GEOLOGY AND STRUCTURE OF THE KOTA-BAIDI AREA, TANAHU DISTRICT, CENTRAL NEPAL, LESSER HIMALAYA

A DISSERTATION

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DEO KUMAR LIMBU

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It is certified that MR. DEO KUMAR LIMBU has worked satisfactorily for his Master's Degree dissertation under my guidance and supervision. He has worked enthusiastically with sincere interest. The dissertation entitled “GEOLOGY AND STRUCTURE OF THE KOTA-BAIDI AREA, TANAHUN DISTRICT, CENTRAL NEPAL, LESSER HIMALAYA” embodies the candidate’s own work. I, hereby, recommend the dissertation for approval.

....

Supervisor

Kabi Raj Paudyal

Assistant Lecturer

Date: ………………

The dissertation presented by MR. DEO KUMAR LIMBU entitled "GEOLOGY AND STRUCTURE OF KOTA-BAIDI AREA, TANAHUN DISTRICT, CENTRAL NEPAL, LESSER HIMALAYA" has been accepted as the partial fulfillment of requirement for the Master's Degree of Science in Geology.

...………………………….

Prof. Dr. Megh Raj Dhital

Head of the Department

………………………

External Examiner

...…………………………

Supervisor

Kabi Raj Paudyal

Assistant Lecturer

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ABSTRACT

The study area is a part of the Lesser Himalaya, central Nepal along the Kota-Baidi area of the Tanahu District. The aim of the study was to prepare a detailed geological map of the area in the scale of 1:25,000. The study area consists of both the rocks of Upper and Lower Groups of the Nawakot Complex, their age ranging from Late Precambrian to Early Paleozoic. The rocks of the Lower Nawakot Group consist of the Nourpul Formation and the Dhading Dolomite whereas the Upper Nawakot Group consists of the Benighat Slate and the Robang Formation. The Malekhu Limestone is missing in the area and the Benighat Slate is not found in normal stratigraphic position which is thrust over the younger sequence, the Robang Formation. The Nourpul Formation consists of mixed type of metasedimentary rocks like shale, mudstone, phyllite, metasandstone, dolomite and quartzite. Occasionally these rocks consist of sedimentary structures like mudcracks and ripple marks pointing right-way-up of the beds. Stratigraphically, the Nourpul Formation is followed upwards by the Dhading Dolomite. It consists of ridge forming stromatolitic dolomite with subordinates of phyllites and quartzites. The well developed columnar stromatolites of this formation show the beds to be in the normal position. The Benighat Slates is characterized by the monotonous sequence of grey to dark grey slate and phyllite with or without calcareous deposits. Based on the calcareous nature, a separate member has been mapped within the Benighat Slate as the Jhiku Carbonates. The youngest sequence of the area is mapped as the Robang Formation, consisting of intercalation of phyllite, metasandstone and quartzite with several bands of metabasites.

The whole study area lies in the core of megasyncline which is named as Kota-Baidi Syncline. It is a tightly strike-out syncline whose trend and plunge is about 277°/17°. Another significant local fold is mapped as Makre Anticline whose trend and plunge is found to be 284°/8°. Two major thrust structures of the area are the Main Boundary Thrust (MBT) in the south and the Chherenga Khola Thrust, nearly parallel to the MBT, in the north. The MBT can be easily demarcated in the field based on lithology and topography whereas the Chherenga Khola Thrust is recognized only on the basis of abrupt change in lithological formations. Numerous mesoscopic folds and faults in different orientations, sedimentary structures, quartz veins, boudinages and pockets of several minerals are also recorded in the field.

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CHAPTER ONE

INTRODUCTION

1.1. BACKGROUND

The study area is a part of authothonous sequence of central Nepal, Lesser Himalaya. It consists of low grade metamorphic rocks like phyllite, quartzite, dolomite, slate and metasandstone. The present study is aimed to prepare the detailed geological map of the area to overcome the existing problems of stratigraphy and structures. For that, efforts were made to spend more time in the field mapping taking traverses through several closely spaced routes. Based on lithological similarity and contact relationship, only four lithological units have been identified and mapped. According to the most adopted classification of Stocklin and Bhattarai (1977) and Stocklin (1980) in central Nepal, the rocks of the study area have been divided into Lower and Upper Nawakot Groups. However, there is neither unconformity was observed between these two groups as mentioned by them nor the exact similarities in lithology. The Main Boundary Thrust (MBT) is the major structure of the area which is demarcated in the field on the basis of lithology and topographic variation. Other prominent thrust named as Chherenga Khola Thrust (CKT) is recognized on the basis of lithology only. Several bands of amphibolites are also encountered in the field mapping. Deep weathering, poor exposure of rocks in ridges, thick vegetation cover and strong topographic relief are some of the problems during mapping. The present thesis is the outcome of one and half month field work.

1.2 LOCATION

The latitude of 27º 45' 00" N to 27º 52'30" N and longitude of 84 º15'00" E to 84º30’00’’ E bound the study area (Fig. 1.1). It lies in the vicinity of Khalte, Keshabtar and Kota-Baidi and covers mainly the northern part of Nawalparasi and south-east part of Damauli. The topographical maps entitled Jugadi Bajar (Sheet: 2784 02D) and kota (Sheet: 2784 02C) published by Department of Survey, Government of Nepal includes the study area. Geologically, the area lies in Lesser Himalayan Zone between Main boundary Thrust (MBT) in the South and the Mastipur area in the North.

1.3. ACCESSIBILITY

The study area lies at about 190 km west from Kathmandu. It is accessible by the Narayanghat-Muglin Highway. Many other roads like Gumaune-Damauli track, Nawalparasi-Dode track, these tracks are under construction, small vehicles are the means of transportation that is also only during dry seasons. Almost all the study area is then only webbed foot-trail links that make accessible to the study area. Some steep slopes are out of reach.

1.4. TOPOGRAPHY AND DRAINAGE

The Gandaki river, the Trisuli river and the Seti river are the major rivers in the study area having the low gradient with wide valleys and generally flows north-south. Kadi Khola, Naldi Khola, Jaubari Khola, Khahare Khola, Bat Khola are the tributaries that flows north-east and finally feeds the major Seti River and Bagar Khola, Bhut Khola, and Labdi Khola are the north–west flowing tributaries that feeds the Seti Khola.

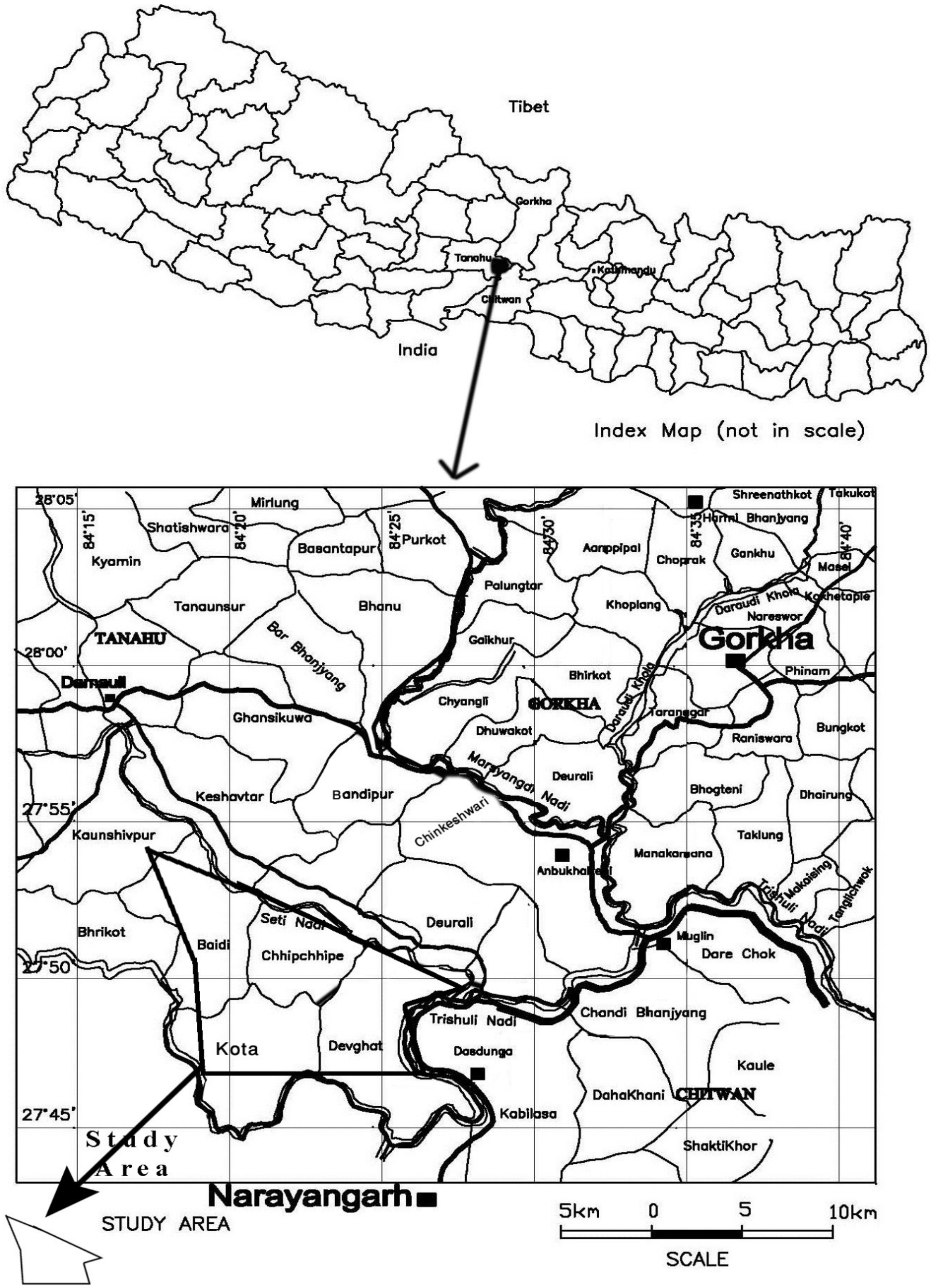


Fig. 1.1: Map showing the location of the study area

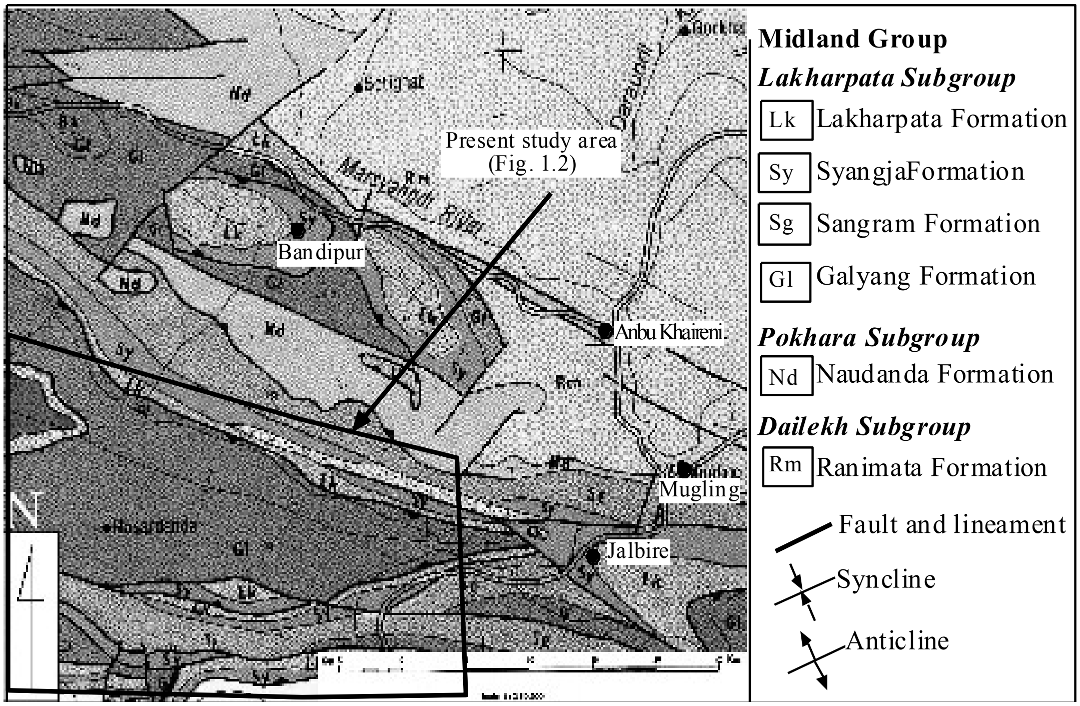


Fig. 1.2: Location map of the study area in the existing geological map of the Central Nepal (After Jnawali and Tuladhar, 1996)

The tributaries that feed the KaliGandaki river in the study area are Tata Khola, Chindi Khola, Chheranga Rugged and steep topography in the study area is manifested by a large fluctuation in altitude difference. The altitude ranges from 209 m at Dode (Left bank of the Kali Gandaki River) to 1603 m at Kalithan Danda. The area is intricately dissected and drained by the networks of steep gradient streams. The Kali khola,Gorban khola and many small unnamed streams.The streams and tributaries that feeds Trisuli River in the study area are Bagandi Khola, Dumre khola and many other small unnamed streams. The Trisuli River and the Seti River meets at Ghumaune and flows as one river i.e. Trisuli river. Finally,the Trisuli River and the Kali Gandaki River meets at Devghat. And, these rivers are the principal feeders of the Narayani River. At least 5^{th} order drainage is common in the area. The drainage pattern in the area is dendritic.

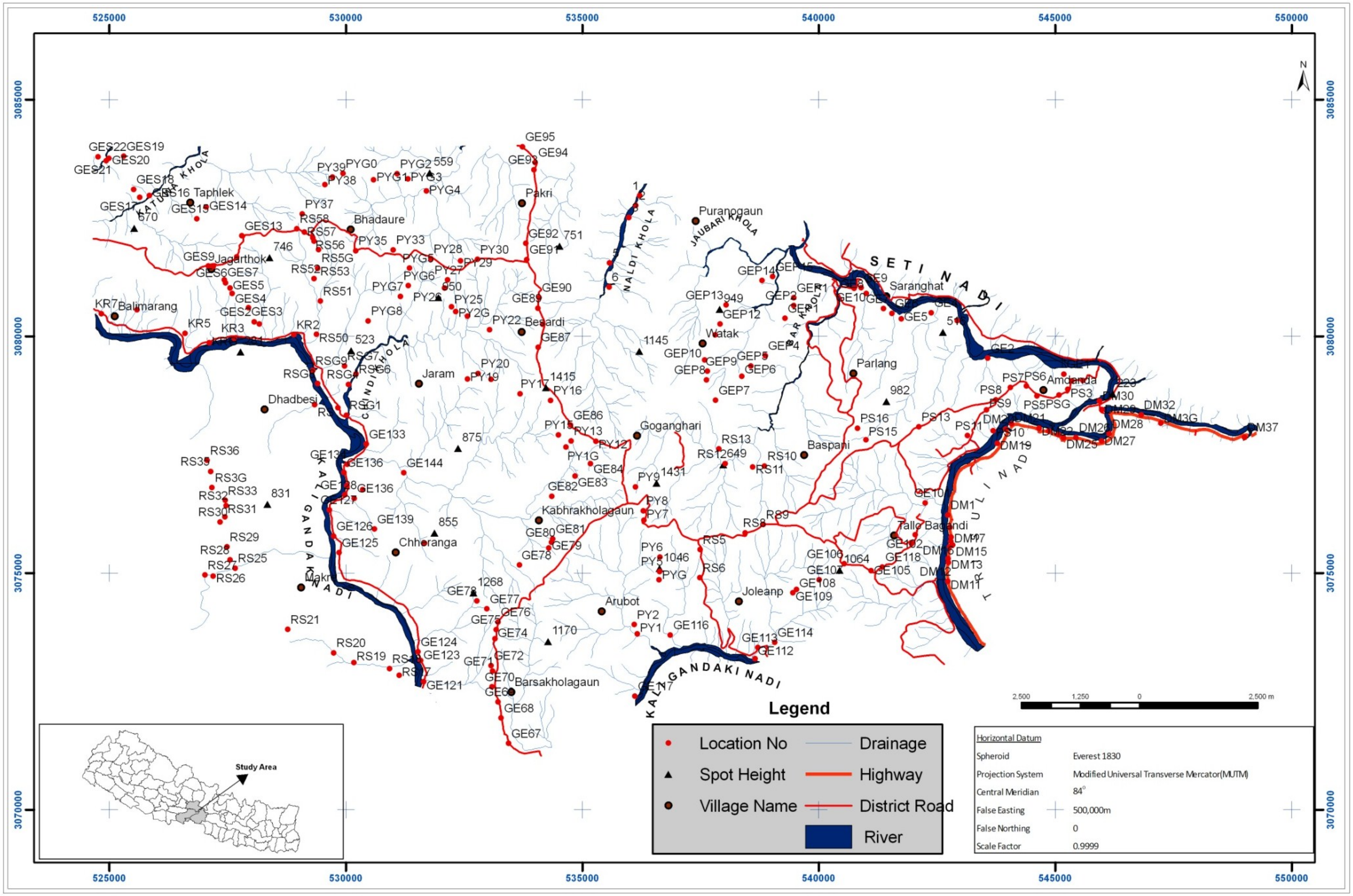


Fig. 1.3: Drainage map of the study area with the locations of outcrop study

1.5. REGIONAL GEOLOGICAL SETTING

The Nepal Himalaya occupies the central part (800 km) of the 2400 km long southwardly convex Himalayan arc. The major five morphogenetic zone of the Nepal Himalaya from south to north (Gansser, 1964, Hagen, 1969) are given below (Fig. 1.4).

North

Tibetan-Tethys Himalaya

-----South Tibetan Detachment Fault System (STDFS) ----

Higher Himalaya

--------------------Main Central Thrust (MCT) --------------------

Lesser Himalaya

-------------------Main Central Thrust (MBT) ---------------------

Sub-Himalaya (siwaliks)

--------------------Himalayan Frontal Thrust (HFT) ---------------

Indo-Gangatic Plain (Terai)

South

Fig. 1.4: Simplified geological division of the Nepal Himalaya

1.5.1. INDO-GANGETIC PLAIN (TERAI)

This is the southernmost zone of Nepal Himalaya. It represents the northern edge of Indo-Gangatic Plain. It is a foreland basin and owes its origin to the rise of Himalaya. The zone is comprised of the Pleistocene to Recent deposits consisting of gravels, sands and clays with average thickness of 1500 m (Upreti, 1999). The sediment deposition is still continuous.

1.5.2. Sub Himalaya (Siwaliks)

This zone is bounded to the south by Main Frontal Thrust (MFT) and to the north by Main Boundary Thrust (MBT). It consists basically of the rocks of fluvial origin belonging to the Neogene age. Mudstone, sandstone and conglomerate are the main lithology. About 5–15 km thick Sub Himalayan sediments exhibit overall coarsening upward succession.

1.5.3. Lesser Himalaya

The Lesser Himalaya is bordered in the south by the Main Boundary Thrust (MBT) and in the north by the Main Central Thrust (MCT). The Lesser Himalaya is mostly made up of unfossiliferous sedimentary and metasedimentry rocks like slate, phyllite, schist, quartzite, limestone and dolomite. The age range is from the Precambrian to the Eocene. Presence of faults, folds, nappes and klippes made the Geology of the Lesser Himalaya more complex.

1.5.4. Higher Himalaya

This tectonic zone lies between the Lesser Himalaya in the south and Tibetan Tethys Himalaya in the north. Kyanite and sillimanite bearing garnet- two mica-gneiss with the high amount of associated metasediments, augen gneiss, migmatite and granite-gneiss are more important lithotype in the Higher Himalaya . The MCT is accepted as the lower boundary and a normal fault system named as South Tibetan Detachment Fault System (STDFS) has been recognized as the upper boundary (Coleman, 1996).

This zone consists of about 10 km thick succession of the crystalline rocks also known as Tibetan Slab (Fort, 1975). Gneiss with subordinate phyllite, schist, quartzite and marble constitute this 5–15 km thick Higher Himalayan Zone.

1.5.5. Tibetan Tethys Himalaya

The northernmost tectonic zone of Nepal Himalaya starts to the STDS and ends up against the Indus-Tsangpo Suture Zone. It includes a thick (>10 m) and continuous sequence of fossiliferous Paleozoic to the Lower Tertiary rocks indicating a platform type epicontinental environment (Fig.1.5).

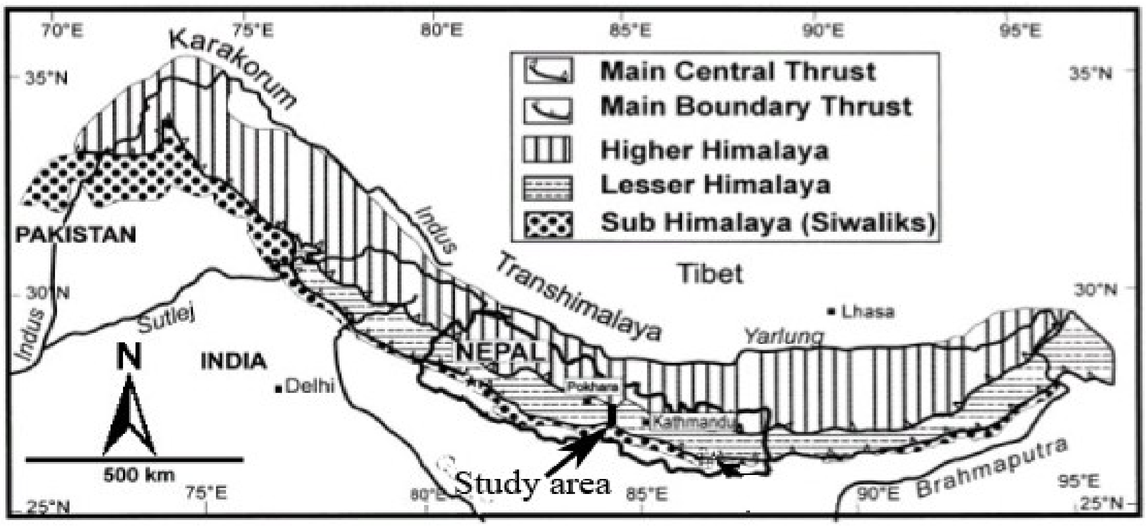


Fig. 1.5: Simplified geological map of the Himalaya showing major litho-tectonic divisions (After Gansser, 1964)

1.6. REGIONAL GEOLOGY OF CENTRAL NEPAL, LESSER HIMALAYA

The Lesser Himalaya is bordered in the south by the Main Boundary Thrust (MBT) and in the north by the Main Central Thrust (MCT). The MBT is a low-angle reverse fault that has brought the older Lesser Himalayan rocks over the much younger Siwaliks. The MCT, on the other hand, lifts the middle level crustal rocks of the Higher Himalaya over those of the Lesser Himalaya. The Lesser Himalaya is a fold-and-thrust belt with complex stratigraphy and structures. There are several thrust sheets stacked one over the other and folded and faulted on a large scale

(Valdiya, 1980). Tectonically the Lesser Himalaya is made up of the autochthonous-paraautochthonous units, with various nappes, klippe and tectonic windows.

Central Nepal Himalaya is also a complex tectonic zone with several faults and folds. The area includes Mahabharat Synclinorium (Stocklin, 1980) in the east, Gorkha-Kunchha Anticlinorium in the north (Arita et al., 1973), Kanhu Syncline (Jnawali and Tuladhar, 1996) in the north west, Tansen Synclinorium (Sakai, 1985) in the southeast and Jajarkot Syncline (Ando and Ohta, 1973) in the west. The Bari Gad-Kali Gandaki Fault (Nakata, 1989) and Phalebas Thrust (Upreti et al., 1980) are the regional faults extending east-west in the area. (Paudel and Arita, 2000) also prepared a simplified geological map of the central Nepal, Lesser Himalaya (Fig. 1.6).

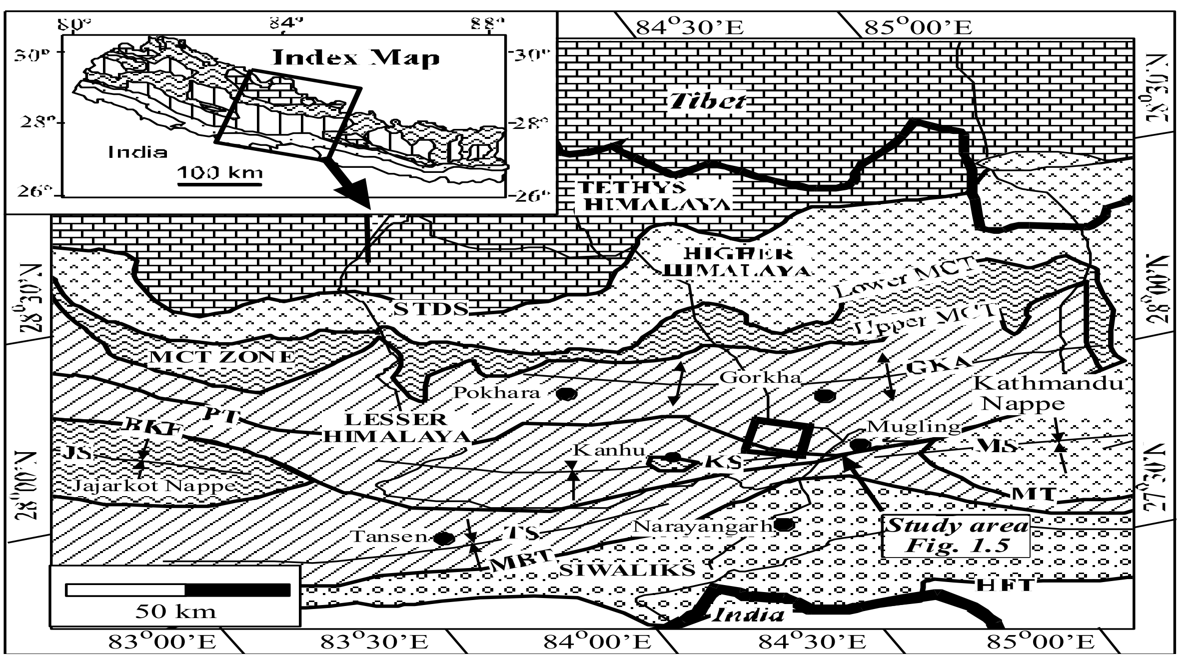


Fig. 1.6: Simplified geological map showing study area Paudel and Arita, 2000

1.7. Geological Problems

There are number of problems and controversies on stratigraphy, tectonics and metamorphism of central Nepal, Lesser Himalaya. Some of the major problems are described below.

1.7.1. Lack of Detailed Geological Maps

Many parts of the Lesser Himalaya still lack detailed geological maps. Stöcklin and Bhattarai (1977) have prepared a detailed geological map of the Kathmandu area for about 250km along the strike. Westward, it covers up to Muglin. A considerable part of Gorkha-Ampipal area has been mapped by Dhital (1995), south-west part of study area (Tansen area) is mapped by Sakai (1985) and western part by Paudel and Arita (1998). However a considerable area between Muglin and Syangja still lacks a detailed geological mapping.

1.7.2. Stratigraphic Problems

A number of stratigraphic classification and nomenclatures exist over the same section i.e. different workers have given different stratigraphic classifications. It is very difficult to correlate the stratigraphic unit by one author to that of the other. This has created great problem not only for accurate correlation of the sequences in contiguous region but also for structural interpretation and tectonic evolution of the Lesser Himalaya as a whole.

1.8. Objectives

The principal objectives of the study were to understand the general geology and structure of the Kota-Baidi area. The following objectives were set out for the purpose.

- To prepare a geological map and its cross section at 1:25000 scale.
- To study lithology, stratigraphy, and geological structures of the area.

1.9. Methodology

The methodological scheme that was adopted to achieve the above objectives has been summarized in the following headings.

1.9.1. Literature Review

Topographic maps, published and unpublished reports and literatures, journals, field manuals and established theories related to the present study were collected from the different sources and studied in detail and made the basis for the field investigation. Topographical maps at 1:25,000 scale published by the Survey Department, Government of Nepal were collected. The toposheets of Jugadi Bajar (Sheet: 278402D.) and Kota (Sheet: 2784 02C) areas were used for the study. Published and unpublished papers, reports and dissertation available at the Central Department of Geology provide a concept on geological conditions of the study area. Based on available information, an investigation program was scheduled for the field works.

1.9.2. Field Work

The field work mainly consists of the field mapping which was carried out by the planned route mapping on 1:25000 scale topographic maps. Wherever possible the mapping was carried out based on the standard lithological units established by Stöcklin and Bhattarai (1977), Stöcklin (1980) in the Central Nepal, Lesser Himalaya. Geological traverses were made mainly on the roads, rivers and foot trails. Mesostructures were sketched. Samples were collected as far as possible for laboratory analysis. Photographs of significant outcrops were taken to interpret the geological data. Brunton compass, geological hammer, chisel, dilute HCl (1:10) were the instruments and tools used during the field works. The field mapping was jointly carried out by me and my juniors.

1.9.3. Table works

All the raw data and rough map prepared in the field was further analyzed and processed after coming back from the field. Geographical Information System (Arc GIS) software was used to prepare the final map and freehand was used to prepare columnar sections, route maps and cross-sections. Relevant photographs taken by digital camera are selected and printed while preparing the dissertation.

1.9.4. Interpretation and Dissertation Writing

Data obtained from the field and the were analyzed systematically using accepted statistical tools and techniques. All the available data on stratigraphy and structures were gathered together to interpret the geology and structure of the area. The final report was prepared in accordance with the guidelines provided by CDG, TU by incorporating all the analysis, results and data collected in the field.

CHAPTER TWO

PREVIOUS STUDIES

Medlicott (1875) was probably the earliest geologist to work on the geology of Central Nepal around Kathmandu. He described the sedimentary and low grade metamorphic rocks to the south and the high grade metamorphic rocks from the north of Katmandu.

Auden (1935) is one of the earliest persons who had given the fair detail geology of Central Nepal Lesser Himalaya. He presented several cross-sections across the Himalaya supporting the nappe theory earlier proposed by Argand (1924). He also recognized the synclinal nature of the Mahabharat Range.

Gansser (1964) gave a boarder framework and geological summary of the Himalaya including the Nepal Himalaya. Hagen (1969) brought forward the nappe concept in the Nepal Himalaya. He reported the Nawakot Nappe made up of low grade metamorphic rocks underlained by a medium to high grade metamorphic rocks of the Katmandu Nappe.

A team of geological researchers from the Hokkaido University, Japan conducted several geological expeditions in Nepal Himalaya from 1955-1975 and published results in 1973 (Hashimoto et al., 1973). It gives the first detailed account of geology, stratigraphy, tectonics and metamorphism of whole Nepal Himalaya.

After 1970, a group of French researchers including Bordet, Le Fort, Colchen, Pêcher, had published a detailed geological map and a number of paper related to the tectonics, metamorphism along several sections of Central Nepal, Lesser Himalaya. (Bordet et al., 1971, Le Fort, 1975, Colchen et al., 1980, 1986; Pêcher, 1977, 1989).

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 two Complexes-the crystalline high grade meta-sedimentary the Kathmandu Nappe (Complex) and beneath it the non-crystalline, low grade the meta-sedimentary Nawakot Complex. The frontal part of the Kathmandu Complex is separated from the Nawakot Complex by the thrust known as the Mahabharat Thrust (MT) (Stöcklin, 1980) and is shown to be a direct continuation of the Main Central Thrust (MCT) (Stöcklin, 1980; Fuchs, 1980; Pêcher and Le Fort, 1986; Pandey et al., 1995). The rocks of southern part of the Kathmandu Nappe are grouped into the Kathmandu Complex; which is subdivided into the Bhimphedi Group (the Late Precambrian rocks) and unconformably overlying essentially fossiliferous sedimentary sequence of the Phulchauki Group (the Lower Paleozoic rocks). The Low-grade metasedimentry rocks outcropping in the north, west and southwest of the Kathmandu Complex has been grouped into the Nawakot complex (Stöcklin and Bhattarai, 1977, Stöcklin, 1980).

Many foreign and Nepalese geologists have carried out individual researches in Central Nepal. Arita (1983) studied the inverted metamorphism in the Modi Khola cross-section and explained the phenomena of the shear-heating along the MCT zone.

Geological map of Gorkha-Ampipal area, Central Nepal, Lesser Himalaya was prepared by Dhital (1995) in 1:50,000 scale. The map covers Anbu-Khaireni (south), Barpak and Bhachek (north) the Chepe Khola (west) and Khanchok (east). In his mapped area the Nepheline Syenite bodies are intruded in the Kuncha Formation.

2.1. Stratigraphy Based on Stöcklin and Bhattarai, 1977 and Stöcklin, 1980

The Nawakot Complex consists almost exclusively of low grade metasediments. It has subdivided into the Lower and the Upper Nawakot Group, the two being separated by an erosional unconformity (Stöcklin and Bhattarai, 1977; Stöcklin 1980, Table 2.1).

The Kuncha Formation is the oldest unit of the Lower Nawakot Group and of the Lesser Himalaya. It forms monotonous, flysch-like alteration of phyllite, phyllitic quartzite and phyllitic gritstone resembling grey wacke. The phyllite is argillaceous, more or less silty or quartzitic and include extremely fine-grained to dense, laminated siliceous varieties. The quartzite is mostly impure, of olive green colour and often shows an oily luster on fresh fracture planes. Clean orthoquartzite is exceptions. Gritty phyllite consists of mostly quartz, very subordinately feldspar, tourmaline and other minerals, which are loosely disseminated in a phyllitic matrix. Less frequent but equally characteristics are fine quartz conglomerate, the pebbles of which rarely exceed 1 cm in diameter. Graded bedding can often be seen, and few layers of dia-basic volcanic materials are locally inter-bedded. The characteristic feature of the Kuncha Formation is a pronounced NNE mineral lineation, which is missing in higher units; it suggests a phase of deformation prior to the deposition of the Fagfog Quartzite (?). Sericite and chlorite are the common metamorphic minerals recognizable in the Kuncha Formation (biotite and small garnets are also reported in some places). The upper contact of the Kuncha Formation with the Fagfog Quartzite is sharp and conformable. The exposed thickness of the Kuncha Formation is more than 3000 m the base being nowhere exposed.

The great thickness of the Kuncha Formation would make a further, subdivided desirable, but monotony of the succession renders this a difficult and time consuming task. Only in the Baspani area, the Baspani Quartzite member has been mapped (Stöcklin, 1977). It is a medium-grained impure quartzite with displaying some cross-beddings. It has slight carbonate content in the matrix, giving a weak but district reaction with dilute HCl. The quartzite is about 200 m thick and forms the steep cliffs. The next member of this formation is the Labdi Phyllite, which represents the top of the Kuncha Formation i.e. it occupies the interval between the Baspani Quartzite (base) and the Fagfog Quartzite (top). The main lithology of this member includes fine-grained argillaceous phyllite. Quartz veining is frequent in phyllite. The thickness is about 200 m. The contact with two quartzite units is conformable and found to be gradational.

The Fagfog Quartzite is a medium to coarse-grained white orthoquartzite with several phyllitic intercalations. It forms a good marker. The quartzite shows yellow, orange and pink colors when weathered. They frequently contain graded bedding, current ripples and trough cross laminae. The contact of the Fagfog Quartzite with the Dandagaon Phyllites is transitional everywhere. It's thickness in type locality is 200 m.

The Dandagaon Phyllites consists of uniform argillaceous to finely quartzitic phyllite of dark, blue-green colour. In weathered condition the rock often displays reddish tints.

Green, fine-grained sericitic and or chloritic quartzite occurs in places as centimeter or millimeter thin intercalations. Occasionally, thin bands of dense dolomite and calc-phyllite have been reported within this formation. The contact with the overlying the Purebesi Quartzites (basal member of the Nourpul Formation) found to be sharp but conformable.

The Nourpul Formation is a mixed lithology of phyllitic, quartzitic and calcareous rock types. The Purebesi Quartzite member contains a clean arkosic quartzite of fine- to coarse-grained. Crossing beddings can often be seen and ripple marks are much more frequent in the beds of quartzite. The middle part of the Nourpul Formation contains predominately phyllite with variable amount of quartzitic and calcareous intercalations. Mostly the sequence consists of similar alternation of phyllite and dolomite, phyllite and quartzite and somewhere pure phyllite only. In the upper part of formation the dolomite and calcareous quartzite becomes more abundant. A characteristic green/buff or green/orange colour banding can be observed due to regular alternation of phyllite (green) and dolomite. By decrease in the phyllite portion these rocks pass gradationally into the Dhading Dolomite. The average thickness of the Nourpul Formation is estimated at about 800 m.

The Dhading Dolomite is a well-bedded to massive bluish-grey to fine crystalline carbonate rock occurring abundant stromatolites at many levels. These algal fossils indicate early Paleozoic age, probably the Early Cambrian. The lower part of the formation is dominated by blue-grey, very fine-grained cherty dolomites inter-bedded with the silver-grey, green and purple slate. The Dhading Dolomite is sharply overlain by the dark grey Benighat Slates of the Upeer Nawakot Group.

The Benighat Slates are dominately a dark-grey, blue-grey to charcoal black, thinly laminated slate with frequent intercalations of siliceous phyllite. The grey limestone and calc-slate and quartzitic phyllite are also found. Mostly, slaty cleavage has developed oblique to the bedding. Pure quartzites are absent or extremely rare. In places, the slate and phyllite show a distinct carbonate contact and more prominent zones of such calcareous rocks have been distinguished as the Jhiku Calcareous Beds. The thicker beds of pure limestone or dolomite are rare. Mostly slates are rich in the graphitic matter. There are some reliable evidences of an erosional unconformity between the Benighat Slates and the overlying Malekhu Limestone.

The Malekhu Limestone consists of thin, platy, yellow, dense, siliceous limestone with pale-green sericitic partings. Acid reacts with the rock only in powder form. Stromatolites are missing but algal mats are frequent in them. Elephant skin weathering and cavernous beds are the characteristics features of this formation.

The Robang Formation and associated quartzite (Dunga Quartzite beds) is the highest unit of the Upper Nawakot Group. The main lithology is phyllite. The white Dunga Quartzite beds (a member of Robang Formation) is distinct. Associated with both the phyllite and quartzite, there occur chloritic and amphibolitic meta-diabases showing sedimentary relationships, as well as more massive, gabbroic or dioritic bodies showing instrusive contacts. This formation is overlain by highly garnet-schist that characterizes everywhere by a thrust named, the Mahabharat Thrust (MT).

2.2. Revised Stratigraphy of Paudyal and Paudel (2011)

Detailed geological mapping was carried out in the Lesser Himalaya of Mugling-Basnpani area, Central Nepal by Paudyal and Paudel (2011), (Fig. 2.1). The area comprises of low-grade metasedimentary rocks of the Lower Nawakot Group. The present study i.e. geological mapping was carried out to extend the units of Paudyal and Paudel (2011) westward, along strike from Seti river area. According to the revised stratigraphy of Paudyal and paudel (2011), Anpu Quartzite does not occupy the base of Nawakot Complex but this is equivalent to the Fagfog Quartzite, the Banspani Quartzite is equivalent to the Purebensi Quartzite, and the Labdi Phyllite is equivalent to the Dandagaon Phyllite. Based on the above observation, a revised stratigraphic classification for the Lower Nawakot Complex has been proposed for the area. According to them, the Kunchha Formation is the oldest unit comprising a monotonous sequence of phyllite, gritty phyllite, metasandstone, calcareous phyllite and metaconglomerate.

Table 2.1: Stratigraphic sub-division of Central Nepal, Lesser Himalaya (After Stöcklin and Bhattarai, 1977 and Stöcklin, 1980)

Complex	Group	Formation	Main lithology	Thickness	Age
Kathmandu Complex	Phulchoki Group	Godavari Limestone	Limestone	300–400 m	Devonian
Kathmandu Complex	Phulchoki Group	Chitlang Formation	Slate, quartzite	1000 m	Silurian
Kathmandu Complex	Phulchoki Group	Chandragiri Limestone	Limestone	2000 m	Cambrian
Kathmandu Complex	Phulchoki Group	Sopyang Formation	Slate, calc. Phyllite	200 m	Cambrian (?)
Kathmandu Complex	Phulchoki Group	Tistung Formation	Metasandstone, Phyllite	300 m	Early Cambrian Or Late Precambrian
Kathmandu Complex	Bhimphedi Group	Markhu Formation	Marble, schist	1000 m	Late Precambrian
Kathmandu Complex	Bhimphedi Group	Kulikhani Formation	Quartzite, Schist	2000 m	Precambrian
Kathmandu Complex	Bhimphedi Group	Chisapani Quartzite	White quartzite	400 m	Precambrian
Kathmandu Complex	Bhimphedi Group	Kalitar Formation	Quartzite, schist	2000 m	Precambrian
Kathmandu Complex	Bhimphedi Group	Bhainsedobhan Marble	Marble	800 m	Precambrian
Kathmandu Complex	Bhimphedi Group	Raduwa Formation	Garinitiferous schist	1000 m	Precambrian
--Mahabharat Thrust--					
Nawakot Complex	Upper Nawakot Group	Robang formation	Phyllite, quartzite	200–1000 m	Early Paleozoic
Nawakot Complex	Upper Nawakot Group	Malekhu Limestone	Limestone, dolomite	800 m	Early Paleozoic
Nawakot Complex	Upper Nawakot Group	Benighat Slates	Slate, argillaceous dolomite	500–3000 m	Early Paleozoic
Nawakot Complex	Lower Nawakot Group	Dhading Dolomite	Stromatolitic Dolomite	500–1000 m	Precambrian
Nawakot Complex	Lower Nawakot Group	Nourpul Formation	Phyllite, Metasandstone	800 m	Precambrian
Nawakot Complex	Lower Nawakot Group	Dandagaun Phyllites	Phyllite	1000 m	Precambrian
Nawakot Complex	Lower Nawakot Group	Fagfog Quartzite	White Quartzite	400 m	Precambrian
Nawakot Complex	Lower Nawakot Group	Kuncha Formation	Phyllite, Quartzite	3000 m	Precambrian

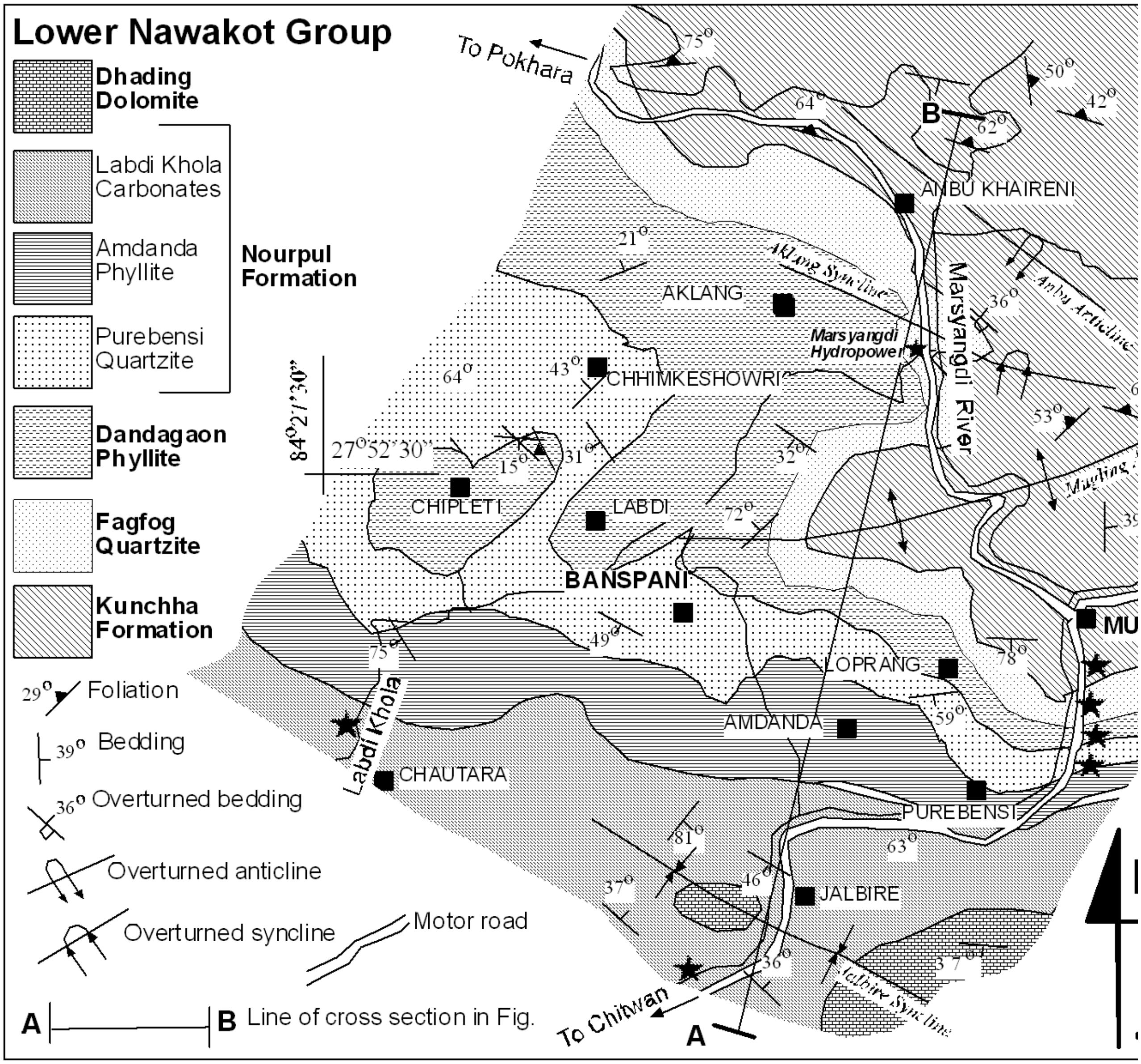


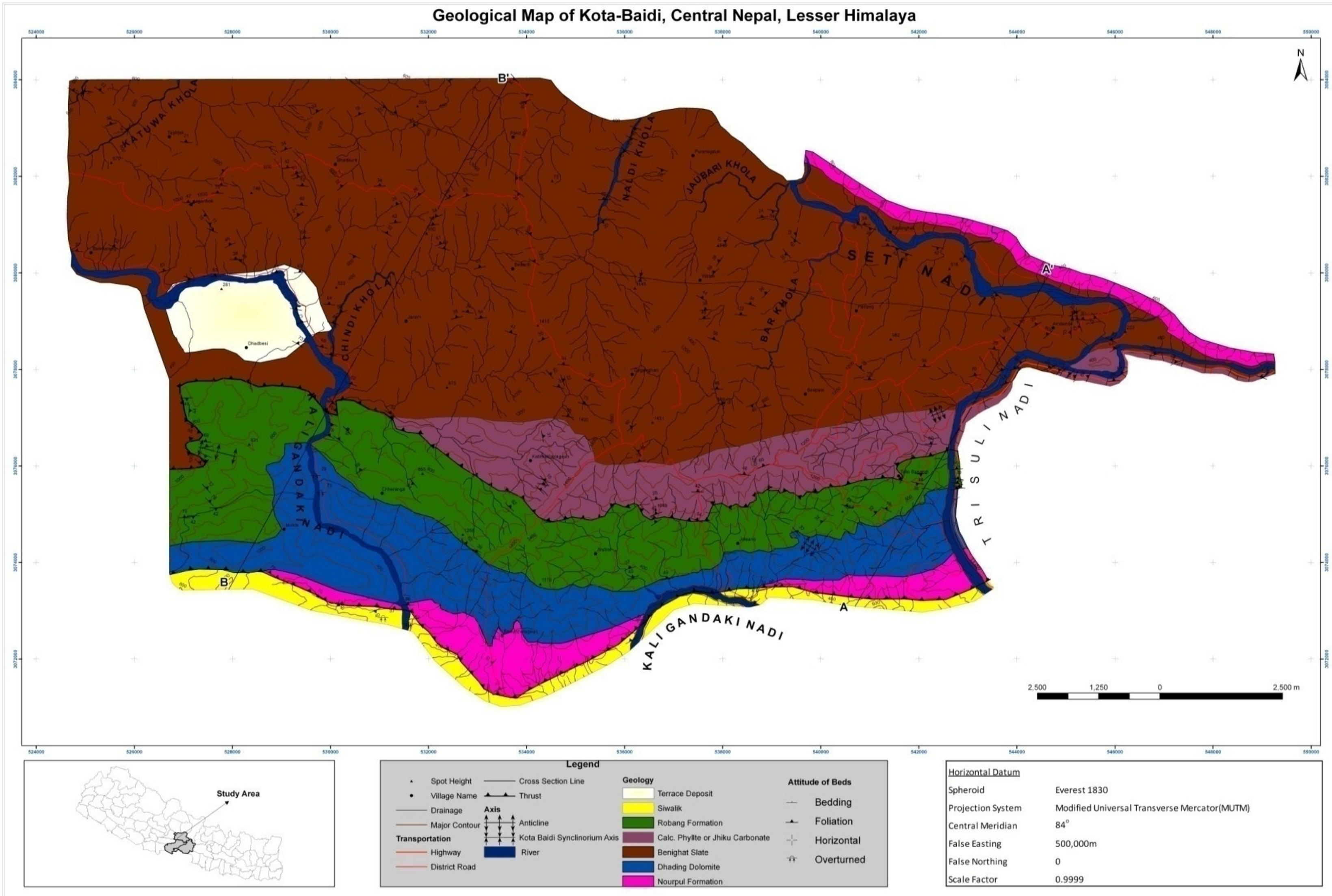
Fig. 2.1: Geological map of Muglin Banspani area, Central Nepal Lesser Himalaya, Paudyal and Paudel (2011)

The Fagfog Quartzite (~Anpu quartzite, 400 m) is composed of white quartzite and uninterruptedly extends from Muglin to Anbu Khaireni, the Dandagaon Phyllite (~Labdi Phyllite, 200 m) is made up of alternations of laminated black phyllite, gritty phyllite, metasandatone, dolomite and quartzite. The Nourpul Formation can be divided into three members. The Purebensi Quartzite (~Banspani Quartzite, 420m) is the lower member that consists of grey to white quartzite with phyllite and amphibolite/greenschist. The middle Amdanda Phyllite member comprises grey, finely laminated phyllite and metasandstone with sporadic layers of dolomite. The upper Labdi Khola Carbonate Member consists of mixed lithology of grey and pink dolomite, pink quartzite, phyllite, greenschist and amphibolite. This unit is also characterized by several hematite bands and copper mineralization. The youngest unit is the ridge-forming Dhading Dolomite.

CHAPTER THREE

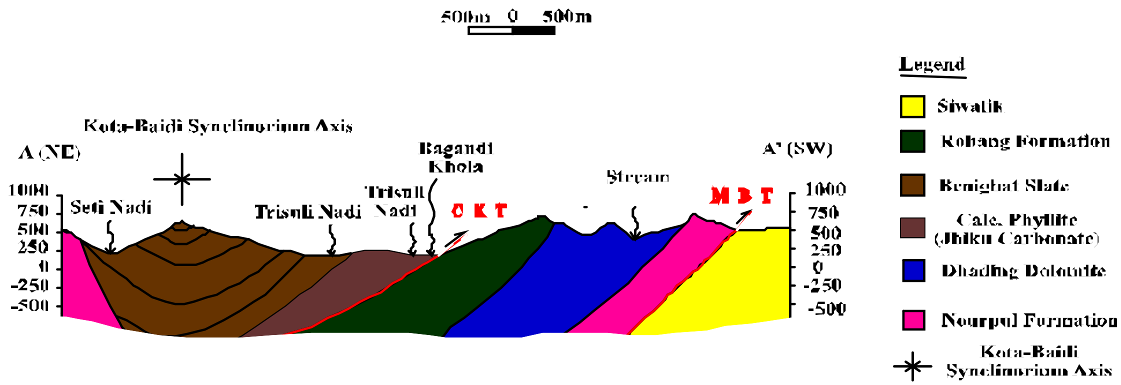
LITHOSTRATIGRAPHY

The present geological study covers the area between three major rivers, i.e. the Kali Gandaki river in the west and south-west, the Trisuli river in the south-east and the Seti river in the north-west to north east. The study area lies within the low grade metamorphic zone, Lesser Himalaya . According to Stocklin (1980), it consists of rocks of Nawakot Complex. The Nawakot complex is further divided into two groups. They are the Lower Nawakot Group and the Upper Nuwakot Group. They are separated by an erosional unconformity (Stocklin, 1980). Stratigraphically (Stocklin,1980), the Lower Nawakot Group comprises the Kuncha Formation, the Fagfog Quartzite, the Dandagaon Phyllite, the Nourpul Formation, and the Dhading Dolomite of which the Kuncha Formation is the oldest and the Dhading Dolomite is the youngest of this group.In the study area the Kuncha Formation, the Fagfog Quartzite and Dandagaon phyllites are missing. Similarly, stratigraphically the Upper Nuwakot Group comprises of the Benighat Slate Formation, the Malekhu Limestone Formation and the Robang Formation of which the Benighat slate is the oldest and the Robang Formation is the youngest of this group.In the study area ,Malekhu Limestone is missing. The Benighat Slate is thrusted upon the Robang Formation breaking the normal stratigraphy sequence in the study area. The rocks of the Lower Nawakot Group are distributed in the southern part of the study area and the rocks of Upper Nawakot Group are distributed to the north of the Lower Nawakot Group in the study area (Fig. 3.1).



Geological Map of Kota-Baidi, Central Nepal, Lesser Himalaya
KATUWA KHOLA
HALDI KHOLA
JAUBARI KHOLA
SETI NADI
CHINDI KHOLA
BAR KHOLA
ALI GANDAKI NADI
TRISULI NADI
KALI GANDAKI NADI
Dhadbesi
B
B'
A
A'
N
2,500
1,250
0
2,500 m
Study Area
Legend
Spot Height
Village Name
Drainage
Major Contour
Transportation
Highway
District Road
Cross Section Line
Thrust
Axis
Anticline
Kota Baidi Synclinorium Axis
River
Geology
Terrace Deposit
Siwalik
Robang Formation
Calc. Phyllite or Jhiku Carbonate
Benighat Slate
Dhading Dolomite
Nourpul Formation
Attitude of Beds
Bedding
Foliation
Horizontal
Overturned
Horizontal Datum
Spheroid
Everest 1830
Projection System
Modified Universal Transverse Mercator(MUTM)
Central Meridian
84°
False Easting
500,000m
False Northing
0
Scale Factor
0.9999

Geological Cross-section of the study area A (NE) to A'(SW)



Geological Cross-section of the study area B (NE) to B'(SW)

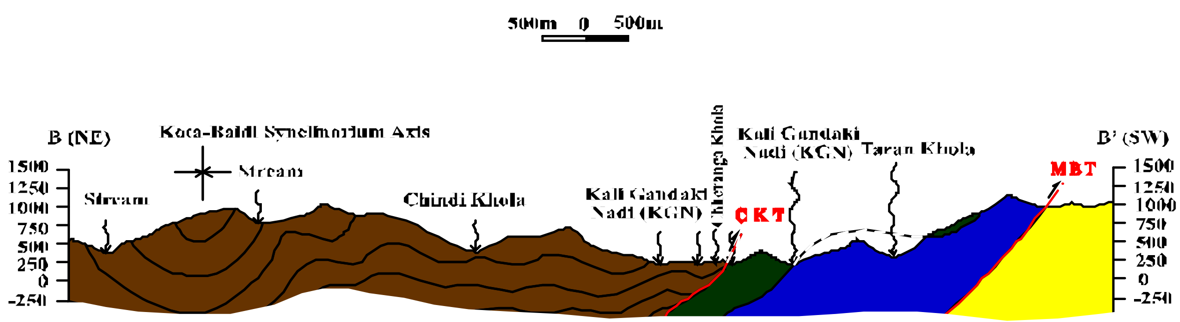


Fig.3.2: Geological Cross-section of the present Geological map.

3.1. Nourpul Formation

The Nourpul Formation is exposed in different parts of the study area. Phwatar and west of it, Nourpul Formation is well exposed immediately north to MBT zone. In places like Kota Baseni, Dode and west of them, Nourpul Formation can be well observed though the area is densely vegetated and disturbed. The main lithology of this formation consists of intercalation of grey colored, medium grained, quartzite, non-calcareous,medium to thick bedded, fine grained phyllites and small lenticular beds of dolomite. At the left bank of the Trisuli river in road section (DM-2), calcareous purple quartzite, green ferruginous quartzite with ripple marks ,blue grey siliceous dolomite and dark grey phyllites are observed. Faintly preserved ripple marks are usually found in the beds of grey quartzites. In Ghumaune, it consists of intercalation of pink quartzites and green phyllites in the ratio of 1:1. It is separated in the south by the MBT. Around Dashdhunga, the Nourpul Formation is entirely covered by colluvial deposits at the road section. However, good exposure can be seen around the confluence of the Seti and the Trishuli Rivers. Here, the main lithology of this formation includes pink quartzite with ripple marks,purple, calcareous phyllite with mudcracks (Fig 3.13) and siliceous dolomite. Poorly developed laminations are observed in the grey metasandstones exposed in Kot Baseni (Fig.3.7, GE-68). Numerous small scale folds of different types and orientations were observed in the Nourpul Formation. The contact between the Nourpul Formation and the overlying Dhading Dolomite is sharp. The approximate thickness of this formation is about 570m in the study area.

3.2. Dhading Dolomite

Dhading Dolomite is conspicuous ridge forming unit of the area. It is widely distributed in the lower reaches of Kottham, Kawadi Khola area, Phosrepani, east and west of Solighopte (Fig.3.1). It consists of grey colored, medium to thick bedded, silicious dolomite. Intercalation of dolomite (80%), phyllite (20%) can be observed in eastern (GE-124) and western (GE-73) part of Solighopte area. The dolomite consists of well developed algal mates and columnar type stromatolites in the area. Dhading Dolomite forms cast topography at the lower reaches of Phosrepani area (Fig-3.8) and columnar stromatolites are abundantly preserved (Fig. 3.17). Beds are weathered and highly fractured and landslide is prominent in the Kawadi Khola area and in just below Kotham area. The phyllites are black in color, fine grained and faintly crenulated. In the upper part of the Dhading Dolomite, grey, medium beds of medium grained quartzite are found intercalated with dolomite. Phyllitic layers (2-3 cm) are also frequently intercalated with dolomite and quartzite beds in around road section just above Phwatar area. Dolomite beds contain columnar type stromatolites pointing right side up. The upper part of this formation is marked by black carbonaceous phyllites which are about 10m to 20m thick and acts as the marker bed. This black carbonaceous phyllite can be observed in around Phosrepani(GE-108), below Kotham (GE-76) and in west of Solighopte (GE-124) at the right bank of Kali Gandaki river. Then the rocks of Robang Formation are found in stratigraphically upwards. The contact(Fig.3.11) between the Dhading Dolomite and Robang Formations is conformable and sharp. The average thickness of this formation in the study area is about 900m.

3.3. Benighat Slate

Benighat Slate is not observed in normal stratigraphic sequence in the study area. It is mapped stratigraphically up of the Robang Formation, being thrust contact (Fig.3.1).Tthere exists no any significant sign of thrust character in the area, except lithogical criteria. It consists of grey to dark grey finely foliated slate/phyllite(95%) with subordinates of metasiltstone, gritty phyllite and lenses of quartzite(5%). Some bands of slate are found calcareous whereas others are not.

Abundant quartz veins and meso-folds are are not uncommon in the area. A large calcareous part of this formation has been mapped as the separate member in the present area.

Calcareous Phyllites or Jhiku Carbonates

Calcareous Phyllites or Jhiku Carbonates member consists of dark grey, greenish-grey argillaceous to gritty phyllites, white to grey dolomite and light grey calcareous metasiltstone and small lenses of quartzite. Intercalation of dark grey phyllites, calcareous metasandstone and thin to thick bedded white dolomite and grey phyllite can be observed in around Phosredada. The greenish-grey to dark grey psammitic phyllite are, laminated, folded and crenulated. Quartz veins of different types can be seen abundantly oriented in different directions. Laminated, gritty, grey to greenish phyllite repeats with thick bedded orthoquartzites. Slates with excellent slaty cleavage are observed in Kabrekholagau and Phagunedada (GE-82) area (Fig.3.9). Intercalation of thin to medium bedded calcareous grey metasandstone, grey to bluish grey phyllites and siliceous dolomite can be observed in around Chanduli-Bhanjyan, Bagandi Khola and Beldada area. Black carbonaceous phyllites can also be observed in this area. The average thickness of this member in the study area is about 375m.

These non-calcereous phyllites of Benighat Slate consists of grey to black, bluish grey to grey in color. This varied in color is due to presence of chlorite, carbon and also due to weathering condition. Phyllites and slates are almost argillaceous but some are gritty or psammitic as well. Phyllites are thinly foliated, crenulated, and folded in the area (Fig.3.12). Slates encountered are dark grey to black in color, lineated, thinly laminated and with distinct slaty cleavage (GEP-14). Black carbonaceous phyllite is the typical characteristic of this formation and exists in most of the parts (DM-299). Quartz veins occur in almost all phyllites and slates sequence of this formation, this quartz veins are parallel or oblique to the foliations. Boudinage of quartz (Fig.

4.4) are also seen in the sequence of black carbonaceous phyllites in Kot-Baidi area(GE-90).Phyllites are found intercalated with thin to medium beds of metasandstone,quartzite,dolomite and dolomitic limestone (Fig.3.10) in very few places. Quartzite and metasandstone are white to pink in color (GES-12).Dolomite and dolomitic limestone are bluish white to bluish grey in color.Dolomitic limestone are very rare and are bluish grey in color and are found intercalated with grey to dark grey phyllites (GES-5) in below Jagarthok area and in opposite of Piughare area(GE-3).Pyllites and slates are the dominent and monotonous sequence in this formation except in some parts like Dubundada area(PY-38) and Kaphaldada area(GES-13). The Dubundada area consists of light to dark grey and bluish grey argillaceous phyllites, sometimes gritty as well. Bluish grey phyllites are found interbedded with thin to thick beds of bluish grey dolomite, and thickly bedded white quartzite (PY-39). The Kaphaldada area (GES-12) and Besardada area (GES-15) lithotype is thin to medium bedded, white to greenish grey phyllites. The approximate thickness of this Benighat Slate Formation in the study area is about 1300m.

3.4. Robang Formation

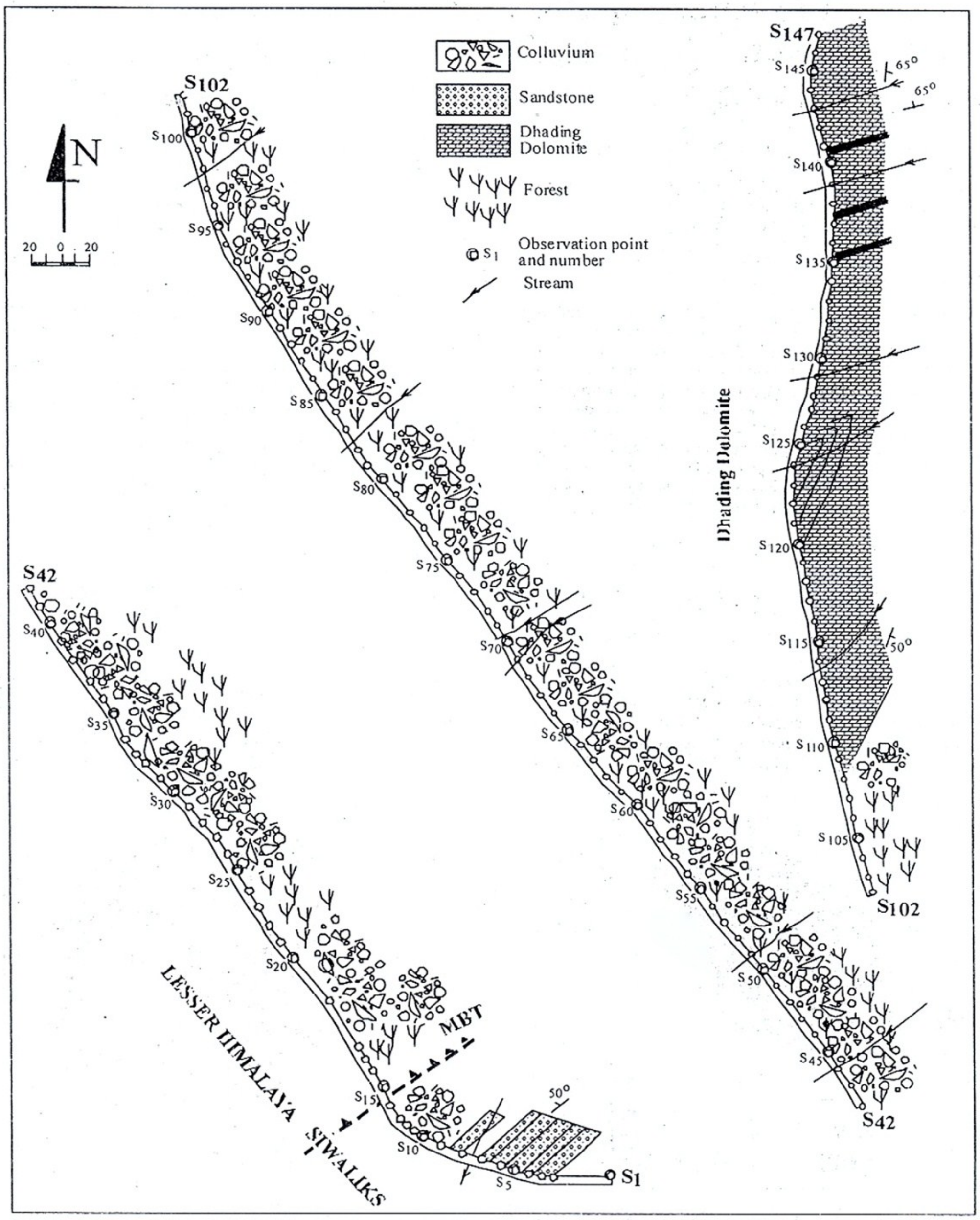
In the present study area, the Dhading Dolomite is followed upward by alternating quartzite and phyllite sequence of the Robang Formation. Quartzite is grey, medium-grained and medium- to thick-bedded (max 30m thick). It is followed by grey, highly deformed and foliated grey,fine-grained phyllites. Quartz veins parallel to foliation are distinct. Two bands of green metabasic rocks with sharp and concordant contact with phyllite and quartzite are observed, in the eastern part of Tallo Bagandi at the Narayanghat road section (Fig. 3.1)

Due to presence of bandings of chlorite mineral the metabasic rock is deep green in fresh outcrop at the left bank of the Trishuli River, below Duighare. The rocks are highly jointed and fractured. Quartz veins of different orientations intersect the outcrop.

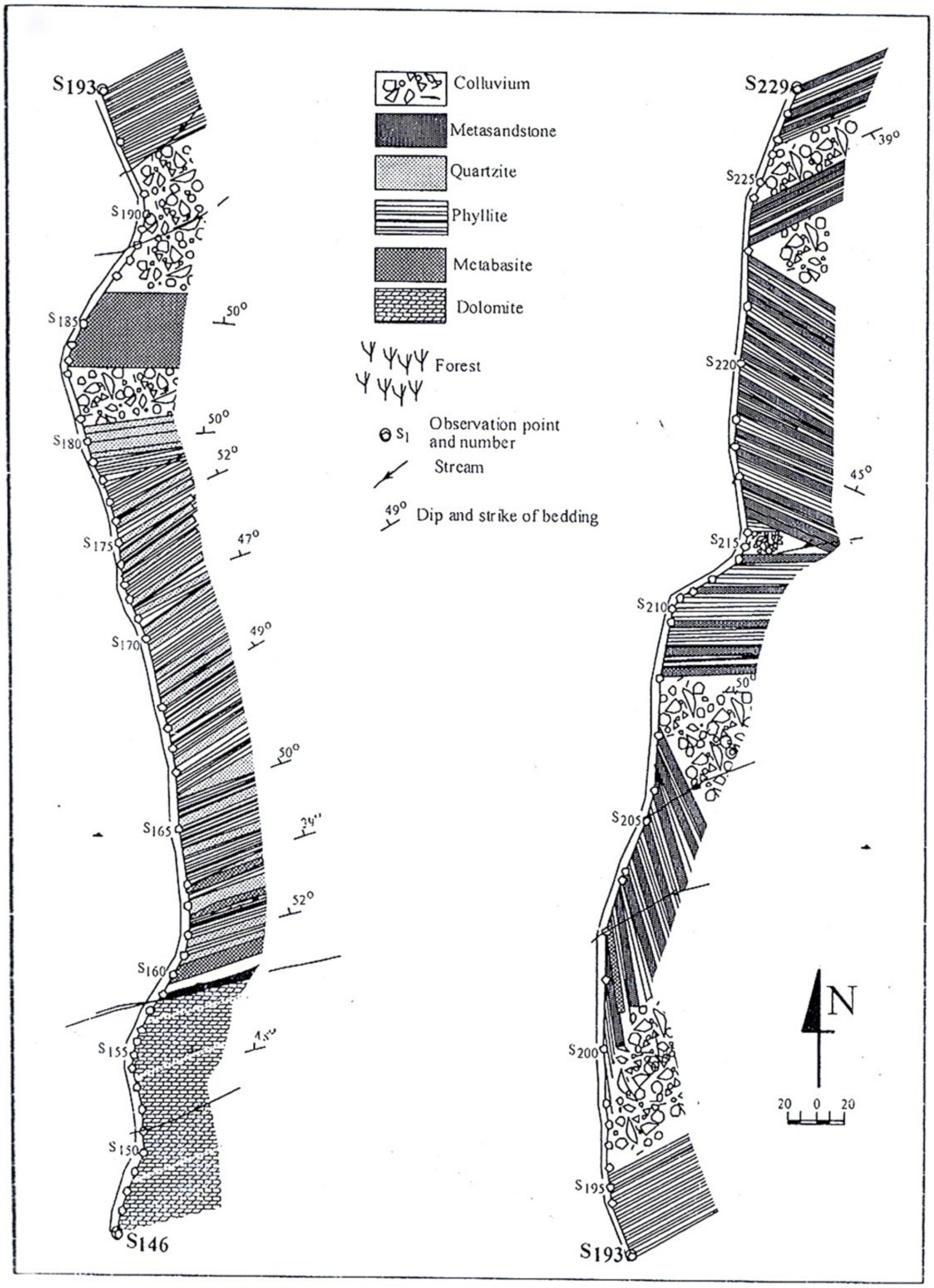
An alternate band of phyllites, quartzite, and dolomite with discordant amphibolites (GE-101) are observed near Bagandi Khola (Fig.3.16). Phyllites are purple in color and shows several boudins of pink dolomite (Fig.3.16) in purple phyllite which is 1cm to 6cm in length. Greenschists are abundantly observed in the ridge between Tallo Bagandi and Mathilo Bagandi area. An exposure of approximately 40m can be observed in the area. Even the cultivated land is covered by the greenschist boulders in the Tallo Bagandi. Finely foliated soapy violet color phyllite are observed in the phrosrepani area. Intercalation of green, violet, phyllites and green grey quartzite is observed around Cheranga, Jaithum and Jamdada area. Cyclic deposit (Fig.3.14) of grey-brown–violet Purple phyllite, with grey-green metasandstone at the right bank of KaliGandaki(GE-135)

Mapable Quartzite member, i.e. Dunga Quartzite of the Robang Formation (Stocklin,1980) is not observed except in Narayanghat-Muglin road section. In present area, the Robang Formation directly overlies the Dhading Dolomite missing two older units: the Benighat Slate and the Malekhu Limestone indicating a prominent unconformity, Malekhu limestone is missing and Benighat slate is thrusted upon the younger formation, the Robang Formation. The contact between the Dhading Dolomite and the Robang Formation is sharp and conformable in the study area. The average thickness of this formation in the study area is about 750m.

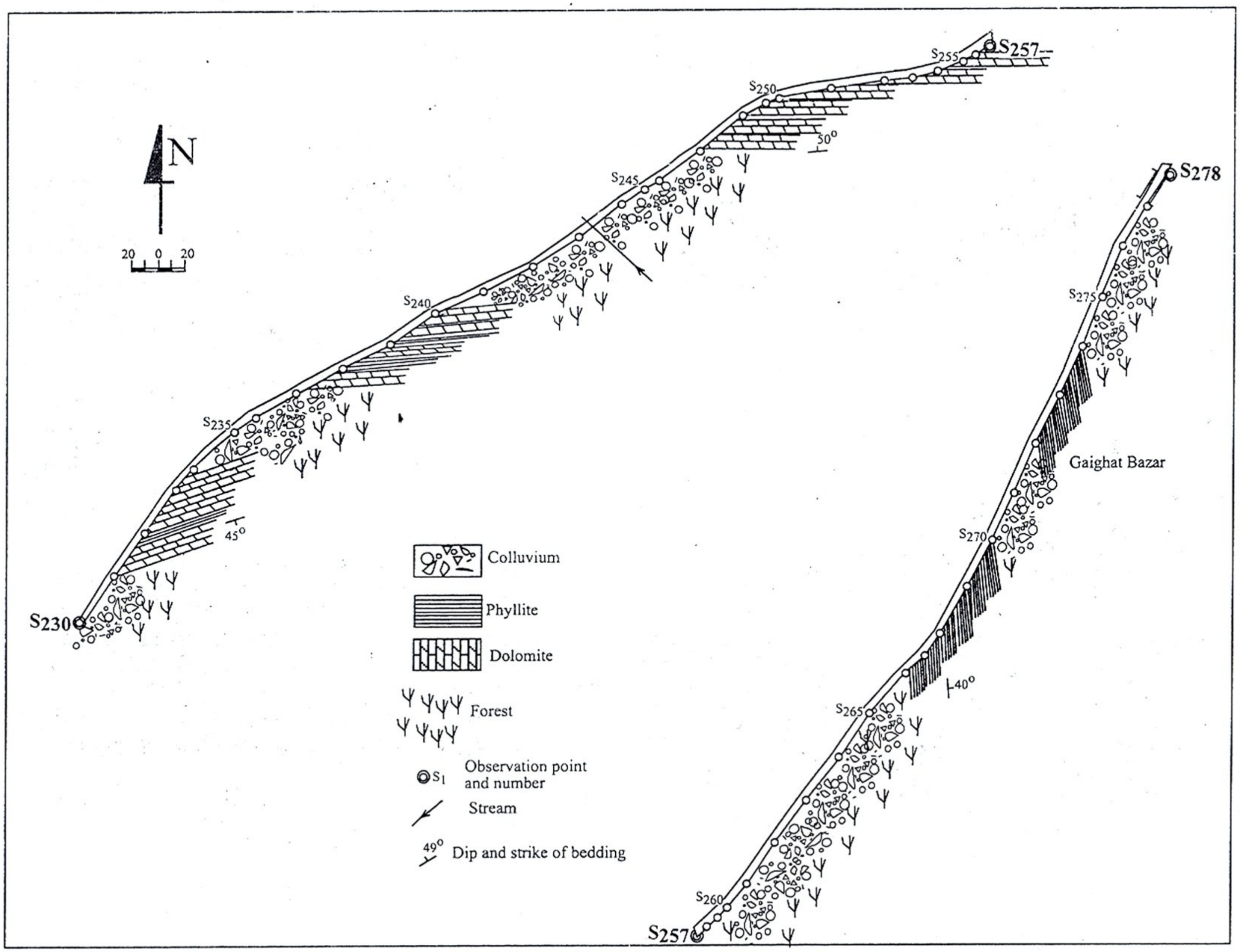
Fig. 3.3 **Geological route map along Dasdhunga-Ghumaune Road.**



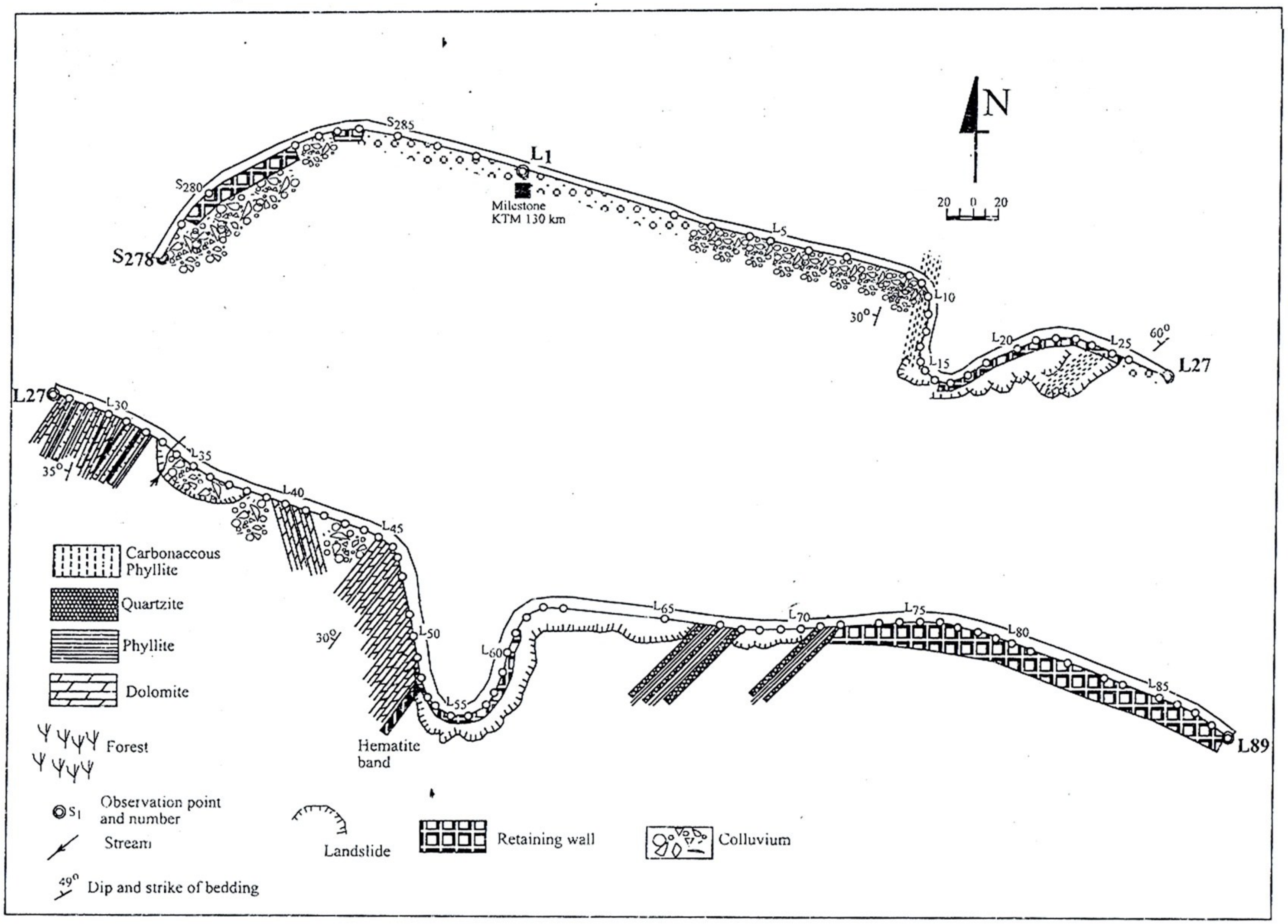
Geological route map along Dasdhunga-Ghumaune road (continued from Fig. 3.3).



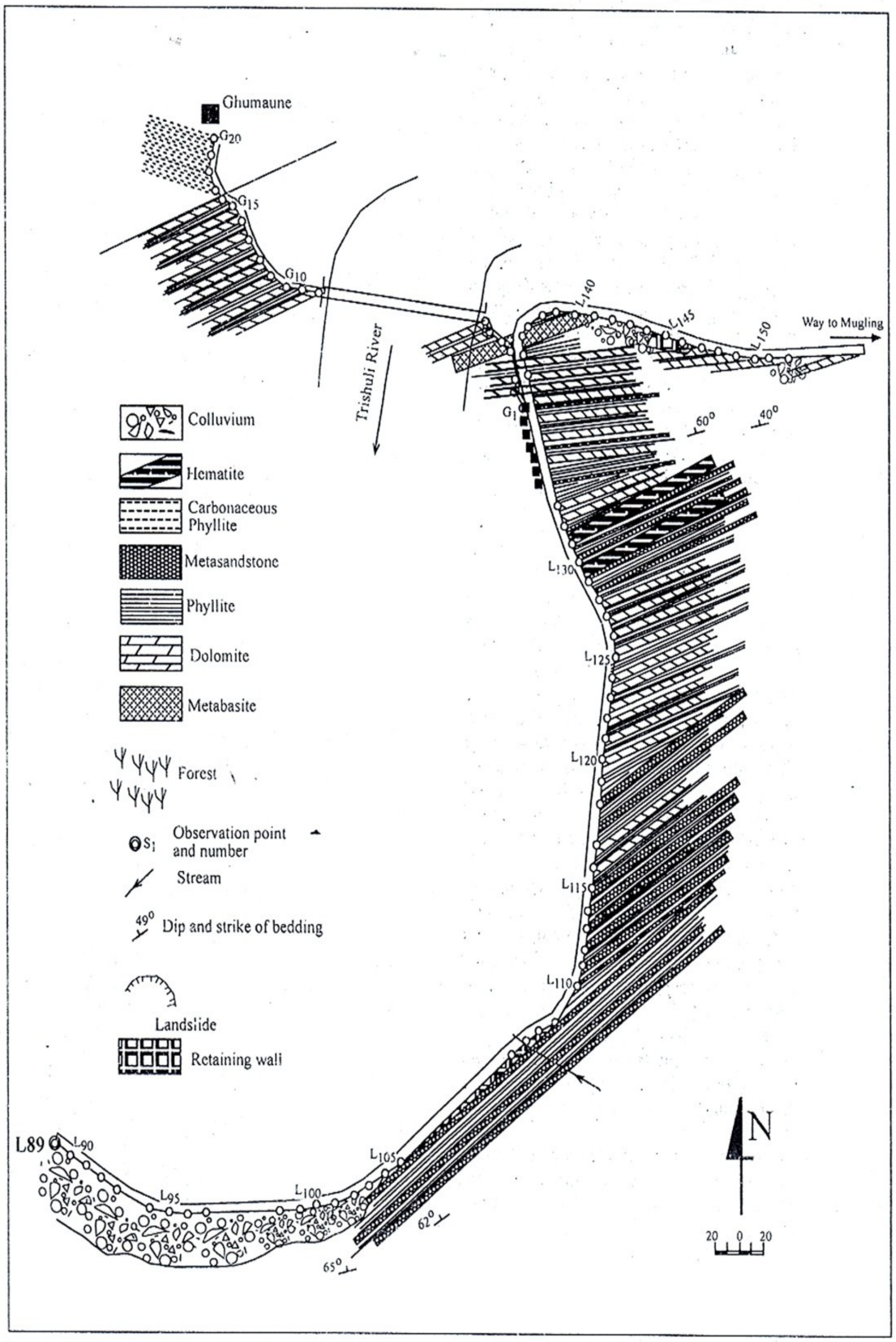
Geological route map along Dasdhunga-Ghumaune road (continued from Fig.3.3).



Geological route map along Dasdhunga-Ghumaune road (continued from Fig.3.3).



Geological route map along Dasdhunga-Ghumaune road (continued from Fig. 3.3).



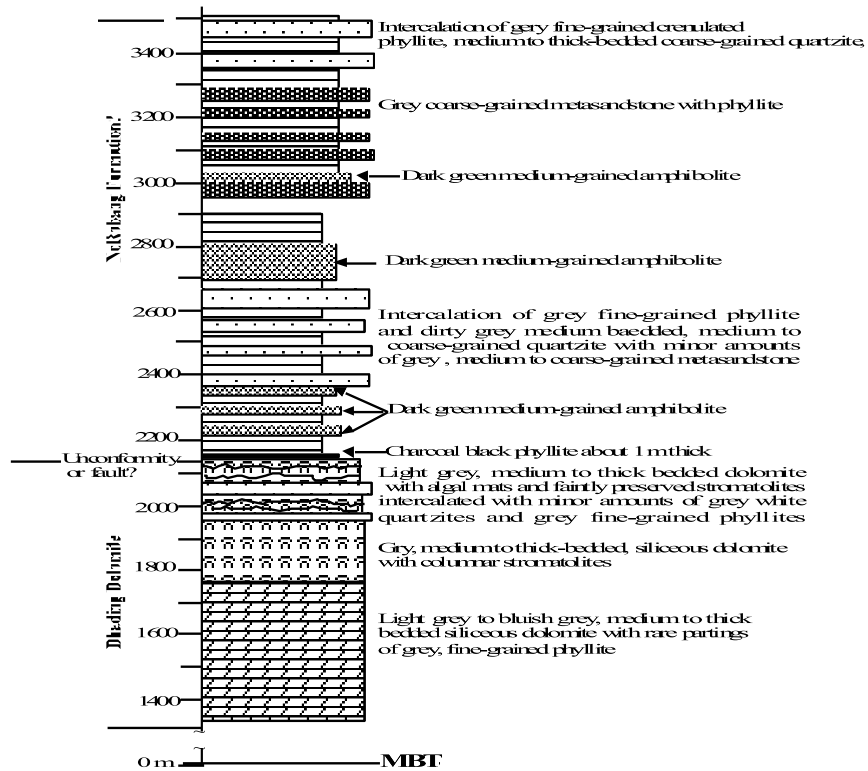


Fig.3.4: Generalized columnar section of the Nawakot Complex in the Dasdhunga area (north of the MBT).

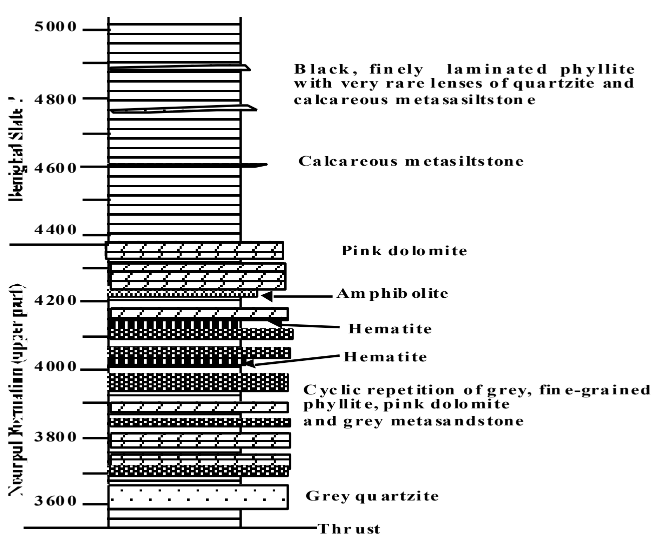


Fig.3.5: Generalized columnar section of the Nawakot Complex in the Ghumaune area.

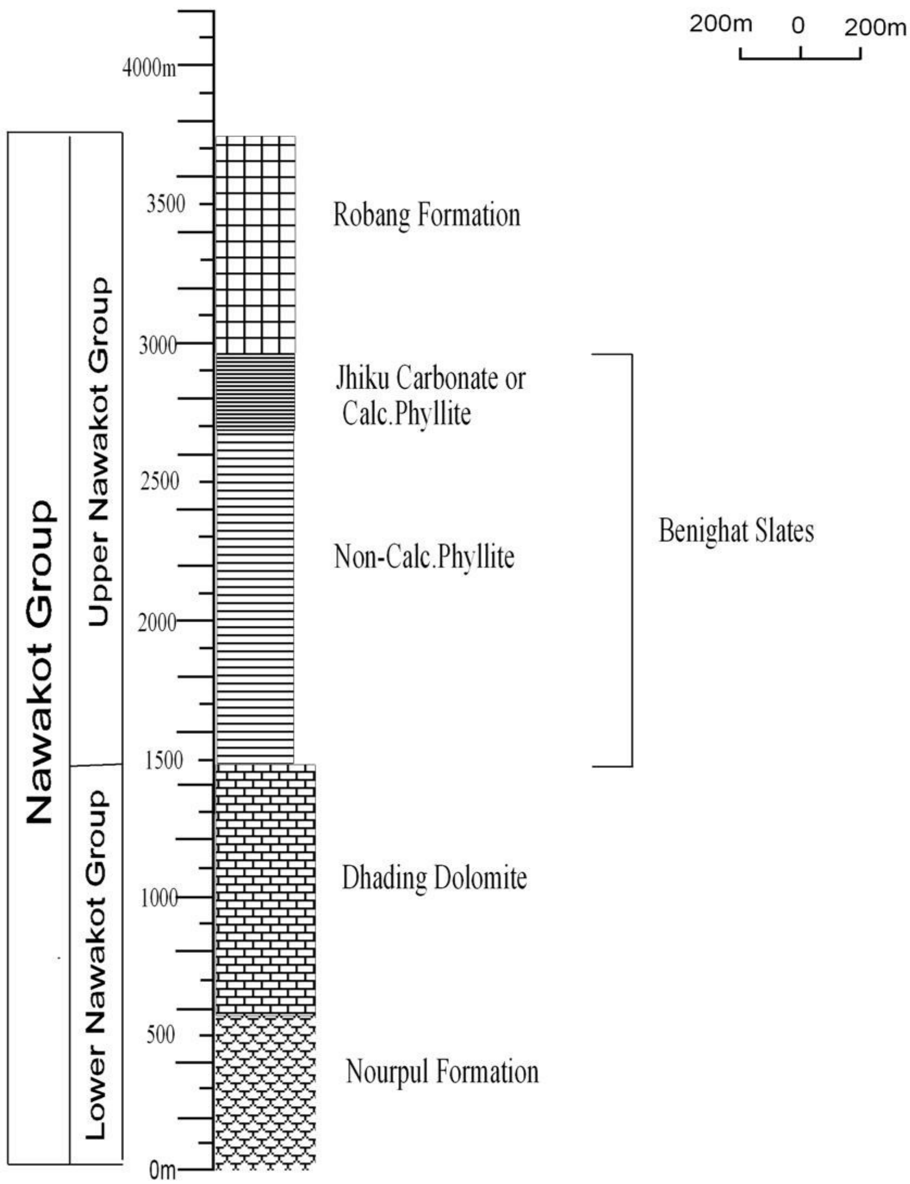


Fig: 3.6.Generalized lithostratigraphy column of the study area,Cental Nepal

Fig 3.7: Photo shows the faintly developed lamination in metasandstone, around Kot Baseni,in the Nourpul Formation.

Fig. 3.8: Outcrop view of cast topography in Dhading dolomite at the lower ridges of Phosrepani area (GE-109), facing SE

Fig.3.9: Outcrop view of slate found in Jhiku Carbonate sequence of Benighat Slate at Phagunedada, facing SW

Fig.3.10: Photograph shows the intercalation of dolomitic limestone and black carbonaceous phyllite of Benighat Slate (location GE:3)

Plate 3.11: Lithological contact between Dhading Dolomite and Robang Formation approx. 12km from Dasdhunga along the Narayanghat-Muglin road,facing NE

Plate 3.12: Folded quartz vein observed in black carbonaceous phyllite in Kotbaidi,facing SW

Fig.3.13: Both Ripple marks and Mudcracks observed in Nourpul Formation at the rt.bank ofTrisuli River near Jalbire,facing NE.

Fig. 3.14: Outcrop view of cyclic deposit of Grey-brown-purple phyllite, and grey-green metasandstone of Robang Formation .GE-126,facing SE

Fig. 3.15: Outcrop shows the Boudinage of pink dolomite in Robang Formation.GE-102, facing SE

Fig.3.16: Exposure of amphibolite discordant contact with bed rocks in Robang Formation at Ghaighat GE-101, facing SE

Fig. 3.17: Columnar type of stromatolites preserved in Dhading Dolomite, found around Phosrepani, facing SE

Fig. 3.18: Crenulated and folded dark grey Phyllite at around Bargau.

CHAPTER FOUR

GEOLOGICAL STRUCTURES

Geological structures are said to be the key to unlock the past environment. Those structures are the special features that are developed during and after the deposition of sediments. Observations of these structures imprint at present, helps to interpret the depositional environment, they underwent in the past. Structurally, the study area is complicated and comprises megascopic to microscopic structures of various origins. The different types of sedimentary and tectonic structures encountered during the field work can be categorized as follows:

4.1. Sedimentary Structures

The sedimentary structures are any of a variety of features in a sedimentary horizon produced by sedimentary processes. Structures formed during or shortly after deposition and those produced during diagenesis. Many such structures are preserved in the study area. Some of the important primary structures so far encountered and identified are as follows:

4.1.1. Beddings and Lamination

The rocks of the study area are derived from the sedimentary origin, showing beddings on successive stratifications. The layers are identified by the change in colour, composition and grain size. The strata are very thickly bedded to finely laminated. Very thickly bedded layers are found in Nourpul and Dhading Dolomite, and thinly laminated phyllites in Benighat slate and Robang Formation.

4.1.2. Stromatolite

Stromatolites are the silicified fossils of algae cluster. They are basically found in algal mate structure and columnar shaped.Columnar type structure help to determine the bedding plane and younging direction. Stromatolites are the typical characteristic of Dhading Dolomite (Fig.3.17) in the study area.

4.1.3. Ripple Marks

Ripple marks are observed in the metasandstone beds of the Nourpul Formation. Both oscillation and current ripples are well preserved in the area(Fig.3.13) . Sharp crest of oscillation ripples shows the younging direction while current ripple gives the paleo-current direction.

4.1.4. Mud Cracks

Mud cracks are noticed in the shale of Nourpul Formation. These structures indicate the aerial exposure of the sediment or shallow water to transition type deposition(Fig.3.13). The convex surface of the wedge of the mud crack indicates the younging direction.

4.2. Tectonic Structures

The geological features that are developed after the diagenesis of the rocks are the secondary structures. These structures can be described within following headings. They are megastructures, mesostructures and microstructures.

4.2.1. Megastructures

Megastructures are the very large geological structures that can be analyzed only by the geological mapping of large area, like large scale faults, folds etc.The different structures encountered during the fieldwork are included in the following subheadings.

a) Fault

The faults extend regionally throughout the study area and are included within this heading. All the faults in the study area are of reverse type with displacement of large blocks, bringing the older rocks above the younger rocks which don't follow the normal sequence of displacement and most of these faults are recognized on the basis of normal stratigraphic position. In the study area, following large scale thrusts are traced.

i) Main Boundary Thrust (MBT)

The MBT is mapped in Phwatar-Dashdhunga and in Hatisal area on the basis of lithological variation and topological change (DM-9, DM-11, RS-20, Fig. 3.1). The thrust has brought the older meta-sedimentary rocks of the Lesser Himalaya above the younger rocks of the Middle Siwalik. The usual trend of thrust is NE-SW with an average dip of 40º–45º towards NE.

ii) Chheranga Khola Thrust (CKT)

The name of the thrust is derived temporarily after the Chheranga Khola. It brings older rocks of the Benighat Slate formation above the younger rocks of the Robang Formation. It extensions around the Chheranga Khola and Ghaighat in the east (GE-135, GE-96, Fig. 3.1). The usual trend of the thrust is NE-SW with an dip between (50-60) degree towards NW. Though there is no much distinct sign of fault character, this thrust has been demarcated on the basis of lithological variation on normal stratigraphic position.

b) Folds

Several folds of different type and scale are observed in the territory of the present study area. Some are discussed as follows.

i) Kota-Baidi Synclinorium

The whole study area comprises a part of megasyncline. It is tightly closed at the Gumaune area. It is an assymetrical syncline. Its one limb is trending towards South-South West and dipping towards north and another limb extends towards North-North East and dipping towards south. The synclinal axis is trending NW and SE from the result of the pole plot (Fig. 4.1) . The general trend and plunge of the synclinorium is $277^0/17^0$. Attitude of the limbs of the fold are given in Annex Ia. Two cross-sections are drawn, AA' in the eastern part and another BB' in the western partfrom the geological map of the study area. These cross-sections (Fig. 3.2) also shows the megasynclinal structure in the study area whose axis passes NW-SE and also have shown the synclinorium axis in the (Fig. 3.1). This megasyncline is temporarily named as Kota-Baidi Synclinorium.

On the basis of air photo interpretation, Stocklin has also indicated this megasyncline in his report saying it, strike out syncline. Present field work and data interpretation made clear that Megasyncline do exist in the area.The core of this megasyncline is occupied by the Benighat Slate . There are numerous small folds within this megasynclione whose axes are trending more or less similar to the axes of megasyncline (Fig. 3.1).

ii) Makre Anticline

The name of the anticline is taken from the Makre village. It is an open, asymmetrical and Plunging fold whose axis passes through NW-SE (Fig. 4.2) in the present area. The general trend and plunge of the axis of this anticline is $284^0/8^0$ from the analysis of the stereonet pole plot. Attitude of the limbs of the anticline is given in Annex Ib. There exist small tight folds associated with this anticline .

4.2.2. Mesostructures

a) Foliation

Foliation is a planar arrangement of dimensionally oriented minerals in metamorphic rocks formed by the recrystallization and segregation of minerals growing under conditions of elevated pressure and shearing stress. Foliation is known by more specific terms like bedding, cleavage, schistose or gneissic layering. This is the typical property of rocks from where they tend to break in parallel surfaces. The slates of the Nourpul Formation, Benighat Slate and the Robang Formation of the study area exhibits the slaty cleavage (Fig. 3.9). The intercalated dark grey slates of Dhading Dolomite are also well foliated. Quartzites of the Nourpul Formation are weakly foliated. The competent rocks like dolomite of Dhading Dolomite, Quartzite and metasandstone of Nourpul Formation and Robang Formation are found to be weakly foliated whereas the politic rocks like phyllites of the all formations are found strongly foliated and deformed.

b) Crenulation Cleavage

Crenulation cleavages are observed in the phyllites of the Benighat Slate which makes the phyllite highly deformed (Fig. 3.18).

c) Lineation

Lineation is expressed by the parallelism of some directional property in the rock. Primary lineation is found in both sedimentary and igneous rocks. Secondary lineation is superimposed in the rocks sometime after they were originally deposited, erupted or intruded. Secondary lineation may be imposed on rocks more than once, so that several differently oriented lineations may be present in the rocks. In our study area, secondary lineation is well developed in the Nourpul Formation, the Benighat Slates and the Robang Formation.

d) Small scale Folds

There exist numerous small scale folds in the study area. Open and closed, symmetrical and asymmetrical, isoclinal to crenulation types of folds are frequently observed in all types of rocks of different formations within the study area (Fig.4.3). Axes of these small scale folds are trending more or less similar to the megasyncline axis. Axes of these folds are shown in the Fig. 3.1.

e) Boudin

Different types of boudin of quartz and feldspar are observed in several places of the study area. In Kotabaidi (GE:), boudins of quartz (upto15cmx4cm) in (Fig. 4.4) are frequently recorded in black slates and phyllites of the Benighat Slate.Similarly, the boudins of pink dolomite (GE:) are found in Ghaighat in the Robang Formation (Fig. 3.15).

f) Joints

Two to four sets of joints are recorded in the rocks of the study area. The Dhading Dolomite frequently exhibits largely spaced joints, sometimes creating confusion in identification of the beddings. The jointed rocks are mostly found responsible for landslides in the rocks of Nourpul Formation.

g) Shear Zones

These are the structures formed by the displacement rocks through cracks. Shear zones are observed in different places (location:PY-10) in the study areas (Fig. 4.5). The general trend of the shear zones are NW–SE.

h) Quartz veins and Tension gash

Quartz veins of different types and orientations are observed in most of the rocks of the study area.some of the veins are parallel to the foliation and others are obliquely oriented. Folded veins are also observed .Tension gash are also observed in some part like in Musimaran of the study area but rare (Fig. 4.6).

4.3. Tectonics and Deformation

The Lesser Himalaya of Central Nepal between the Kali Gandaki river, the Trisuli river and the Seti river areas show megasyncline structure. One limb trending South-South west and dipping towards north and another limb trending towards North East-East and dipping towards south. It is tight and close near Gumaune area (Fig. 3.1).

The deformations are commonly seen in the study area. There are numerous small scale folds within the study area rocks. Locally overturned beds are also observed as shown in the (Fig. 3.1). Crenulation can be seen in the phyllites. Lineations are also observed in the phyllite, quartzite and meta-sandstones and often show fine crenulation.

In the study area folding of all scales (microscopic, mesoscopic and megascopic) are observed. The megasyncline or Kota-Baidi synclinorium, Makre anticline and almost all the small scale, anticlines and synclines generally have the same axes trend, i.e. North-west to South East direction (Fig. 3.1). These small scale folds are tight, isoclinals, drag type whose axes trend is generally more or less parallel to the megasyncline axis. There also exists numerous quartz veins some are parallel and oblique to the foliation, some are folded and some forms boudins. By interpreting these folds data statistically, we can conclude that these folds are formed by the general N-S stress applied concurrently with the general Himalayan trend.

There are numerous small scale brittle faults and shear zones cross-cutting the ductile structures (foliations), jointed rocks, active landslides observed in the study area, which indicates that the Himalaya orogeny process is still active. Two mapable thrusts are observed. Out of them, the MBT is well exposed and separates the younger rocks of Siwaliks and the older rocks of the Lesser Himalayan meta-sediments, which is trending SW-NE and steeply (40°-45°) dipping towards north. Similarly, another Chheranga Khola thrust is also north dipping (40°-55°) and SW-NE trending, more or less parallel to the MBT.

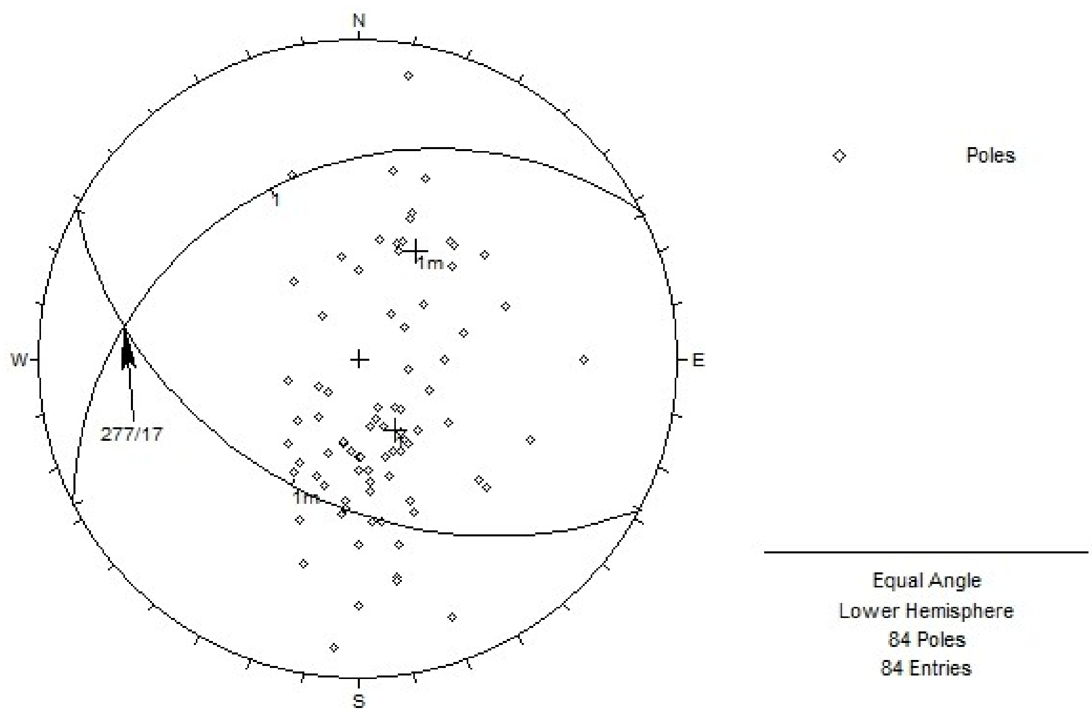


Fig. 4.1: Stereonet pole plot, representing limbs and axis of Kota-Baidi Synclinorium

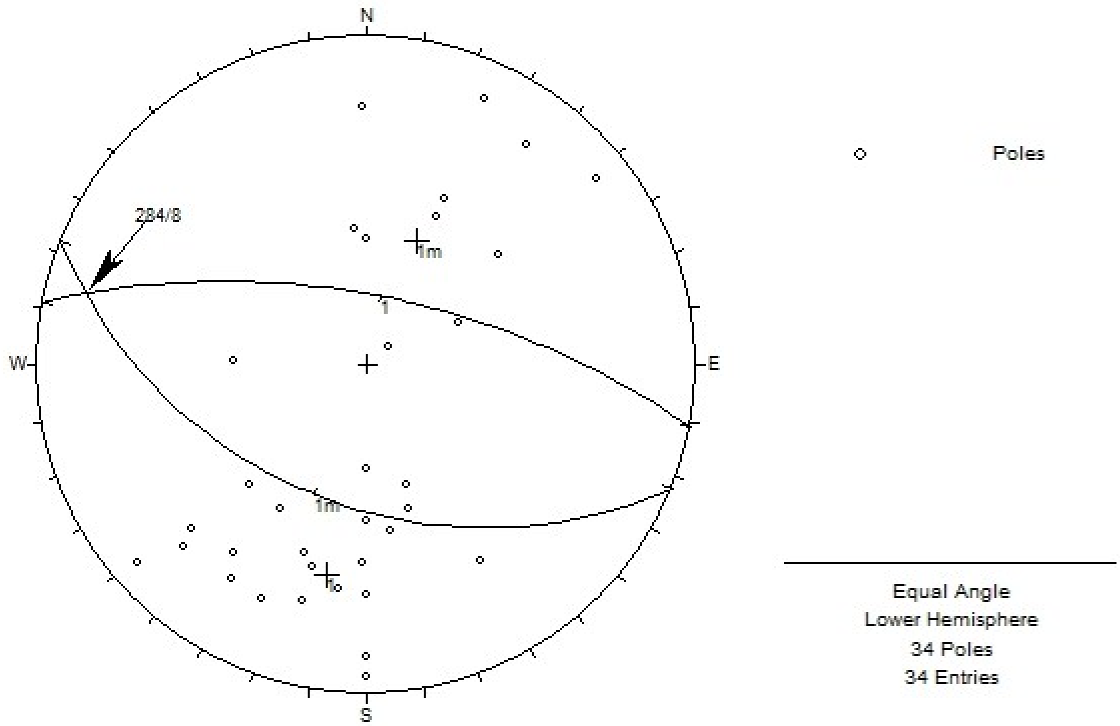


Fig. 4.2: Stereonet pole plot, representing limbs and axis of Makre anticline

Fig.4.3: Photograph shows the distinctly developed meso-fold in black Slate in opposite of Saranghat (GE-5), facing SE

Fig.4.4: Boudinage (D>20cm) of quartz observed in Benighat Slate in Kot-Baidi (GE-90), facing SE

Fig. 4.5: Shearing on Phyllites at Bimraswara.

Fig. 4.6: Quartz veins,Boudin,and tension gash in Benighat Slate at Dumsimaran

CHAPTER FIVE

CONCLUSIONS

- The study area consists of the metasedimentary rocks of both Lower and Upper Nawakot Groups. Only Nourpul Formation and Dhading Dolomite of Lower Nawakot Group and the Benighat Slate and the Robang Formation of Upper Nawakot Group are distributed in the study area. Benighat Slate is thrusted over the Robang Formation breaking the normal stratigraphic sequence.
- The Dhading Dolomite is followed up section by the Robang Formation in the study area, indicating a prominent unconformity. However, there is no any field relation of unconformity except lithological breakage.
- The major mappable thrusts are the Main Boundary Thrust, and the Chheranga khola Thrust both are distinguish on the basis of lithology.
- The whole study area comprises a megasyncline, temporarily named as Kota-Baidi Synclinorium, with an axis trend and plunge, 277°/17°. A local anticline observed and mapped in the present study area is Makre anticline, named after Makre Village, with an axis trend and plunge 284°/8°. There are many small scale folds present, trending as megasynclinorium.
- Mesostructures and microstructures such as foliation, lineation, shear zone and S-C fabric are also well developed in the area. The orientation of the mesostructures is parallel with megastructures.

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Annex Ib: Attitude of limbs of the Makre Anticline

Location	Dip Amount	Dip Direction
RS-21	75	32
RS-23	62	1
RS-24	34	245
RS-25	42	180
RS-27	70	0
RS-28	76	45
RS-29	72	47
RS-30	54	44
RS-31	83	204
RS-32	54	352
RS-33	69	7
RS-34	58	205
RS-35	44	92
RS-36	45	175
RS-37	10	230
GE-125	73	15
GE-126	79	216
GE-127	83	0
GE-128	76	24
GE-129	76	179
GE-130	53	205
GE-131	51	0
GE-132	65	15
GE-133	62	18
GE-134	55	230
GE-135	87	0
GE-136	70	35
GE-137	35	0
GE-138	85	49
GE-139	69	330
GE-140	84	231
GE-142	49	344
GE-143	42	342
GE-144	54	31

Annex Ia: Attitude of the axis of the Kota-Baidi Synclinorium

Location	Dip Amount	Dip Direction
RS-51	54	352
RS-52	21	323
RS-53	48	5
RS-54	52	6
RS-55	22	344
RS-56	50	340
RS-57	42	355
RS-58	17	55
2	62	200
3	52	200
4	50	220
5	60	0
6	20	140
7	35	140
8	50	200
PY-16	35	335
PY-17	42	20
PY-18	54	355
PY-19	35	345
PY-20	30	10
PY-22	61	348
PY-24	67	15
PY-25	81	340
PY-26	70	350
PY-27	34	340
PY-29	25	340
PY-30	31	180
PY-33	34	360
PY-35	32	320
PY-37	34	330
PY-39	32	330
PY-40	32	320
PY-41	18	338
PY-42	20	235
PY-43	37	256
PY-44	61	295

Location	Dip Amount	Dip Direction
GE-85	41	345
GE-86	84	5
GE-87	44	15
GE-88	41	30
GE-89	69	350
GE-90	16	44
GE-91	20	215
GE-92	26	73
GE-93	63	160
GE-94	62	190
GE-95	54	230
PS-1	45	225
PS-2	50	5
PS-3	52	250
PS-4	70	270
PS-5	23	320
PS-6	29	330
PS-7	25	35
PS-8	30	45
PS-9	29	10

Continue of Annex Ib

Location	Dip Amount	Dip Direction
GEP-1	18	280
GEP-2	50	218
GEP-3	30	230
GEP-4	56	315
GEP-5	34	18
GEP-6	32	5
GEP-7	56	20
GEP-8	45	355
GEP-9	38	355
GEP-10	44	30
GEP-11	59	315
GEP-12	38	305
GEP-13	27	293
GEP-14	24	350
GEP-15	84	190
GE-1	30	270
GE-2	43	200
GE-3	45	225
GE-4	42	190
GE-5	40	200
GE-6	42	198
GE-8	36	170
GE-9	34	359