation is carbonaceous slate and white quartzite but in the present study area not all the lithology are found. Only the black schist and white quartzite was observed due to the metamorphism. This formation was terminated by the MCT. No any exposure was observed in the study area similar to the Robang-Malekhu Limestone of Stöcklin and Bhattarai (1977).

Le Fort (1975) divided the Higher Himlaya into three formations namely Formation I, Formation II and Formation III. The rock unit observed above the MCT in the study area is similar to the Formation I of Le Fort (1975) which consist retrograde metamorphic zone near the MCT and kyanite banded gneiss.

The MCT was kept about 250 north of the Sidhin Village because in the vicinity of the MCT, high grade of metamorphism, geomorphologically and lithostratigarphically. The MCT is the initial of isograd zone of kyanite and the termination of garnet zone. In thin section, kyanite and garnet mineral was not seen but observed in outcroup. The Upper Main Central Thrust (UMCT) of Arita (1983) is similar to the MCT of study area.

5.2 Metamorphism

The index mineral along with the mineral assemblage in the rocks is the key to understand the metamorphism. The petrographic study made possible to delineate the metamorphic zones in the area.

5.2.1 Metamorphic Zonation

A metamorphic zone is bounded by the two mineral isograds; the latter is the line joining the first appearance of an index mineral (Annex 3). In the study area, four metamophic zones are identified which are described below in the ascending order.

5.2.1.1 Biotite zone

The chlorite zone is not observed in the study area. The southernmost part (Upallo Dip to Hemja) of the study area lies in biotite zone. The biotite zone extends beyond the Dip, Anante Thati, Khoramukh, Lumre and continues up to the Saiti Ghatta. The biotite is abundant in the pelitic rocks.

5.2.1.2 Garnet zone

Garnet zone starts from the Saiti Ghatta Village and continues up to a little north of the Sidin Village. It extends beyond the Kalimati, Girim and Purundun Villages. The upper boundary follows the MCT, the tectonic boundary. Inside the zone, the garnet is found in the pelitic as well as psammitic rocks.

5.2.1.3 Kyanite zone

The lower boundary of this zone is confined by the MCT in the north of the Sidin Village. It is extands beyond the Ghipli and Ramche Villages. The upper boundary is not observed in the field because it is beyond the scope of the study area.

5.2.2 Metamorphic facies

The mineral assemblages that are observed in rocks are the indication of temperature and pressure environment that the rock was subjected to. This temperature and pressure is referred to as the metamorphic facies. In the present study, pelitic rocks are considered for the facies identification. The rocks of the Lesser Himalaya are of greenschist to amphibolite facies which is of the high temperature and low pressure type. The pelitic rocks of the greenschist facies have the mineral assemblage of muscovite-chlorite-quartz-K feldspar to biotite-muscovite-quartz-K feldspar. This is common assemblage of the Lesser Himalaya of the study area. The amphibolite facies has the mineral assemblage of muscovite-biotite-quartz-plagioclase as well as garnet-biotite-muscovite-quartz in the pelitic rocks which are common assemblages in the northern part of Lesser Himalaya in the study area. In the Higher Himalaya, amphibolite and granulite facies are identified. The pelitic rocks of the amphibolite facies have the mineral assemblage kyanite-garnet-muscovite-biotite-quartz and sillimanite-biotite-muscovite-garnet-quartz. Both of these assemblages are common in the area above MCT. Further, the pelitic rocks of the granulite facies of the Higher Himalaya have the mineral assemblage sillimanite (kyanite)-garnet-orthoclase-plagioclase-quartz.

5.2.3 Metamorphic history

One of the most challenging jobs is to interpret the metamorphic history of the Himalaya. It is definitely, associated with the tectonics. The detailed metamorphic evaluation is not possible from the petrographic study alone which is beyond the scope of this dissertation.

However, from the study of the thin sections, we can observe at least two metamorphic events in the Lesser Himalaya. The first event includes the chlorite to garnet grade metamorphism which is prograde type, moving down to the MCT. It is probably, due to the movement of the Higher Himalayan rocks over the Lesser Himalaya along the MCT. It is followed by second event which caused the retrograde metamorphism. The garnet and biotite are seen to get altered into chlorite in the thin sections of the Lesser Himalayan rocks.

Similarly, the Higher Himalaya experienced three events of the metamorphism as revealed by the petrographic study. These include the two events of the prograde metamorphism followed by one event of the retrograde one. The first event is the high temperature – low pressure type kyanite grade metamorphism. The second event includes the sillimanite grade metamorphism. Sillimanite is fibrolite type. The kyanite and sillimanite grade metamorphism histories are placed into the two events because kyanites are almost parallel to the foliation and sillimanites are oblique and cut haphazardly to the foliation. The third event in the Higher Himalaya is retrograde metamorphism. This is revealed by the alternation of the kyanite into muscovite as well as garnet and biotite into chlorite.

The metamorphic history mentioned above is related with the development of the MCT and the movement of the rock units along it. Paudel and Arita (2000) carried out a study of the metamorphism of the Himalaya with respect to the evolution of the MCT in the central Nepal. Their study is correlated to the present study too. The kyanite grade prograde metamorphism of the Higher Himalaya is similar to the Eo-Himalayan metamorphism (M1) of Paudel and Arita (2000) which is considered to be developed prior to the development of the MCT. The sillimanite grade prograde metamorphism is named as Neo-Himalayan metamorphism (M2) which is happened during the development of the MCT (syn-MCT) and their (M3) is similar to the retrograde metamorphism of the Higher Himalya which according to them, developed after MCT (post-MCT). Alternation of kyanite into muscovite and garnet into chlorite happened after the development of the MCT. Similarly, the Lesser Himalayan prograde metamorphism is developed concurrent to the MCT and the Lesser Himalayan retrograde metamorphism is developed post-MCT.

Le Fort (1975) in his famous hot iron model relates the phenomenon to the movement of the hot Higher Himalayan rocks over the comparatively cold Lesser Himalayan rocks along the MCT. On this process, the hot slab lost its heat to the colder Lesser Himalayan rocks producing the prograde inverted metamorphism in the uppermost part of the footwall (Nawakot Complex) and retrograde inverted metamorphism at the base of the hanging wall (Kathmandu Complex).

Chapter Six

Conclusion

After the completion of the geological mapping and the petrography of the area, following conclusions are made:

- ✓ The area consists of two broad rock units i.e. the Lesser Himalaya and the Higher Himalaya, the Lesser Himalaya lies structurally below the Higher Himalaya which are separated by the MCT.
- ✓ The Lesser Himalayan sequence consists of four rocks units which are as Kuncha Formation, Fagfog Quartzite, Marble and Schist and Black Schist and Quartzite. This sequence rocks unit is low to medium grade metasedimentary and metamorphic rocks like metasandstone, phyllite, schist and marble having quartz, feldspar, chlorite, biotite, muscovite and garnet.
- ✓ The Higher Himalayan sequence consists of only one rocks unit in the study area which is Kyanite banded Gneiss. This sequence rocks unit is medium to high grade metamorphic rocks like schist and gneiss having quartz, feldspar, biotite, muscovite, kyanite and garnet.
- ✓ There is the inverted metamorphic zonation in the area. The biotite zone lies in the structurally lowest rocks and the kyanite zone lies in the structurally highest rocks.
- ✓ The Lesser Himalayan rocks experience one garnet grade prograde metamorphism followed by another retrograde metamorphism whereas the Higher Himalayan rocks experienced two progrades metamorphism of kynite and sillimanite grades respectively at different times followed by the last retrograde metamorphism.
- ✓ The prograde metamorphism of Lesser Himalaya is concurrent to the development of the MCT while the retrograde one is post-MCT.

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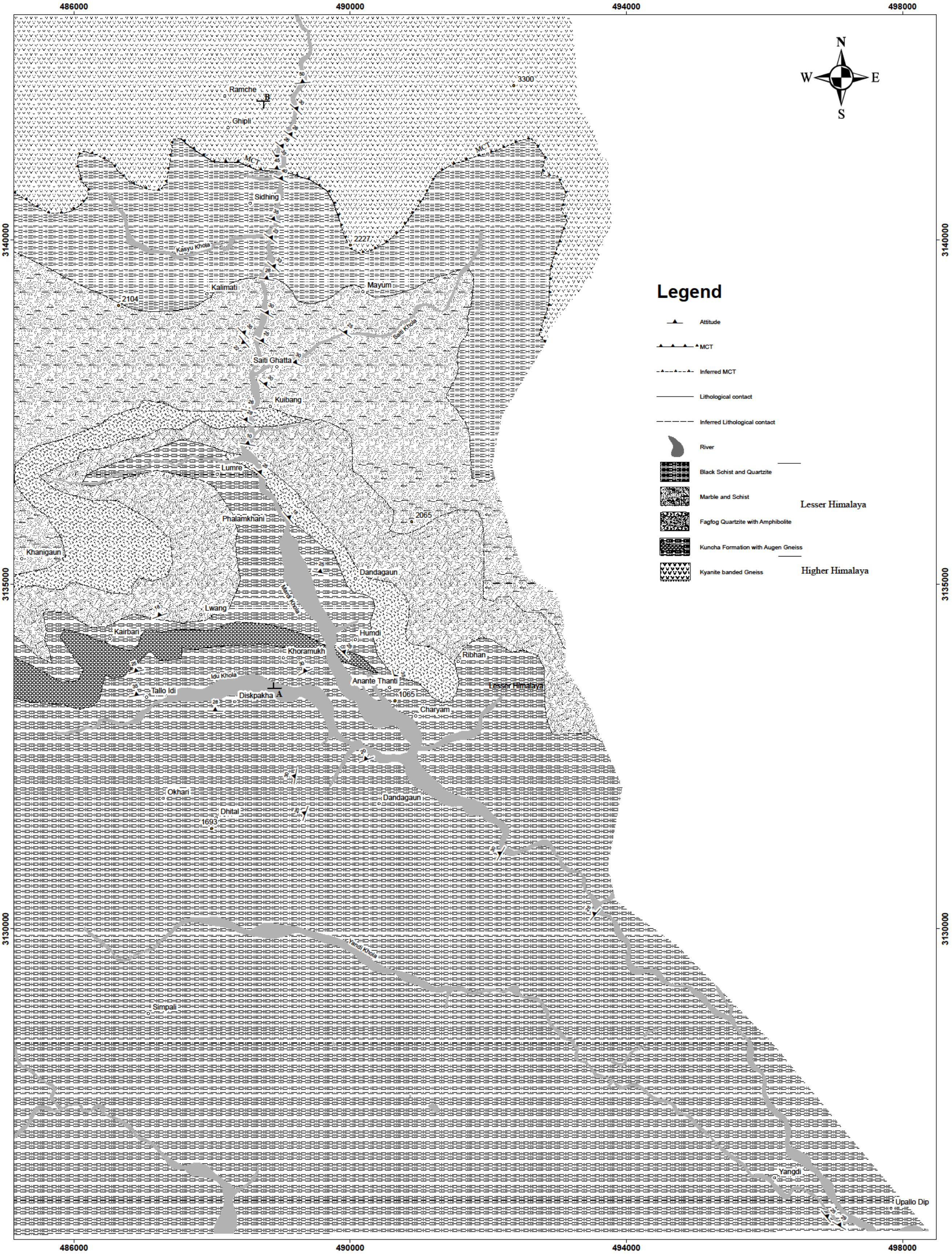
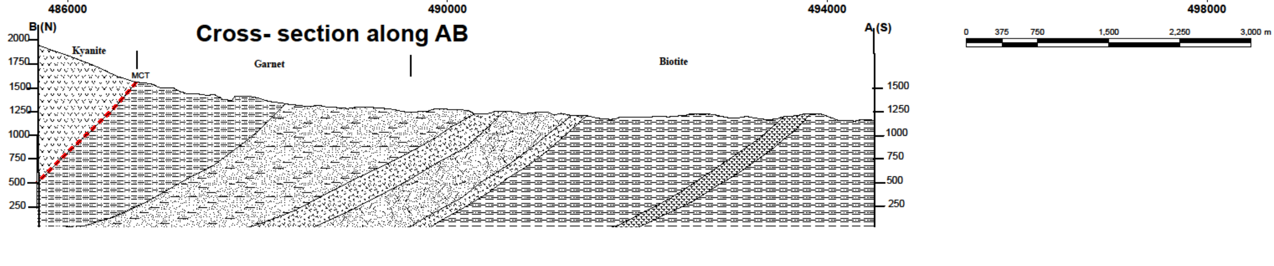
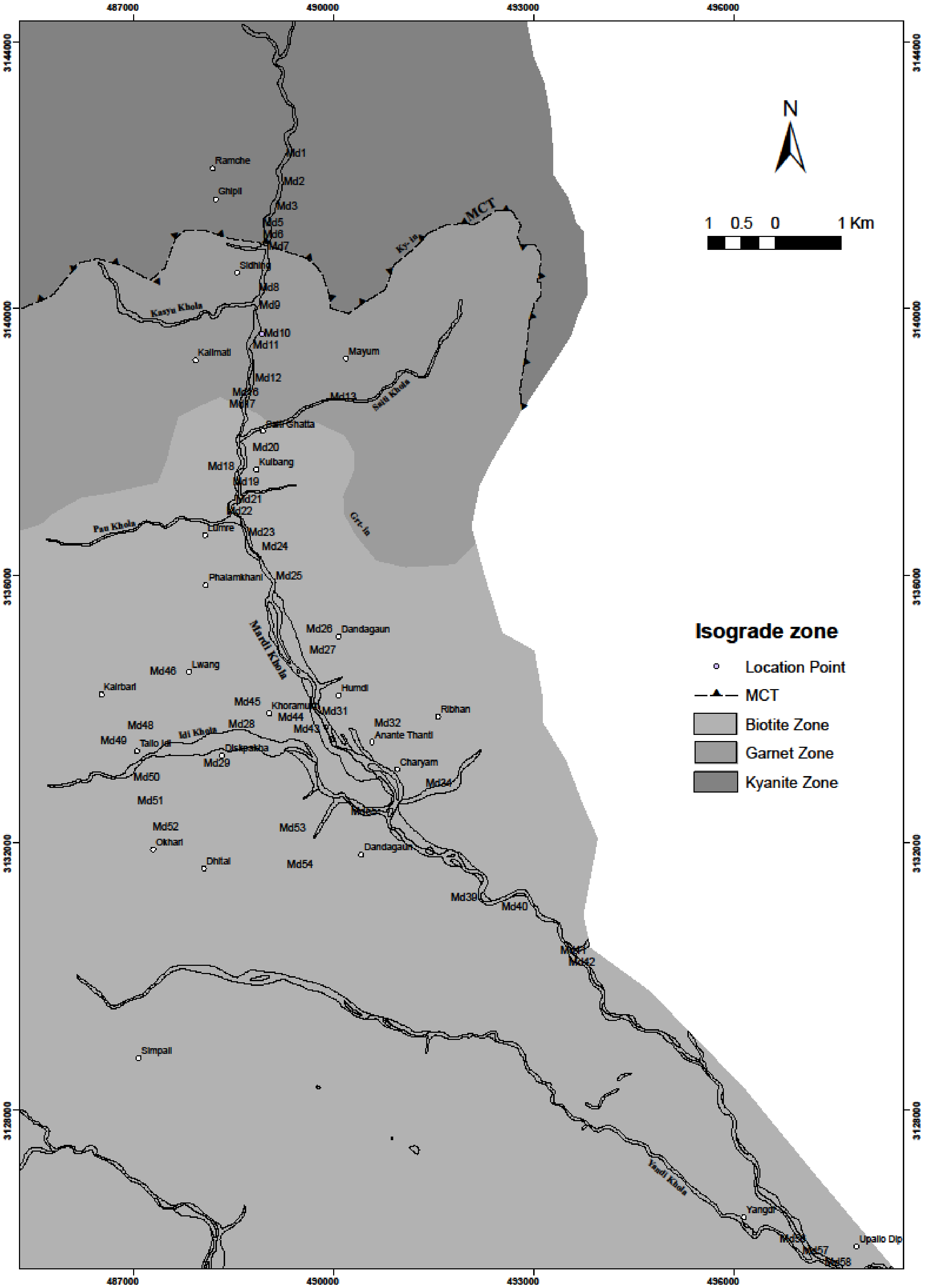
LIST OF ANNEXES

Geological map of Mardi Khola Section from Upallo Dip to Ramche





Isograde map of study area



STUDY OF THE ROCK IN THIN SECTION

1. Sample No.: Md11
2. Location No.: Md11
3. Formation: Black Schist and Quartzite
4. Minerology:

Mineral	Percentage			Average Percentage
	Field 1	Field 2	Field 3	
Quartz	87	86	84	87
Orthoclase	5	6	7	5
Muscovite	2	1	3	2
Biotite	6	5	7	6

- Mineral Assemblage: Bt + Ms + Qtz + Or
- Index Mineral: Biotite

5. Texture:
- Grain Size: ≈ 100 nm
- Shape: Subhedral to Euhedral
- Shear Feature:

6. Deformation:
- Foliation: 1 set
- Folds: Not observed
- No. of deformation events:

7. Interpretation:
- Grade: Medium
- Facies:

8. Inclusion:

STUDY OF THE ROCK IN THIN SECTION

1. Sample No.: Md 18
2. Location No.:Md18
3. Formation: Marble and Schist
4. Minerology:

Mineral	Percentage			Average Percentage
	Field 1	Field 2	Field 3	
Quartz	22	21	23	22
Orthoclase	19	18	21	19
Muscovite	20	25	15	20
Biotite	33	31	32	33

- Mineral Assemblage: Bt + Ms + Qtz + Or
- Index Mineral: Biotite

5. Texture:
- Grain Size: < 100 nm
- Shape: Subhedral to Euhedral
- Shear Feature:

6. Deformation:
- Foliation: 1 set
- Folds:
- No. of deformation events:

7. Interpretation:
- Grade: Medium
- Facies:

8. Inclusion:

STUDY OF THE ROCK IN THIN SECTION

1. Sample No.: Md17
2. Location No.: Md 17
3. Formation: Marble and Schist
4. Minerology:

Mineral	Percentage			Average Percentage
	Field 1	Field 2	Field 3	
Dolomite	70	65	68	68
Quartz	2	1	3	2
Orthoclase	15	10	17	15
Biotite	1	-	1	1

- Mineral Assemblage: Bt + Dol + Orthoclase + Qtz

- Index Mineral: Biotite

5. Texture:
- Grain Size: > 100 nm
- Shape: Subhedral
- Shear Feature:

6. Deformation:
- Foliation: 1 set
- Folds:
- No. of deformation events:

7. Interpretation:
- Grade: Medium
- Facies: Greenschist

8. Inclusion:

STUDY OF THE ROCK IN THIN SECTION

1. Sample No.: Md 21
2. Location No.: Md 21
3. Formation: Fagfog Quartzite
4. Minerology:

Mineral	Percentage			Average Percentage
	Field 1	Field 2	Field 3	
Quartz	82	78	85	82
Plagioclase	9	7	12	9
Biotite	8	7	6	7
Muscovite	1	2	-	1

- Mineral Assemblage: Bt + Ms + Qtz + Pl
- Index Mineral: Biotite

5. Texture:
- Grain Size: ≈ 100 nm
- Shape: Subhedral to Euhedral
- Shear Feature:

6. Deformation:
- Foliation: 1 set
- Folds:
- No. of deformation events:

7. Interpretation:
- Grade: Medium
- Facies: Greenschist

8. Inclusion:

STUDY OF THE ROCK IN THIN SECTION

1. Sample No.: Md 47
2. Location No.: Md 47
3. Formation: Kuncha Formation
4. Minerology:

Mineral	Percentage			Average Percentage
	Field 1	Field 2	Field 3	
Quartz	23	25	30	26
Orthoclase	45	35	41	40
Biotite	30	25	15	23
Muscovite	3	1	2	2

- Mineral Assemblage: Bt + Ms + Or + Qtz

- Index Mineral: Bt

5. Texture:

- Grain Size: > 100 nm to < 100 nm
- Shape: Anhedral to Subhedral
- Shear Feature:

6. Deformation:

- Foliation: 1 set
- Folds:
- No. of deformation events:

7. Interpretation:

- Grade: Medium
- Facies: Greenschist

8. Inclusion:

STUDY OF THE ROCK IN THIN SECTION

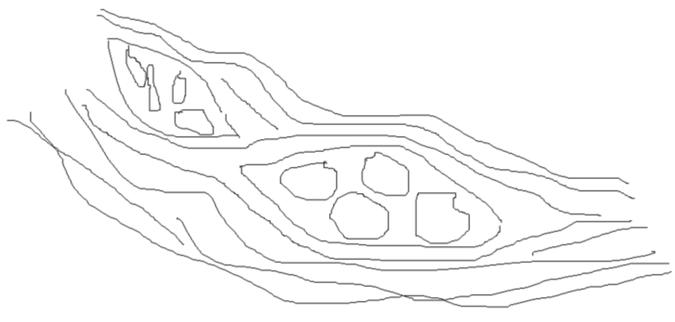
1. Sample No.: Md 30
2. Location No.: Md 30
3. Formation: Kunchha Formation
4. Minerology:

Mineral	Percentage			Average Percentage
	Field 1	Field 2	Field 3	
Quartz	20	25	16	20
Orthoclase	61	60	62	60
Plagioclase	6	5	4	5
Biotite	5	3	6	5
Muscovite	3	10	15	10

- Mineral Assemblage: Bt +Ms + Or + Qtz + Pl
- Index Mineral: Bt

5. Texture:
- Grain Size: > 100 nm to < 100 nm
- Shape: Subhedral to Euhedral
- Shear Feature:

6. Deformation:
- Foliation: 1 set
- Folds:
- No. of deformation events:



7. Interpretation:
- Grade: Medium
- Facies: Greenschist

8. Inclusion:

STUDY OF THE ROCK IN THIN SECTION

1. Sample No.: Md 23
2. Location No.: Md 23
3. Formation: Kuncha Formation
4. Minerology:

Mineral	Percentage			Average Percentage
	Field 1	Field 2	Field 3	
Hornblende	80	78	84	80
Quartz	6	4	7	
Feldspar	8	6	11	
Biotite	3	-	-	
Muscovite	3	2	5	6

- Mineral Assemblage: Bt + Ms + Hb + Fs + Qtz
- Index Mineral: Biotite

5. Texture:
- Grain Size: ≈ 100 nm
- Shape: Subhedral
- Shear Feature:

6. Deformation:
- Foliation: 1 set, due to Hornblende
- Folds:
- No. of deformation events:

7. Interpretation:
- Grade: Medium
- Facies: Amphibolite

8. Inclusion:

STUDY OF THE ROCK IN THIN SECTION

1. Sample No.: Md 43
2. Location No.: Md 43
3. Formation: Kuncha Formation
4. Minerology:

Mineral	Percentage			Average Percentage
	Field 1	Field 2	Field 3	
Quartz	70			
Feldspar	10			
Biotite	7			
Muscovite	8			

- Mineral Assemblage: Bt + Ms + Qtz + Fs
- Index Mineral: Biotite

5. Texture:
- Grain Size: > 100 nm
- Shape: Subhedral to Euhedral
- Shear Feature: Fold and foliation developed by mica band

6. Deformation:
- Foliation: 1 set
- Folds: 1 set
- No. of deformation events:

7. Interpretation:
- Grade: Medium
- Facies: Greenschist

8. Inclusion:

STUDY OF THE ROCK IN THIN SECTION

1. Sample No.: Md 56
2. Location No.: Md 56
3. Formation: Kuncha Formation
4. Minerology:

Mineral	Percentage			Average Percentage
	Field 1	Field 2	Field 3	
Quartz	40	40	40	40
Orthoclase	45	40	45	40
Biotite	5	5	6	5
Muscovite	7	11	-	10
Chlorite	3	4	3	5
Plagioclase	-	-	1	

- Mineral Assemblage: Bt + Chl + Ms + Qtz + Or + Pl

- Index Mineral: Biotite

5. Texture:

- Grain Size: ≈ 100 nm
- Shape: Subhedral to Anhedral
- Shear Feature: elongated mineral of biotite

6. Deformation:

- Foliation: 1 set, weakly developed
- Folds:
- No. of deformation events:

7. Interpretation:

- Grade: Low
- Facies: Greenschist

8. Inclusion:

STUDY OF THE ROCK IN THIN SECTION

1. Sample No.: Md 1
2. Location No.: Md 1
3. Formation: Kyanite banded Gneiss
4. Minerology:

Mineral	Percentage			Average Percentage
	Field 1	Field 2	Field 3	
Quartz	8	10	15	10
Feldspar	68	75	70	70
Muscovite	15	17	13	15
Biotite	3	5	6	5

- Mineral Assemblage: Bt + Ms + Fs + Qtz
- Index Mineral: Biotite

5. Texture:
- Grain Size: > 100 nm
- Shape: Subhedral
- Shear Feature: elongated mineral of biotite

6. Deformation:
- Foliation: 1 set
- Folds:
- No. of deformation events:

7. Interpretation:
- Grade: Medium
- Facies: Greenschist

8. Inclusion: