LITHO-BIOSTRATIGRAPHY OF SIWALIK SEDIMENTS IN ARUN KHOLA AREA IN NAWALPARASI AND PALPA DISTRICTS, WESTERN NEPAL.

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RECOMMENDATION

This is to certify that MR. YUBARAJ LAMICHHANE has completed this dissertation work entitled **"LITHO-BIOSTRATIGRAPHY OF SIWALIK SEDIMENTS IN ARUN KHOLA AREA IN NAWALPARASI AND PALPA DISTRICTS, WESTERN NEPAL"** as a partial fulfillment of the requirements of M. Sc. Degree in Geology under our supervision. To our knowledge this work has not been submitted for any other degree. We, hereby, recommend the dissertation for approval.

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Abstract

The study area located in the Nawalparasi and Palpa District of Western Development Region of Nepal. The toposheet No 099-11, 099-12, 099-15 and 099-16 cover whole section of the study area. Geographically the study area extends from longitude $83^0$47'50''E to $83^0$58'11''E and latitude from $27^0$40'2''N to $27^0$44'55''N. The total area covered is 163 sq Km.

This desertation is concerned with the lithological and biological study of the mentioned area. This area is lies in the Siwalik Group of the Nepal Himalaya. The lithology of that area is like as the other parts of the Nepal but the naming are in different aspect. The study area covers the detail study of the rock unit between the CCT and MBT. Lithilogically the area is classified as Arung Khola Formation, Binai Khola Formation, Chitwan Formation and Deorali Formation. The Arung Khola and Binai Khola Formation are further divided into three members as Lower, Middle, Upper respectively. In these rock units the grain size is of the formation are increasing from older to younger units.

Study of thin section of various location shows that the sandstone is of the arkose, lithic arenite and feldspathic types. The climate of the Siwalik formations is sub humid to humid.

Palynologcal study is main parts of this thesis. Many pollen samples prepared and analysis has been done. Altogether 22 taxa belonging to 14 families of plant are documented from the Arung Khola Formation. The Arung Khola Formation is deposited in shallow water depositional basin. These texa are warm loving. Plam are common in the studied sample sho the tropical to sub tropical climate. These pollen represent the age of Late Miocene to early playstocene and climate as sa humid and warm as experienced in Terai area of Nepal today.

Geological map, cross-section, columnar section, thin section preparation, pollen sample preparation, Paleocurrent analysis were done during the lab work and disertation preparation time. The paleo current flow from the pebble imbrication is found as S56^0W around the Khani Damar Area.

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List of Abbreviation:

Al : Lower Member of the Arung Khola Formation

Am : Middle Member of Arung KholaFormation

Au : Upper Member of the Arung Khola Formation

Bl : Lower Member of Binai Khola Formation

Bm : Middle Member of Binai Khola Formation

Bu : Upper Member of Binai Khola Formation

AMSL : Above mean sea level

C.B.P Corrected Bedding pole

CCT : Central Churia Thrust

Cong : Conglomerate

HFT : Himalayan Frontal Thrust

MBT : Main Boundary Thrust

Mst : Mudstone

Qtz : Quartz

RF : Rock Fragments

Sst : Sandstone

UCN : Under Cross Nicol

CHAPTER I
INTRODUCTION AND BACKGROUND

1.1 Background

Middle Miocene to Early Pleistocene Siwalik Group of the Nepal Himalaya is the youngest mountain belt in the Himalayan Arc. This foreland basin came to an existence after the collision of Indian Plate to the Eurasian Plate at Eocene time during the Himalayan orogeny. The Siwalik Group of rocks which are occasionally knows as Churia Group is delimited by the Lesser Himalaya to the North and Indo-Gangetic Plain to the South. Tectonically, this group is located between the Main Boundary Thrust (MBT) in North and Himalayan Frontal Thrust (HFT) in South. The Siwalik sediments are deposited by braided river system flowing from the North while the Himalayan Mountain Ranges were rising. The weathering mantle of Lesser Himalayan and Higher Himalayan rocks supplied the sediment influx that was being deposited in the foreland basin. The rate of upliftment of the Himalayan Range is also reflected in the Siwalik sediments. When the upliftment was slow the fine grained sediments were deposited however during the time of high upliftment the coarse grained sediments were deposited in the Siwalik Basin. These fluvial sediments are very good archive to study the flora and fauna during the upliftment process. Plant megafossils (leafs, wood), macro (fruits, seeds) and microfossils (pollen, spores, diatoms) are accurate proxies to understand the ecology as well as the evolution of monsoonal climate system in this area. This study mainly focuses on the study of lithostratigraphy, sedimentary environment and climate on the basis of available plant microfossils along the Arun Khola and its tributaries in Nawalparasi and Palpa area Western Nepal.

Rock sample were taken from different location for pertological and pollen analysis. Pollen analysis help to predict the paleo-climate and petrological analysis help to study about the mineral composition. Pebble orientation data also taken from different location which helps to reconstruct the paleocurrent flow and thus gives the provenance analysis of the study area. Columnar section also draws in various locations to study the variation in grain size, thickness and composition and the depositional environment within the Siwalik sequence.

1.2 Objectives

The main objectives of the proposed research are as follows:

1. To prepare detail geological map of the Northern belt of the CCT in 1:25,000 to MBT.
2. To study the petrography, sedimentological and lithological succession of the proposed area.
3. To study the structure of the study area.
4. To identify the sedimentary environment, provenance and paleo-current analysis.
5. To reconstruct the climate during the Siwalik deposition on the basis of available plant microfossils (i.e. pollen and spores).

1.3 Location and accessibility

The study area is located in the Nawalparasi and Palpa District of Western Development Region of Nepal. The toposheet No 099-11, 099-12, 099-15 and 099-16 cover whole section of the study area. Geographically the study area extends from longitude 83^{0}47’50”E to 83^{0}58’11”E and latitude from 27^{0}40’2”N to 27^{0}44’55”N. The total area covered is 163 sq km. This area is bounded by the MBT in the North near Lame Damar, CCT in the South near Damargau, Mainaghat in the East and Bebake at the West.

The study area is easily accessible with the Motorable road through Prithivi Highway to Mugling and Mahendra Highway upto Arun Khola Baazar Nawalparasi district. The study area is located from 260 Km West from Kathmandu, takes about 6 hours travel by bus. Many gravelled road and earthen (seasonable road) make accessible the whole study area from Arun Khola Bazar and Dumkibas. Foot trails from Damargau to Lame Damar, Damargau – Dwari to Raikot, Dumkibas – Kudapani to Anikramh, Arun khola Gau – Rakachuli to Sardi and Rithapani- Bebake to Sardi and different river like Arun Khola, Binai Khola, Ramu Khola, Murali Khola, Khorsani Khola, Khorandi Khola and Sonai Khola make easy to cover the whole section of the study area. The Siwalik succession is well exposed in different river sections.

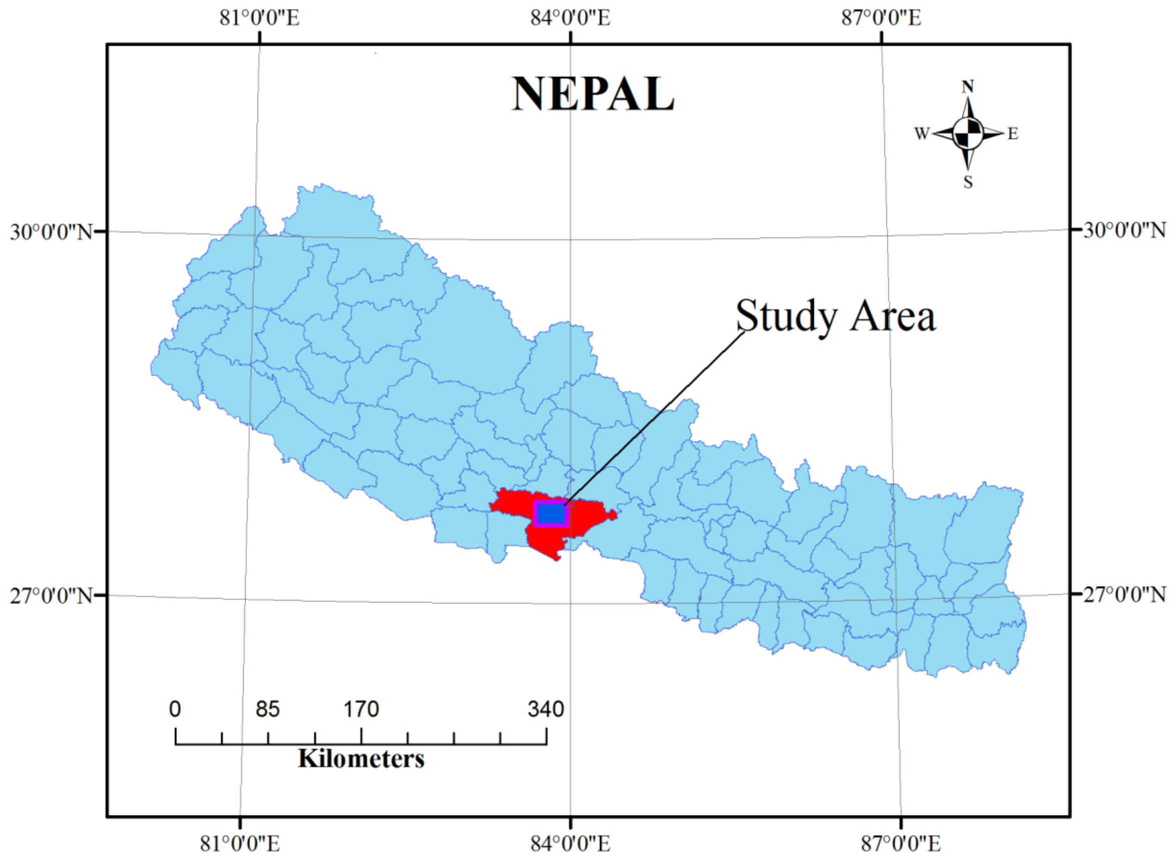


Figure 1: Location map of the study area.

1.4 Topography and Drainage

The topography of the study area ranges from 185 m at Arun Khola to 1208 m at Rakachuli above mean sea level (amsl). The South of the study area is gently sloped whereas the North is steeply sloped. Small dome like peaks are common in the MBT zone of the study area.

The area is drained by Narayani River from the South and other rivers Arun Khola and Binai Khola of second order, Murali Khola, Ramu Khola, Chyuribas Khola, Khorsani Khola, Sonai Khola of third order and Jilan Khola, Sadi Khola, Hemrali Khola Dharodi Khola of Forth order are present on the study area. Almost all rivers are perennial but due to large accumulation of the sediment the river percolate to some feet depth from surface during the dry season. The accumulation is very economical. The rivers are very distructive in rainy season. It carry large boulder also. Flood of 2070-04-07 damaged many houses, school, cultivated land on the bank of Arun Khola. Five people of same family with their domestic animals were killed during that flood. Overall drainages are of dendritic in nature.

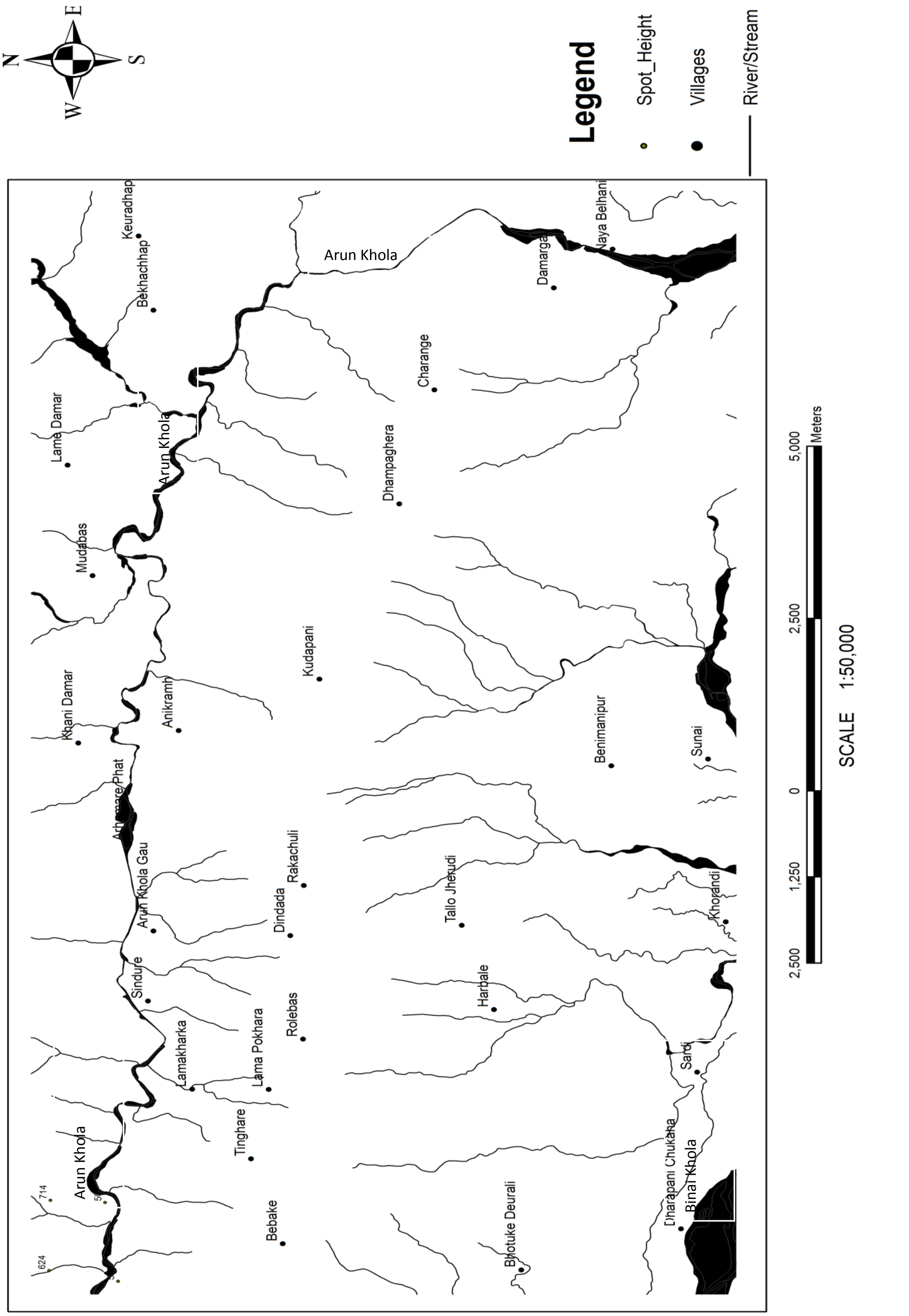


Figure 2: Drainage map of the Study area.

1.5 Climate

The climate of the study area is varied. In summer, the Southern part (around Arun Khola Bazar and Dumkibas) is terribly hot than that of Northern part. In the South there is long time fog coverage during winter with average temperature of about 6^0C but in summer the temperature is very high about 40^0C. The Northern part is more comfortable but strong wind is common on the hilly side (around Khudapani, Bebake, Rakachuli). Local houses are small and roof of the house are gentle slope facing toward the wind direction. The area get heavy rain fall in the monsoon time.

1.6 Land Use

The total land of study area is divided into main three types as settlement land, vegetated land and forest land. Forest land cover about 90% of the study area but deforestation for settlement and forest fire is main problem of that area. The population is dense at Arun Khola and Dumkibas area but sparse on the hillsides. Fertile and cultivated land located on the bank of Arun Khola is endangered from flood. The main crops cultivated in river terraces are paddy, wheat and potatoes. Steep terrain is covered with low productive land which is cultivated for millet, corn, mustard, and barley. Most of the people of that area are Magar. Agriculture and animal husbandry are main occupations of the study area. The cow, buffalo, pig and poultry are common household animals. Forest cover the geological exposure make difficult to collect the data from the ridges.

1.7 Limitation of the Study

The proposed area belongs to the Western Nepal around the Nawalparasi and Palpa District. That covers mainly the Sub-Himalaya. Preliminary investigation in this area was made by Tokuoka et al. (1986) but no detail geological map with multiproxy climate analysis has been found. The Topological map is also incomplete and many information is not included on this map which create problem for the field work. Recent flood of (2070-04-07) cover of the rock exposures on the bank of the rivers, the extreme hot weather conditions in summer and frequent forest fires are the main problems to carry out smooth field work in the study area.

CHAPTER II
LITERATURE REVIEW

The geological study of the Nepal Himalaya started systematically in 1950 but the earlier investigations did not receive much attention to the Siwalik Group of rocks as most of the geological researches were focused in the Lesser and Higher Himalayas because of their potentials to the mineral deposits. In last three decades many local and foreign scientists explored the Siwalik Group in Nepal in different expects. Since 1980, the Siwalik sediments started to get attention because of its fresh exposures along East-West Highway. The highway was under construction and running parallel to the Churia Range. Many freshly exposed Siwalik succession were unique open book for geoscientists to understand its lithostratigraphy, magnetostratigraphy and biostratigraphy collectively. The Siwalik Group is very important to study the paleo-climate changes after the collision of Indian sub-continent to the Eurasian continent in Eocene because the entire fauna and flora recorded in this group of rocks are good proxies to understand the evolution of monsoonal climatic system, denudation, weathering and upliftment of the Himalayan mountian range. The previous researches done by different sceintists in the Siwalik Group are listed below.

Auden (1935) is the first person to work on the Siwalik Group. He made the study at Udaypur Garhi–Anraha and Amlekhganj–Sonatar area and purposed the three fold classification of the Siwalik as Lower Siwalik (broun weathered sandstone and chocolate clays), Middle Siwalik (Thick bed of sandstone with feldspar and mica) and Upper Siwalik (dominated by conglomerate over sandstone and mudstone).

Bordet (1961) purposed the fining upward sequence of the Siwalik. He indicated the Siwalik of east Arun gorge significantly show the deposition of coarser to finer sediments from lower to upper portion of the cycle. Pebbly sandstone at the lower portion of the cycle and clay at the upper portion of the cycle. It is divided into the Lower, Middle and Upper Formations (Gansser, 1964)

Similarly, Hagen (1969) made study at various part of Nepalese Siwalik. He also follows the three fold classification as followed by Auden. Both of them purposed the name in according to the grain size variation. Fine grained sandstone and mudstone at the older formation and coarse grained up to boulder conglomerate at the top of the sequence.

Itihara et al. (1972) recognized the Siwalik into the Lower, Middle, Upper Formations on the basis of the grain size. Lower Formation is composed of fine grained sandstone. Middle Formation composed of pebble bearing sandstone and conglomerate and Upper Formation composed of massive boulder conglomerate.

Yoshida and Arita (1982) made study at the Surai Khola, Partakot, Badganga, Narayani River and Hetauda, Arung Khola area western Nepal (present study area). They also made three fold classifications as Lower, Middle and Upper Siwalik.

Sharma et al (1973) made study at Dang (Koilabas), Butwal, Amlekhganj sections and purposed the two fold classification of Siwalik sediments as the Lower Siwalik and Upper Siwalik according to the grain size and cementing material.

Walker (1975) made the study about flow type volume of the water current. Generally long axis of pebble is perpendicular to the flow direction is due to the clasts rolling on the bed, long axis is parallel to the flow direction in the case of conglomerate associate with sediment gravity flow or flash flow.

Chaudhari and Gill (1981) study the heavy mineral distribution in the sub Himalaya of the Nepal. According to them staurolite serve as important content of the Lower Siwalik, kyanite is of the Middle Siwalik and sillimanite is marker of the Upper Siwalik.

West and Munthe (1983) reported vertebrate fossils from the Dang area and correlated the Siwalik sediments from India and Pakistan. Munthe et al. (1983) discovered a fossil hominoid tooth from the Tinau Khola section in the west Nepal. This was a first hominoid recorded from Nepal. The palaeontological investigations from this research group have been recorded in their later publications in West et al. (1991) and West (1997).

Tokuoka et al. (1986, 1988, and 1990) studied the stratigraphy and geology of the Churia Group, Arung Khola section, west central Nepal. They named the rock unit as the Arung Khola Formation, Binai Khola Formation, Chitwan Formation and Deorali Formation in according to the grain size variation and proportion of mudstone and sandstone.

The litho-biostratigraphy of the Siwalik Group was massively studied by Corvinus (1988a, 1988b, 1990, 1993, and 1994) and Corvinus and Rimal (2001) in the Surai Khola section in the west Nepal and Rato Khola section in the eastern Nepal. They discovered many invertebrates, vertebrates and plant fossils and correlated the Siwalik Group of Nepal with that of the Siwalik Group from Potwar Basin in Pakistan. This biostratigraphic correlation established the age of the Siwalik Group in Nepal. Corvinus proposed fivefold classification of the Siwalik sediments from the Surai Khola section as the Bankas Formation, Chor Khola Formation, Surai Khola Formation, Dobata Formation and Dhan Khola Formations in the Surai Khola section. Gurung et al. (1998) studied the mollucan fossils from the same section of the Siwalik. Khosla et al. (1995) reported several species of fresh water Ostracoda from the Surai Khola section. Significant contributions towards the study of plant mega fossils were made in a series of studies made by Prasad (1990a, 1990b, 1994, and 1995), Prasad and Awasthi (1996), Prasad and Pradhan (1998), Prasad et al. (1997), Prasad et al. (1999), Konomatsu and Awasthi (1999), Prasad and Pandey (2008) from the Surai Khola, Koilabas, and Arung Khola-Binai Khola sections in the western Nepal. The palynological investigation from the Siwalik sediments in the Surai Khola section has been made by Sarkar (2000) and Hoorn et al. (2002).

Appel et al. (1991), Appel and Rosler (1994), Gautam and Appel (1994), Gautam and Pant (1996), Rosler et al. (1997), Roesler and Appel (1998), Gautam and Roesler (1999) studied the magnetostratigraphy of the Siwalik Group in Surai Khola, Arjun Khola, Amiliya-Tui and, Tinau Khola sections. Kafle et al. (1992) investigate the concordant volcanic dykes in the Lower Siwalik around Dwar Khola area in the central Nepal.

Hisatomi (1992) made the detail study of petrology and provenance of Siwalik Groups in the Arung Khola, Binai Khola area, west central Nepal. Based on the major composition of the sansstone of that area were divided into three groups as Lower Member of the Arung Khola and Middle Member of the Arung Khola belongs to the quartzose arenite, Upper member of the Arung Khola Formation intermediate composition and the Binai Khola Formation abundance of the lithic fragments.

Sah et al. (1994) recorded vertebrate fossils from the Siwalik succession on the Rato Khola section. They purposed the Khairani Formation, Maithan Formation, Patu Formation, Gwang Khola Formation, Gauridada Formation, Bhiman Formation in the descending order of the age. These formations are of coarsening up sequence with fining up cycles mainly composed of alternate beds of mudstone, sandstone and conglomerate. They studied vertebrate fossils include two molars and fragmentary limb bone of an extinct elephants from the Patu Formation.

Sah et al. (1994) classified the Siwalik in the Hetauda-Amlekhganj section as the Rapti Formation, Amlekhganj Formation, Churia Khola Formation and Churia Mai Formation according to proportional and grain size variation. Sah et al.(1995) studied lithostratigraphy of the the Katari area Eastern Nepal and they purposed the fivefold classification as Katari Formation (Quartz arenite and mottled), Kakaru Formation (Ripple marks crossbedded massive sandstone), Ghurmi Formation (Lithicto Arkosis sandstone), Belsoth Formation (micaceous sandstone and mudstone), Garasa Formation (pebbly– gravelly clast supported Conglomerate) and Tribeni Formation (conglomerate of highly compacted, rounded to sub-rounded clast of marble, quartz, granite, limestone)in descending order. These Formations are of the age middle Miocene to early Pleistocene. A very well marked unconformity separates the Siwalik rocks from the older Lesser Himalayan rocks.

Dhital et al. (1995) studied of geology and structure of Siwalik and Lesser Himalayan around Surai Khola–Baradanda area of Mid-western Nepal and followed the fivefold classification as proposed by Corvinus (1988a, 1988b, 1990, 1993, and 1994). They classified the Siwaliks as Bankas Formation, Chor Khola Formation, Surai Khola, Formation, Dobata Formation and Dhan Khola Formations from older to younger formation. Adhikari and Rimal (1996) worked on the lithostratigraphy of the Bagmati River region and established lithostratigraphy as Lower Siwalik, Middle Siwalik and Upper Siwalik in according to the grain size and compositional variation.

Ulak and Nakayama (1998) extended the work done by Sah et al. (1994) to the further east to the Bakiya Khola section. Their study mainly focused on the evolution of fluvial style of the Siwalik Group and purposes the eight facies F1 to F8. According to them F1 and F2 indicate fine grained meandering system, F3, F4, F5 indicate flood flow dominated sandy meandering, deep sandy meandering and sallow braided system respectively. F6 is not seen in Hetauda section. F7 and F8 gravelly braided river system and debris flood flow dominated braided river system.

Gautam and Rosler (1999) studied depositional chronology and fabric of the Siwalik Group sediments in central Nepal from magnetostratigraphy and magnetic anisotropy of sandstones. Gautam and Fujiwara (2000), Gautam et al. (2000) studied magentostratigraphy of the Siwalik rocks from Karnali River section west Nepal. They established time frame of the Siwalik sediments from respective sections on the basis of magnetic polarity reversals. The palaeomagnetic study of the Siwalik Group is massively done in the many river sections in the west Nepal. Such study from the eastern part of the Siwalik Group is still lacking. Paleomagnetic Studies of the Bakiya Khola section, central Nepal was carried out by Harrison et al. (1993). They establish the depositional age of Siwalik is in between 4.9 Ma to 11.2 Ma. They also noted that the high sedimentation rate in between 0.1 and 1.5 mm/yr in cyclic order with the period between 1.5 Ma and 400000 years. Nakayama and Ulak (1999) studiedd evolution of fluvial style in the Siwalik Group in the foothills of the Nepal Himalaya and they conclude as the overall coarsening sequence with individual fining up cycle in Hetauda Amlekhjung area. Gautam et al. (2012) measured the magnetostratigraphic dating of the prime-time sedimentary record of Himalayan tectonics and climate for new age constraints (13–10 Ma) from the Siwaliks of the Tinau Khola north of CCT.

Dahal et al. (2000) studied fresh water ostracods from the Siwalik succession of the Butwal area, western Nepal and noted twelve fresh water Ostracodes (*Cypris, Herpetocypris, Candonopsis, Ilyocypris, Darwinula* etc.) species from fossiliferous bed of the Siwalik in the Butwal area. Samples containing of almost all closed carapaces indicate the rapid rate of sedimentation in reducing sedimentary environment. Tamrakar and Khakurel (2001) studied sand balls, mud ball and armored mud balls observed from the Siwalik Group along the Churia Khola, Amlekhgunj, central Nepal and suggests that the physical and mechanical properties of sandstones are depending on their degree of cementation rather than their ages of deposition. Petroleum Exploration Promotion project, Department of Mines and Geology (2001, 2002) made a detail map of the Sub-Himalaya, central Nepal. Tamrakar et al. (2002) reported toppled structure with sliding in the Siwalik Hills, midwestern Nepal. Pradhan and Sharma (2003) made the Palynological study of pre-Siwalik rocks of Sub Himalaya Bagmati Marin Khola central Nepal. The pollen and Spore of age Oligocene to Miocene were reported from this unit. Tamrakar and Khakurel (2012) further elaborated the Lithologic and morphometric characteristics of the Chure River Basin. The drainage evolution pattern in the Chure Khola Basin is discussed in their paper.

Sigdel et al. (2011) made lithostratigraphic study of the Siwalik Group, Karnali River section, Far-west Nepal Himalaya. In this study the stratigraphy of an almost complete succession of the Siwalik Group was studied in the Karnali River section. The Siwalik Group in this section consists of the Chisapani, Baka, Kuine, and Panikhola Gaun Formations, in ascending order, all newly defined in this study. The Chisapani Formation is equivalent to the Lower Siwalik, and is dominated by mudstone. It is subdivided into lower, middle, and upper members. The Baka Formation corresponds to the Middle Siwalik, and is characterized by “salt and pepper” sandstone. The Baka Formation is also subdivided into the lower, middle, and upper members. The Kuine and Panikhola Gaun Formations together correspond to the Upper Siwaliks. The Kuine Formation is characterized by well-sorted and imbricated pebble to cobble conglomerates, whereas the overlying Panikhola Gaun Formation consists of poorly sorted, matrix-supported boulder conglomerates. They also made petrographic study on that area (Sigdel et.al 2013).

Paudayal (2012, 2013a) made a detailed palynological study from the Siwalik sediments (Karnali River Section) Far western Nepal to find the paleovegetation evolution in Siwalik. On the basis of palynological assemblages he reported tropical to subtropical climate during the deposition of Siwalik sediments in the Karnali River section. He also made the detailed palynogical study in Dudhaura Khola section, eastern Nepal and reported many tropical to subtropical vegetation growing in that area during the deposition of Siwalik sediments (Paudayal 2013b).

CHAPTER III
MATERIALS AND METHODS

The geological study of an area needs a series of field investigations and laboratory experiments. Several methods adapted for this research are summarized in detail in the following sections.

3.1 Desk Study

Topographic map and Aerial Photographs, published and unpublished reports, literatures, journals, bulletins, and thesis related to the present study were collected from different sources and reviewed. The necessary data were also collected from internet sources. Toposheet maps of scale 1:25000 are used for making geological details of the study area.

3.2 Field work

The field work of 25 days was carried for dissertation. The work is divided into first phase (Poush 27- Magh 13, 2069 B. S) reconaissance field work and second phase of verification field visit (Chaitra 2070 B. S). Different routes were selected to cover the whole study area. The routes covered during the filed works were Arun Khola section, Damar Gau to Dwari, Dwari to Raikote, Dumkibas to Kudapani along the Khorsani Khola, Khudapani to Anikram, Arun Khola Gau to Rakachuli, Rakachuli to Tallo Jelludi, Rithapani – Bebake to Sardi. During the field visits data were collected for geological map, sample collected for petrological and pollen analysis, columnar sections were prepared, and data for paleocurrent analysis were collected. Important sedimentary feature, photographs, structural and tectonic features were also noted during the field work along the field routes. Along with this, all other poosible data were collected to prepare the final dissertation.

3.3 Laboratory work

Lab work for petrological and palynological samples were performed separately during the dissertation preparation.

3.3.1 Laboratory work for petrological samples

Laboratory work and study for petrological sample were done at the laboratory of Central Department of Geology Kirtipur, Kathmandu which is well equipped and facilitated for petrological study. In total 10 petrological samples were prepared. For this the samples were cut into slices in rock cutter to make small pieces. The samples were then smoothed by rubbing on the grit of different coarseness then dried on heater to remove water bubble.

After this process the sample were glued on the glass slide (size, 3cm × 8cm) and allowed a day for good setting. After this sample again cut in the small rock cutter and make easy to rub the slide. The slide were rubbed on the grit of decreasing grain size (200, 400, 600, 800, 1000, 1200 and then in water) and until it becomes the thickness of about 0.032 mm and finally observed mineral presence on petrological microscope.

3.3.2 Laboratory work for palynological samples

The palynological samples were prepared at the laboratory of Central Department of Geology Kirtipur, Kathmandu which is well equipped and facilitated for palynological sample preparation and study. The palynological samples need a series of chemical treatment to extract the organic residue from the inorganic fraction. The experiment is described below.

a. Grinding the sample in mortar to make a fine powder.

b. Boiled the sample in Conc. HCl for few minute to remove presence of carbonate.

c. Kept the sample in Conc. Hydrofluoric acid (HF) in a polyethylene beaker for 2-3 days to remove silicates.

d. Sample Transfer to the large polyethylene beaker containing 3-4 liters of water to wash the excess of HF.

e. Sample boiled with Conc. HCl to remove fluorite.

f. Collection of organic residue, washing with water and centrifuging in 2000 rpm (rotations per minute)

g. Chlorination: The sample was treated with a freshly prepared saturated solution of $KClO_3$ and immerses the sample in hot water bath for 5 minutes.

h. Wash with water and glacical acetic acid two times.

i. Acetolysis: The sample was treated with the mixture of nine part acetic anhydride and one part of sulphuric acid.

j. Hot water bath (keeping the sample in boiling water for 10 to 15 minutes)

k. Washing of sample with acetic acid after acetolysis

l. Treatment with the heavy liquid ($ZnCl_2$ with specific gravity ~ 2.0 and water at the top).

m. Centrifuging the sample to 3000 rpm for 30 minutes to separate the organic matter with its inorganic matter.

n. Extract the organic residue in glycerin for microscopic examination.

o. Permanent slide are made with glycerin jelly.

3.3.3 Light Microscopy (LM)

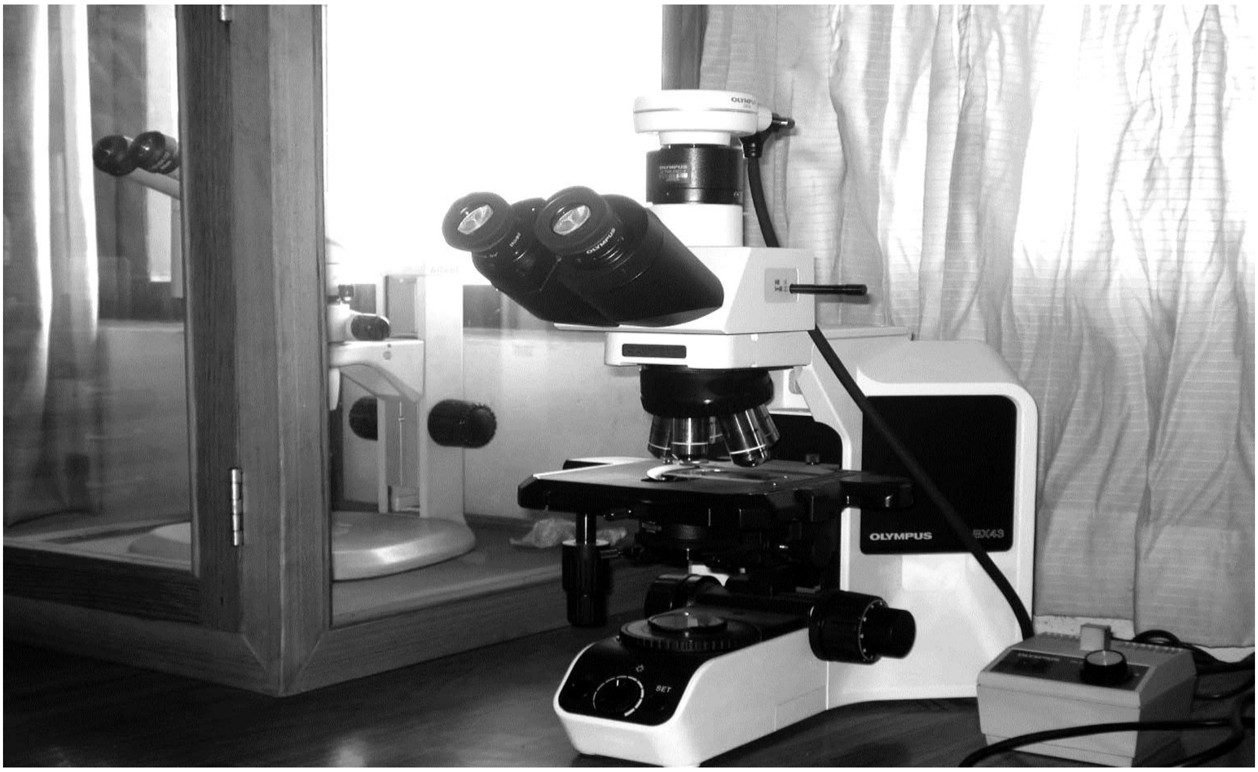


Figure 3: Olympus BX43 microscope for light microscopyfor pollen study.

The organic matter which obtained after complex process is collected in the closed glass tube with plastic lid in glycerine to form the free suspension of pollen. For the analysis the sample was transferred to the glass slide with pipette and distributed uniformly in the glass slide and examine under the OLYMPUS BX-43 Light Microscope under 10x, 40x or 60x objectives with moving uniformly throughout the section to observe and count the pollen grain. Photographs also take from the light Microscopy with pollen at the proper position.
The pollen was kept in such a way that it does not float or sink completely in the glycerin. With the help of a needle the pollen was oriented either in polar or equatorial view or to a required position. The optic section of the pollen grain was focused to take the photograph.

The light microscope (LM) photograph was taken with an OLYMPUS digital camera mounted on OLYMPUS BX-43 microscope (Figure: 3). Photographs were taken at 60x with the help of computer OLYMPUS DP2 software.

4.3.3.1 Chlorination

The sample was treated with a freshly prepared saturated solution of Potassium chlorate, ($KClO_3$ ca. 3 cm in test tube), glacial acetic acid (ca. 1.5 cm in test tube) and a few drops of conc. Hydrochloric acid (HCl). The test tube containing the mixture was stirred with a glass rod and placed in a beaker with boiling water in an upright position for five minutes. Frequent stirring was needed to prevent the overflow of the boiling mixture. The test tube was then removed from the hot water bath and allowed to cool before it was centrifuged at 2000 rpm for 2 minutes and decanted. In order to free the sample of any remaining chemicals sample was washed with water and centrifuged three times. It was also washed with glacial acetic acid twice to remove the water prior to acetolysis.

4.3.3.2 Acetolysis

Acetolysis solution was made by mixing nine parts of acetic anhydrite and one part on conc. H_2SO_4 (Erdtman 1954) under strict precaution. The mixture is highly corrosive and explosive if it comes into contact with water. The sample was then treated with the acetolysis solution and placed in a hot water bath for five minutes. The color of the mixture turns brown during this treatment. The sample was removed from the bath and allowed to cool before centrifuging and decanting the liquid fraction. The residue was washed and centrifuged once with glacial acetic acid and three times with water. About 2 cm of heavy liquid ($ZnCl_2$) was added to the test tube containing the residue. This step was followed by adding water with a help of a glass rod making sure that these two liquid do not mix. On centrifuging it at 3000 rpm for one minute a layer of organic suspension at the boundary of the heavy liquid and the water appeared which was transferred gently to a clean test tube leaving the mineral particles and liquid behind. The organic matter thus extracted was washed in water twice and mixed with glycerin and ready for microscopic study.

3.3.4 Data Analysis

Pebble orientation data which were collected from field were proceed for the statistical analysis of paleocurrent from the stereographic projection and vector magnitude method.

The vector mean gives the paleocurrent direction and magnitude gives the flow consistency.

For vector mean $V_{mean} = Tan^{-1} (\sum Sin\ \theta \ / \sum Cos\ \theta)$

Where θ is the azimuth angle made by each pole of pebble after tilt correction, which is done for the structurally tilt of the strata exceeding 10^0 (Potter and Pettijhon, 1963).

For Vector Magnitude $R = \sqrt{\sum(Sin\theta)^2 \ + \ \sum(Cos\ \theta)^2}$

Generally R is express as percentage as $\frac{R}{n} \times 100 = \sqrt{\sum(Sin\theta)^2 \ + \ \sum(Cos\ \theta)^2} \ \times \frac{100}{\mathrm{n}}$

Where n is number of poles.

Vector mean is the expression for the perfect orientation of the pebble which also depends upon the flow type volume of the water current. Generally, long axis of pebble is perpendicular to the flow direction is due to the clasts rolling on the bed, long axis is parallel to the flow direction in the case of conglomerate associate with sediment gravity flow or flash flow (Walker 1975).

3.3.5 Data processing, Interpretation and Report Preparation

All the data and information which were collected from the desk study, field study, and laboratory work were analyzed and provide some interpretation of the result. Columnar section of each member were prepared in the scale of 1:50 scale by using computer software Corel Draw, geological map and cross-section were prepared in the ArcGIS 9.3 and AutoCAD. The tabulated data of paleocurrent were presented and processed in Microsoft Excel. The photos were processed in the Adobe Photoshop. Ten samples were studied for mineral and grain size variation in the petrological microscope. Three palynological samples were studied with BX 43 biological microscope at Central Department of Geology, Tribhuvan University. Using light microscope, photomicrographs were taken at the magnification of x600. Palynological terminologies were used following the description made by Punt et al. (2007). The finding of that study will be describe and documented in the upcoming chapter.

CHAPTER IV
RESULTS

Nepal Himalaya covers about one third of the total 2400 Km of the greater Himalayan Range. It is separated by Mechi River in the East with Darjeeling at 26^{0}22’ N, 80^{0}04’ E and Mahakali River in the West with India at 30^{0}27’ N, 88^{0}12’ E. Geometrically it forms the shape like elongate rectangle with average East-West axial length 885 Km and varying width of 130 – 225 Km (Gansser 1964 , Hagen 1969) from South to North.

4.1 Major tectonic zone of the Nepal Himalaya

Tectonically, the Nepal Himalaya is divided into five tectonic divisions. From South to North they can be listed as; Terai Zone, Sub-Himalaya Zone, Lesser Himalaya Zone, Higher Himalaya Zone, and Tibetan Tethys Zone. (Gansser 1964; Hagen 1969).

Tibetan Tethys Zone

-------------------- STDS --------------------

Higher Himalaya Zone

-------------------- MCT--------------------

Lesser Himalaya Zone

--------------------MBT --------------------

Sub Himalaya Zone

--------------------HFT--------------------

Terai Zone

South to North (↑)

The Higher Himalaya is separated by the normal faulting South Tibetan Detachment Zone (STDS) from the Tibetan Sedimentary Series above, and by the Main Central Thrust (MCT) from the Lesser Himalaya below. South of the Lesser Himalaya lies the Sub-Himalaya, separated from the Lesser Himalaya by the Main Boundary Thrust (MBT). The Sub-Himalaya is separated from Indo-Gangetic Plain by the Himlayan Frontal Thrust (HFT). The tectonic zones are nearly parallel and are characterized by their lithology and stratigraphy, tectonics, structure and geological history (Fig. 4).

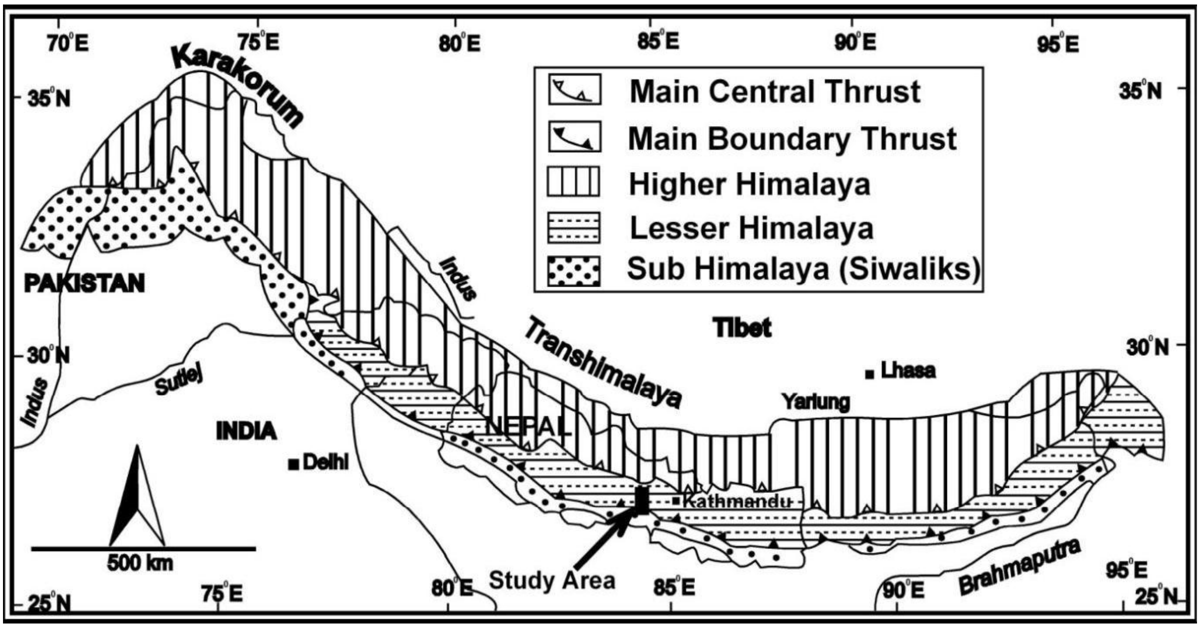


Figure 4: Simplified Geological Map of the Nepal Himalaya showing major litho-tectonic division (After Gansser, 1964).

4.2 Regional Geology of the adjacent area

Many researchers studied the Siwaliks of the West Nepal and the adjacent of the study area. They classified the rock unit of the Siwalik Group based on the lithological characters into three units as the Lower, Middle and Upper Siwaliks (Auden 1935; Gansser 1965; Nakajime 1982, Tokuoka et al., 1986, 1988, 1990).

4.2.1 Siwalik in the Eastern Nepal

Shrestha and Sharma (1996), Sah et al. (1994, 1995) studied Katari and Rato Khola sections and prepared the detail map of the area. According to them Pre-Siwalik rock occur in the form of thrust bound slices and extended over 50 km along NE- SW direction. Sah et al. (1994) divided the rock of Katari and Rato Khola area in six different units according to their physical properties (Table: 1). Ulak (2004) in the Chatara area and Ulak (2006) Kamalai Raver.

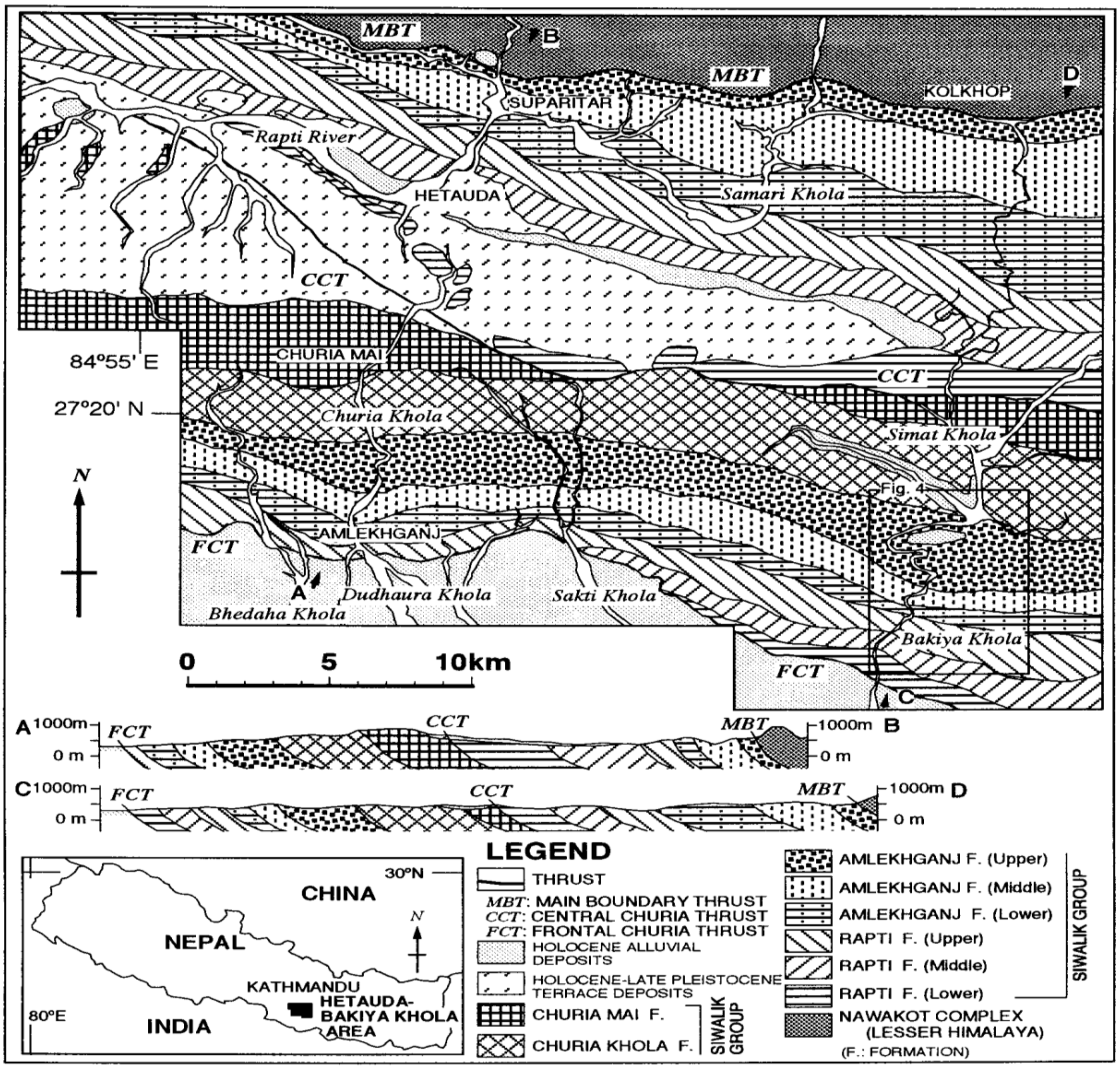


Figure 5: Geological map of the central Nepal after Ulak and Nakayama (1999).

4.2.2 Siwalik in the Central Nepal

Sah et al. (1994), Ulak and Nakayama (1999) established lithostratigraphy of the Siwalik in the Hetauda - Bakiya Khola section Central Nepal. They divided the rock unit of that area as Rapti Formation, Amlekhganj Formation, Churia Khola Formation and Churia Mai Formation. They also divided Rapti and Amlekhganj Formations into Lower, Middle and Upper Member respectively. The CCT separates the whole Siwalik into Southern belt and Northern belt. In most of the sections the Rapti Formation and Amlekhganj Formations are exposed in the Northern belt. Adhikari and Rimal (1996) worked and established lithostratigraphy of the Bagmati River region as the Lower, Middle and Upper Siwaliks. Petroleum Exploration Promotion Project, Department of Mines and Geology (2001 and 2002) made a detail survey of the Sub-Himalaya, Central Nepal. They divided the rock unit into the Siwalik and Pre-Siwalik Group. The Siwalik Group is further divided into Lower, Middle and Upper Siwalik Formation. The Middle Siwalik is further divided into lower middle Siwalik and upper Middle Siwalik members. The Lower Siwalik is fine grained sandstone interbedded with greenish grey to red purple mudstone. The Lower Middle Siwalik (MS1) consists of fine grained sandstone with siltstone, red coloured shale, mudstone and marl. The upper member of Middle Siwalik (MS2) consists of medium to coarse grained sandstone, subordinate with the siltstone and mudstone. The Upper Siwalik composes of pebble to boulder conglomerate interbedding with greenish grey mudstone. Red to buff coloured mudstone is common in Upper Siwalik indicating paleosolhorizons.

4.2.3 Siwalik in the Western Nepal.

Siwaliks in the Western Nepal was studied by Zigler (1964), Itihara et al. (1972), West et al. (1983), Herail et al. (1986), Corvinus (1988), Geological mapping also have performed by Department of Mines and Geology of Nepal. Tokuoka et al. (1986, 1988 and 1990) studied the Siwalik Group of rocks in Central Nepal along Arung Khola, Binai Khola, Tinau Khola, Dumkibas and Narayani River sections. They proposed the whole lithostratigraphy into four successive rock units as the Arung Khola Formation, Binai Khola Formation, Chitwan Formation and Deorali Formation from older to younger. The two lowermost formations are again subdivided into the lower, middle, upper members respectively according to the grain size variation and change of mudstone and sandstone proportion. The Chitwan and Deorali Formations are composed of conglomerates. The well lithified matrix supported pebbly conglomerate is found in the Chitwan Formation. Angular to sub angular clast of mudstone and sandstone dominated conglomerate is found the topmost Deorali Formation. By using magnetostratigraphy this four-fold classification is correlated with three fold classification of the adjacent area by Gautam and Rosler (1999). On the basis of lithostratigraphy and sedimentological characters Sigdel et al. (2011) divided the rock of the Karnali River section, Far Western Nepal as the Chisapani Formation, Baka Formation, Kuine Fromation, Pani Khola Gau Formations in ascending order. The Chisapani Formation is equivalent to the Lower Siwalik, Baka Formation is equivalent to the Middle Siwalik. The Kuine Formation compese of clast supported conglomerate and Pani Khola Gau Formation consist of matrix supported boulder conglomerates.

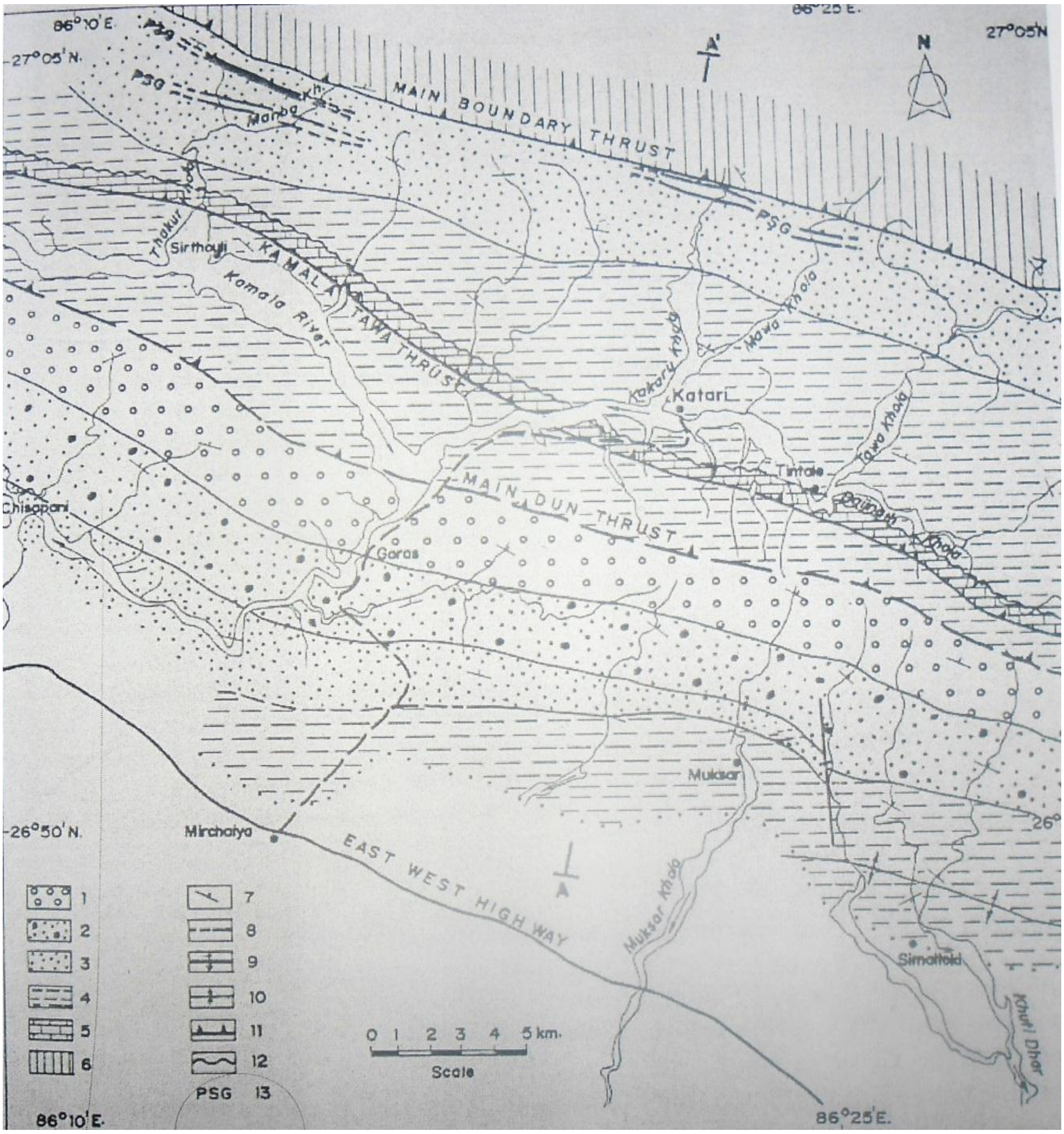


Figure 6: Geological Map of the Eastern Nepal (after Sharma and Shrestha, 1996).

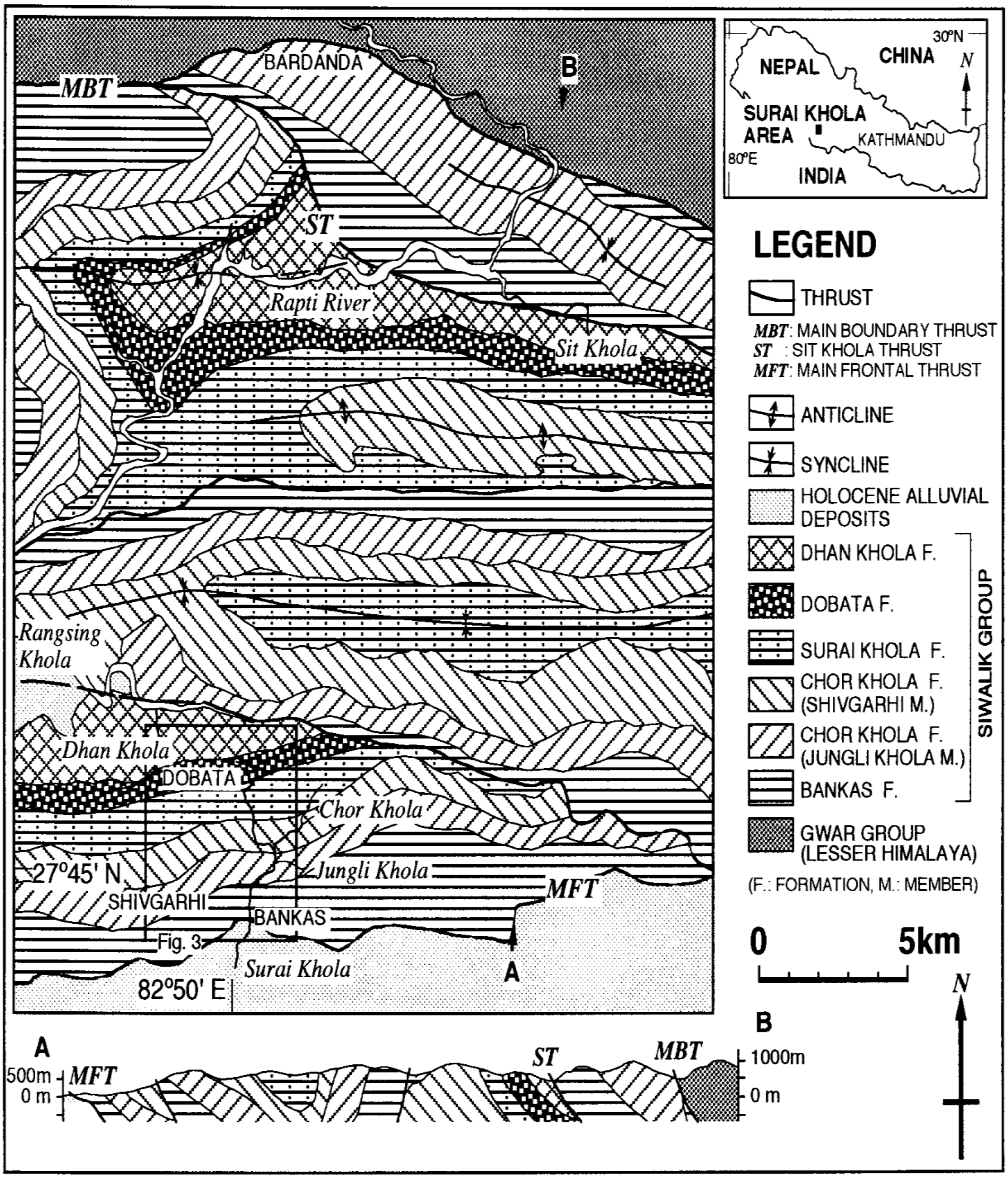


Figure 7: Geological map of western Nepal (after Dhital et al. 1995) Surai Khola area.

Table 1: Correlation of the Siwalk Group of rocks from the different parts of Nepal.

<table>
<tr><th>Auden 1935 *(1)</th><th>Glenne & Zielgler 1964 (2)</th><th>Hagen 1969 (3)</th><th>Sharma 1973 (4)</th><th>Yoshida & Arita 1982 (5)</th><th>Present study area Tokuoka et al. 1986 **</th><th>Sah et al. 1994 (6)</th><th>Corvinus & Nanda 1994 And Dhital et al.1995 (7)</th><th>Sah et al. 1995 (8)</th><th>Sah et al. (1994)
Ulak & Nakayama (1998) (9)</th></tr>
<tr><td rowspan="4">Upper Siwalik</td><td rowspan="7">Conglomerate Facies</td><td rowspan="4">Upper Siwalik</td><td rowspan="7">Upper Churia Group</td><td rowspan="4">Upper Siwalik</td><td rowspan="2">Deorali Fm</td><td rowspan="2">Bhiman Fm</td><td rowspan="3">Dhan Khola Fm</td><td rowspan="2">Tribeni Fm</td><td>Churia Mai Fm</td></tr>
<tr><td rowspan="2">Churia Khola Fm</td></tr>
<tr><td rowspan="2">Chitwan Fm</td><td rowspan="2">Gauridada Fm</td><td rowspan="2">Garasa Fm</td></tr>
<tr><td rowspan="2">Dobata Fm</td><td rowspan="5">Amlekhganj Fm</td></tr>
<tr><td rowspan="6">Middle Siwalik</td><td rowspan="6">Middle Siwalik</td><td rowspan="6">Middle Siwalik</td><td rowspan="5">Binai Khola Fm</td><td rowspan="2">Gwang Khola Fm</td><td rowspan="2">Belsoth Fm</td></tr>
<tr><td rowspan="4">Surai Khola</td></tr>
<tr><td rowspan="3">Patu Fm</td><td rowspan="3">Ghurmi Fm</td></tr>
<tr><td rowspan="6">Sandstone Facies</td><td rowspan="6">Lower Churia Group</td></tr>
<tr><td rowspan="5">Rapti Fm</td></tr>
<tr><td rowspan="4">Arung Khola Fm</td><td rowspan="3">Maithan Fm</td><td rowspan="3">Chor Khola</td><td rowspan="2">Kakaru Fm</td></tr>
<tr><td rowspan="3">Lower Siwalik</td><td rowspan="3">Lower Siwalik</td><td rowspan="3">Lower Siwalik</td></tr>
<tr><td rowspan="2">Katari Fm</td></tr>
<tr><td>Khairani Fm</td><td>Bankas Fm</td></tr>
</table>

*Note (1): Udaypur Garhi–Anraha and Amlekhganj–Sonatar area, (2): Kali Ganga Sarada River, Karnali Taptakunda Koilabas, Butwal, Kali Gandaki, Amlekhganj-Hetauda and Sapta Koshi areas, (3): Various part of Nepalese Siwalik, (4): Dang Koilabas, Butwal, Amlekhganj sections, (5): Surai Khola, Partakot, Babganga, Narayani River and Hetauda (**) Arung Khola area Western Nepal (Present suudy area), (6): Rato Khola area Eastern Nepal, (7) Hetauda-Amlekhganj area, (8) Katari Section Eastern Nepal, (9): Bakiya khola area Hetauda central Nepal.

4.3 Geology of the study area

4.3.1 Introduction

In the Western Nepal the Siwalik Group divided into two belts by a thrust fault known as the Central Churia Thrust or CCT as Northen Belt and Southern Belt. The study area lies on the Northern Belt which extends upto Main Boundary Thrust (MBT) in the North to the CCT in the South. It consists of only two formations as the Arung Khola Formation and Binai Khola Formation. Chitwan and Deorali Formation lies on the South of CCT. The two formations are well exposed along the Arun Khola and Murali Khola section of the study area. CCT is passing around from Damargaun which bring the rock unit of older sequence Arung Khola Formation above the younger sequence of Chitwan and Deorali Formations. The previous researcher Tokuoka et al. (1986) made the preliminary study of the area and correlated with other parts of the Siwalik. The detail descriptions of individual formation and its members are described below.

4.3.2 Arung Khola Formation

In the Northern belt of CCT the Arung Khola Formation extends adjacent to the CCT above the Chitwan Formation in the Arun Khola area and above the Deorali Formation in Binai Khola section. According the grain size, chemical composition and mudstone-sandstone proportion, the Arung Khola Formation is further divided into three members as lower, middle, upper members. These members are easily distinguishable in the field as well as in petrographical studies.

4.3.2.1 Lower Member of Arung Khola Formation (Al)

The Al member is well exposed along the Arun Khola around Damargau, Khorsani Khola, Khorandi Khola and on the way from Bebake to Sardi. It consists of alternating bed of fine grained grey coloured, calcareous sandstone (10-50 cm) with greenish grey to red purple variegated mudstone (50-100 cm). The mudstone proportion is larger than that of sandstone on this member. The total thickness of this member is about 640 m. Some marl beds also noted during the field study along the Arun Khola section. Motteled mudstone and small lenticels of coal (4 cm) was also recorded. Parallel lamination, large scale trough cross lamination small scale current ripple lamination is frequent in the sandstone beds. The figure 8 shows the detail lithology of this member. The photo micrograph of thin section is also as in figure 11 which shows fine grained sandstone with some lithic fragments

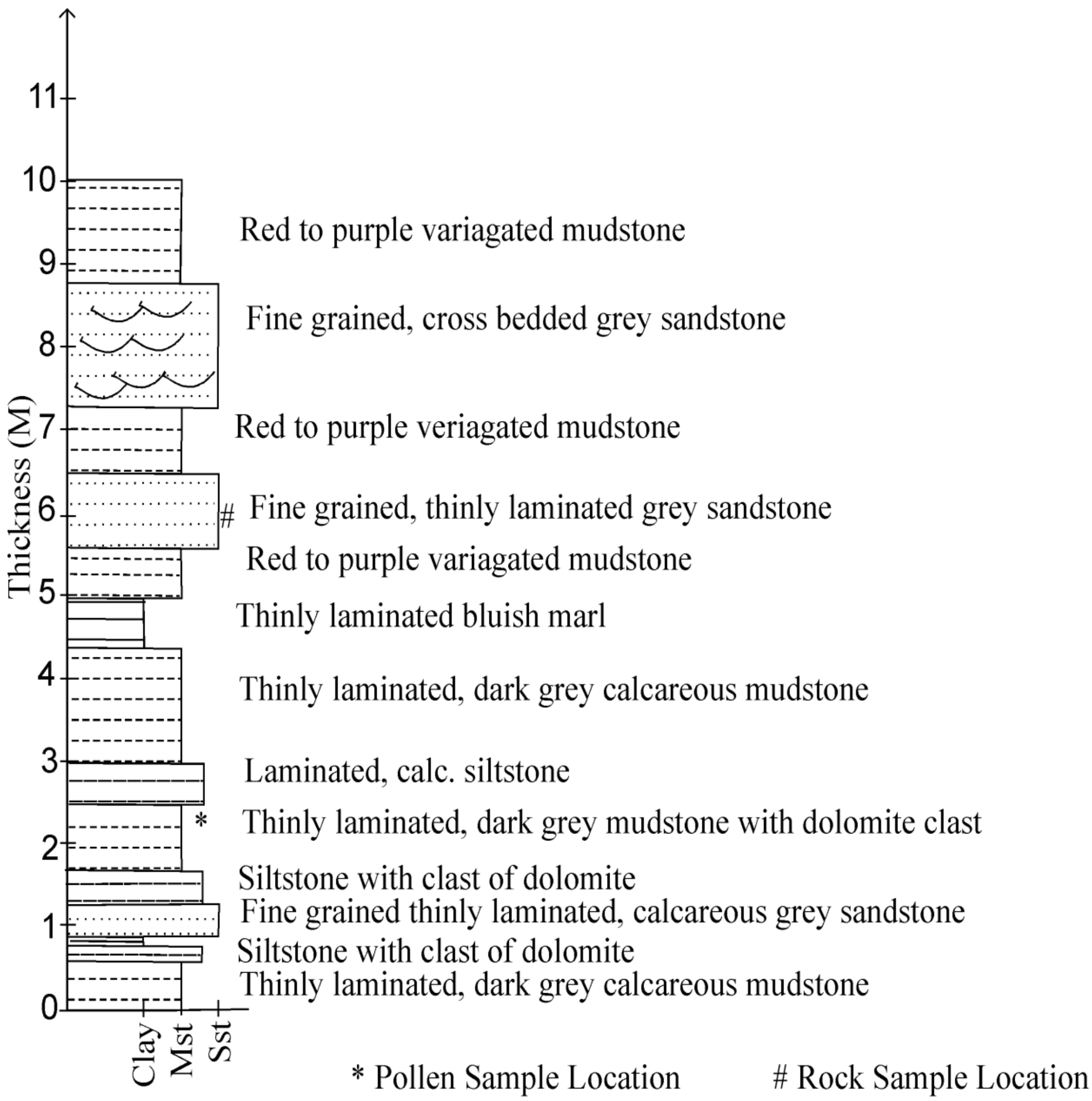


Figure 8: Detail Columnar Section of the Lower Member of the Arung Khola Formation below the Suspension Bridge from Damar Gau to Charange.

4.3.2.2 Middle Member of Arung KholaFormation (Am)

This member is also well exposed along the Arun Khola, Khorandi Khola, Khorsani Khola, Dharodi Khola section of the Northen belt. This member is rich in sandstone than that of Al member and proportion of mudstone and sandstone is almost equal. It has the total thickness of 850 m. Mudstone is often variegated and sandstone (0.5-3 m) is fine grained and calcareous. Small scale cross laminations, ripple marks are frequent in this member. The figure 9 shows the detail lithology of this member. The photomicrograph of thin section is also as in figures 12, the grain size of sandstone also increased. Fining up cycle of grain size on the individual bed/lamination is well noticeable.

4.3.2.3 Upper Member of Arung Khola Formation (Au)

The Au member is well exposed some meter downstream from the confluence of Arun Khola and Ramu Khola along the Arun Khola, Rakachuli village and also on the way from Raikote to Dwari. This member consists of coarse grained biotite rich sandstone (1-2 m in thickeness) with small amount of mudstone alteration. Small trough cross laminations parallel laminations, ripple cross laminations and planar cross laminations were also observed. Mudstone is sometimes variegated. The total thickness of this formation is 600m. Molluscan fossil were also noted from this member. The figure 10 shows the detail lithological character of this member. The photomicrograph of thin section of the sample is as in figure 15.

4.3.3 Binai Khola Formation

This formation is extended upto the MBT in the Northern belt in Arung Khola area. This is primarily consists of the massive sandstone, salt and pepper sandstone, pebbly sandstone and some conglomerate. The amount of mudstone is very less on this formation. This is the footwall of the MBT in the Arun Khola area. This formation is also divided in three members as the lower, middle, upper according to the sandstone properties and thickness of the conglomerate.

4.3.3.1 Lower Member of the Binai KholaFormation (Bl)

The exposure consists of alternating sequencs of thick bedded pepper and salt type sandstone (several meters in thickness), fine sandstone and thin beds of siltstone. Sometime pebble bearing sandstone and comnglomerate (upto 1 m in thickness) also observed. Sandy limestone and calcareous sandstone were also present on this member. The total thickness of this member is about 1000 m. This is well exposed along the Ramu

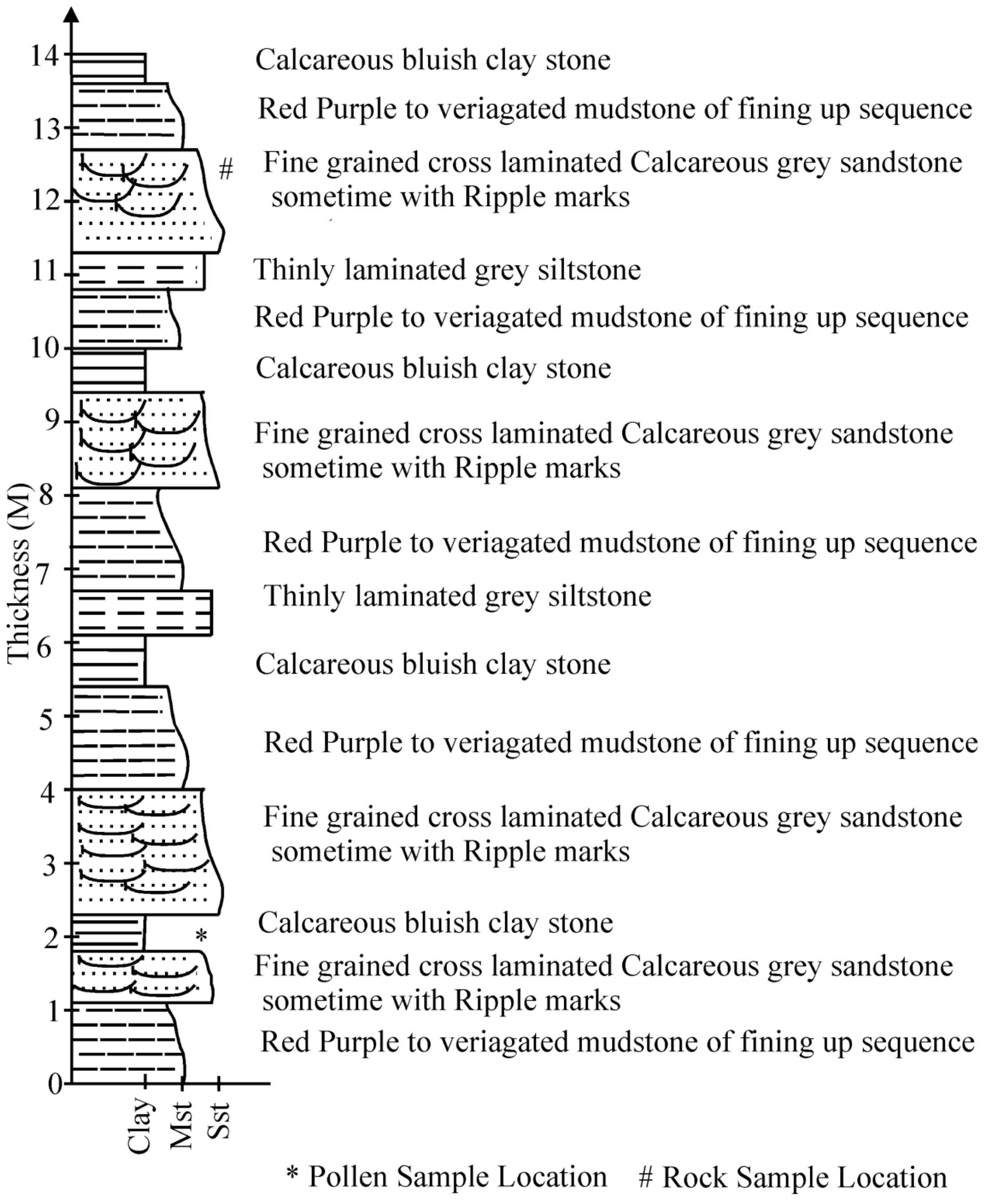


Figure 9 : Detail Columnar Section of the Middle Member of the Arung Khola Formation about 500 m upstream from Damargaun at the height of 250m AMSL.

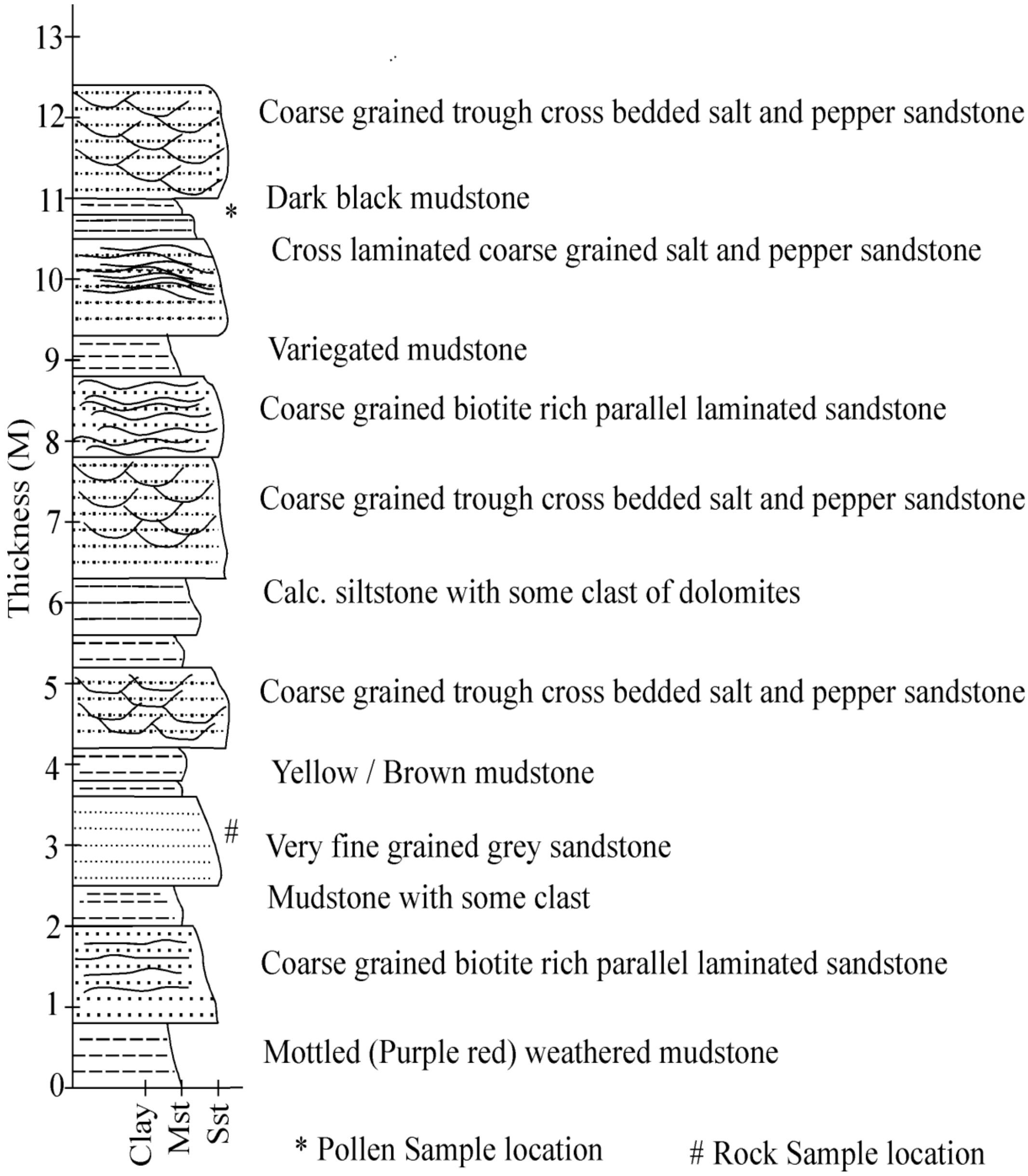


Figure 10: Columnar section near Khudapani Village on the way from Khudapani to Anikram Upper Member of Arung Khola Formation.

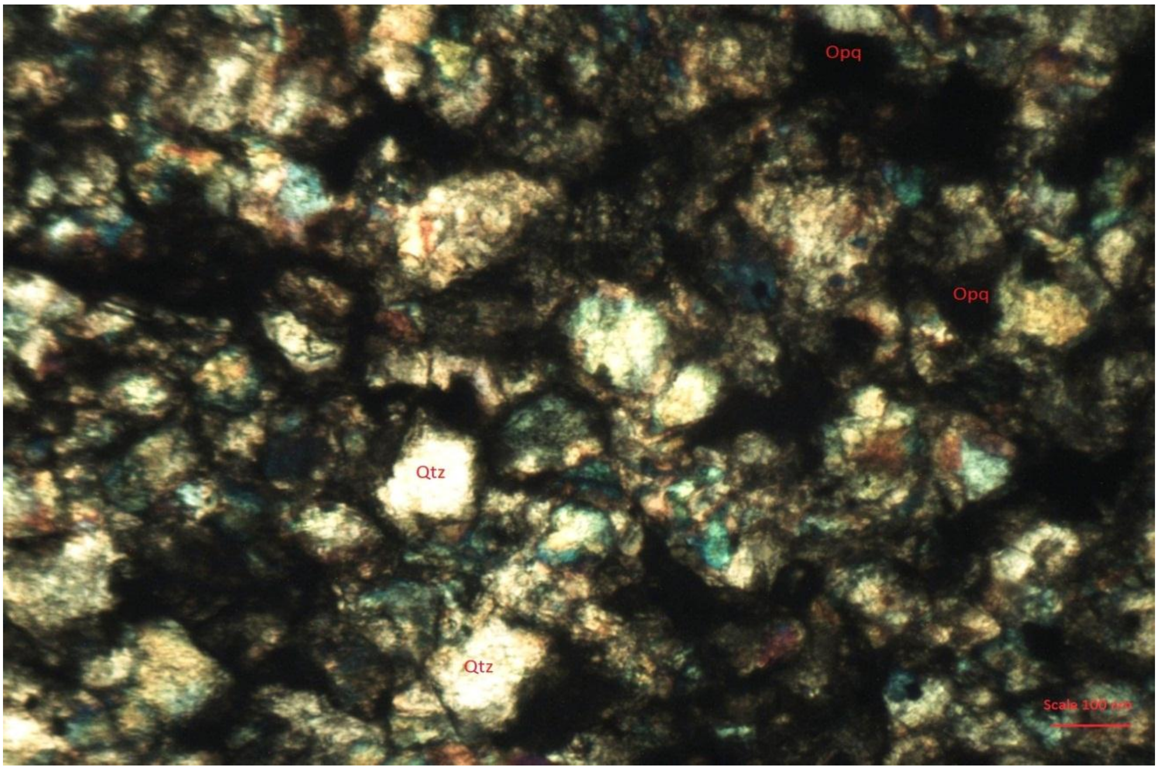


Figure 11 : Photomicrograph of the Lower Member of the Arung Khola Formation.

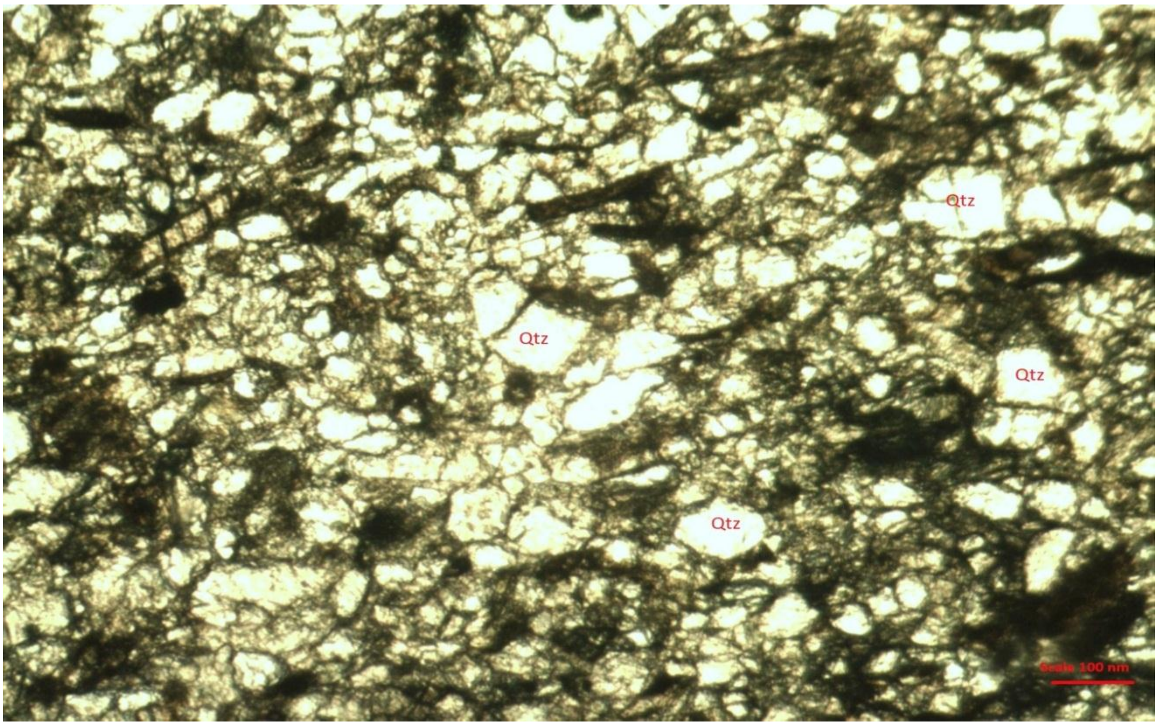


Figure 12 : Photomicrograph of the Middle Member of the Arung Khola Formation.

Khola, Murali Khola, Churybas Khola on the study area. Molluscan fossils were found by Tokuoka (1986) on this member but we could not notice any of them. Presence of conglomerate was documented in the upper part of this member. The detail columnar section of this member is as shown in figures: 13.

4.3.3.2 Middle member of the Binai Khola Formaton (Bm)

This is also well exposed along the Ramu Khola, Murali Khola, Hermali Khola, Churybas Khola on the study area. This is composed of massive salt and pepper pebbly sandstone (3-4) m with the pebbly conglomerate (1-3) m. The size of pebbles range from (1-6) cm, well rounded in both conglomerate and pebbly sandstone. Pebbles are of smoky quartz, sandstone, and siltstone, are well cemented with calcareous material. Convolute bedding, flute clast, climbing ripple marks, bioturbation on the mudstone are well exposed. The total thickness of this member is about 360 m in that area. This is the foot wall of the MBT in the study area around Lame Damar, Khani Damar. Some layers of highly crushed coal and mud also present on this member near MBT.

4.3.3.3 Upper Binai Khola Formation (Bu)

This member is not exposed in the Northern belt of CCT (present study area) along the Arun Khola section. It is composed of coarse grained thickly bedded pepper and salt pebbly sandthone with frequent intercaleation of the conglomerate of thickness 10-20 m. Pebbles on this member are of large size. The proportion of conglomerate is larger than sandstone. Trough cross bedding, scouring structure with rip-up clast, sand balls are also frequent. The total thickness of this member is about 500 m in the Binai Khola section. No Molluscan fossil were noted on this member.

4.3.4 Chitwan Formation

This formation is exposed on the small foothill along the way from Arun Khola to Damargaun in the Southern belt. It is also exposed on the narrow strip of Dumkibas along the Jyemere Khola. It is composed of semi consolidated clast supported conglomerate (10-20 m) thick alternation with sandstone and mudstone. Clasts are rounded pebble to cobble size with composition of quartzite and rarely of calc. quartose sandstone. Cross laminations and parallel laminations are well developed on this formation. The total thickness of this formation is about 500 m.

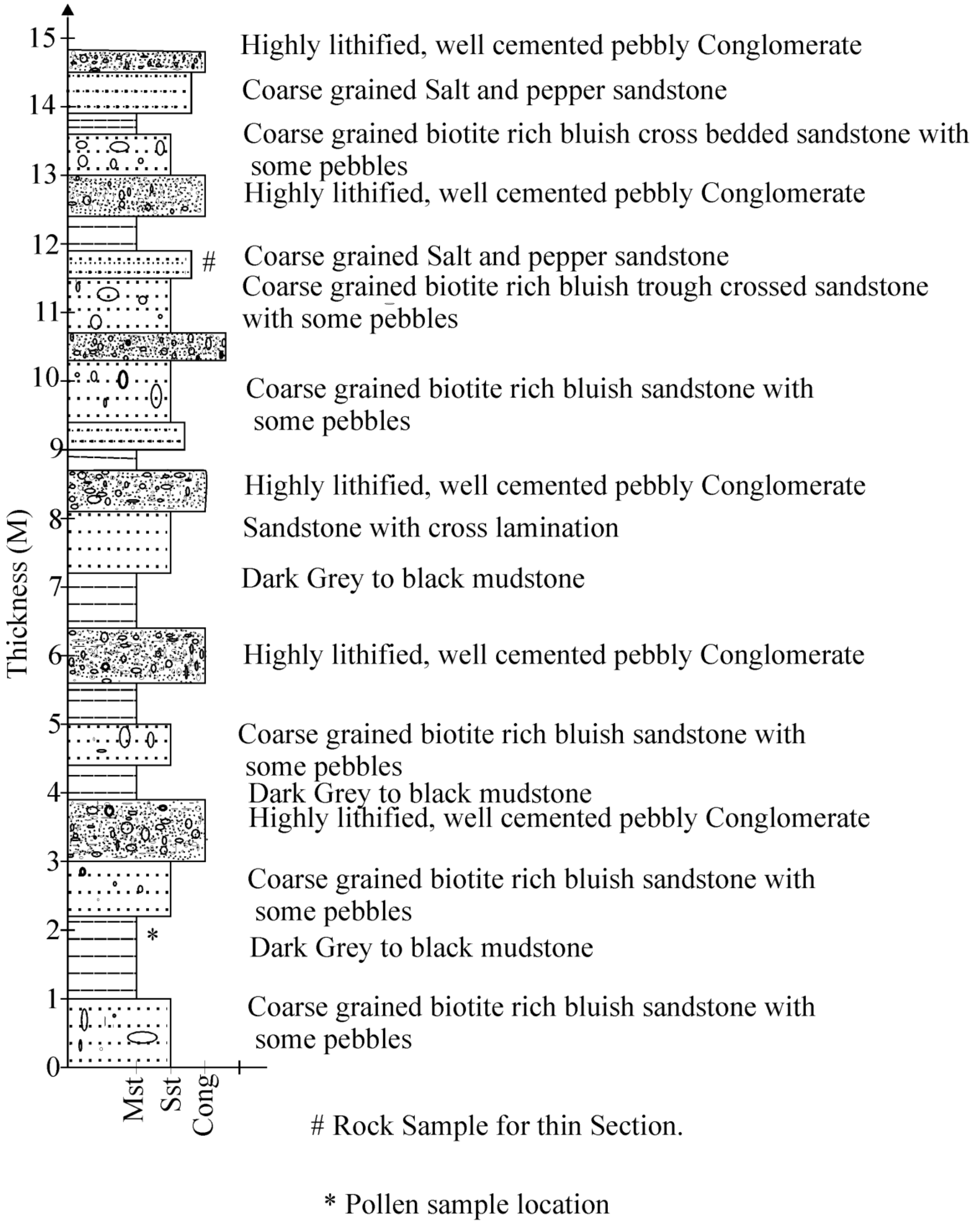


Figure 13: Detail columnar section of the Lower Member of the Binai Khola Formation near the confluence of Arun Khola and Ramu Khola.

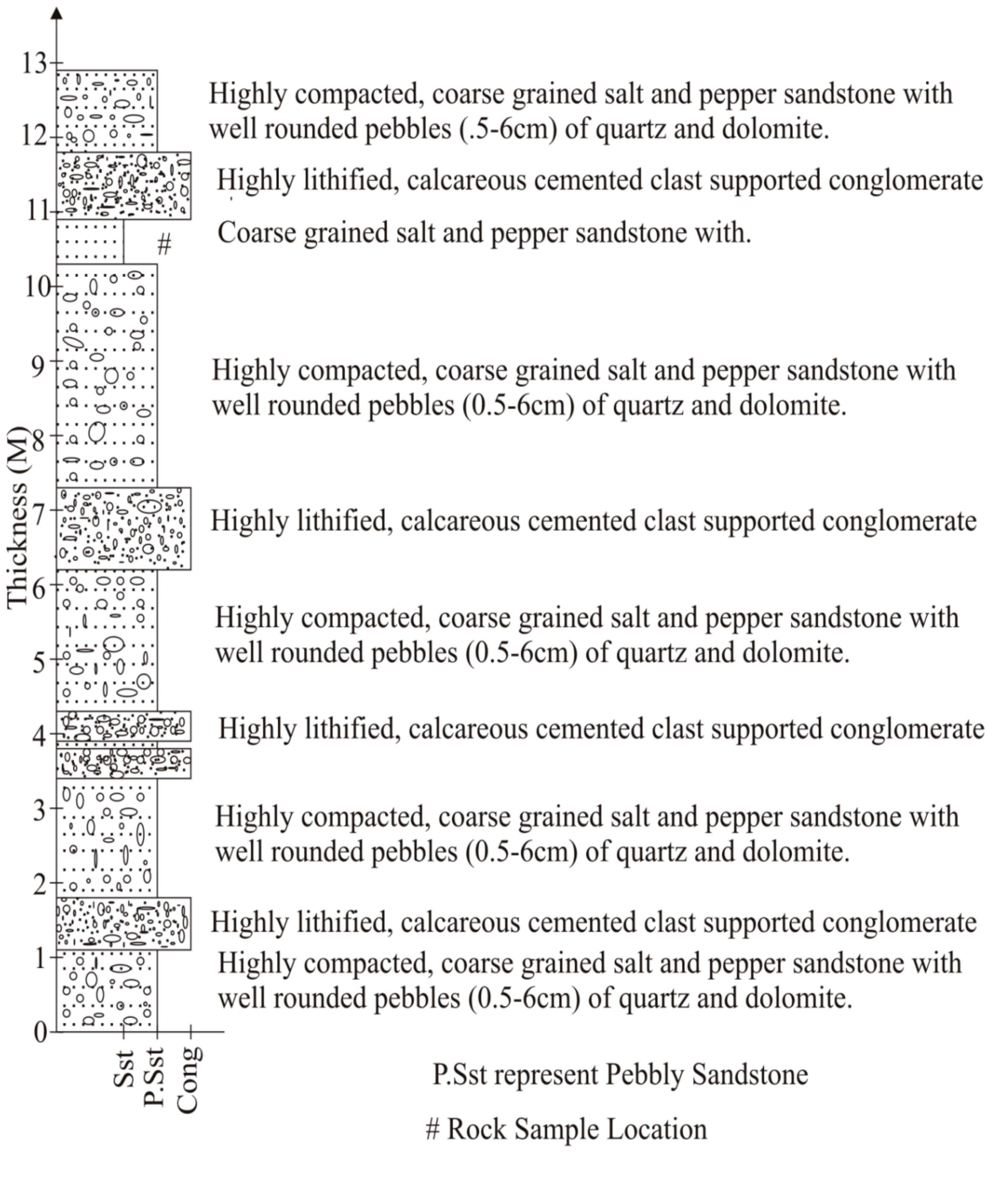


Figure 14 : Detail columnar section of the Middle Member of the Binai Khola Formation near Khani Damar village along the small Stream at the height of 450m from AMSL.

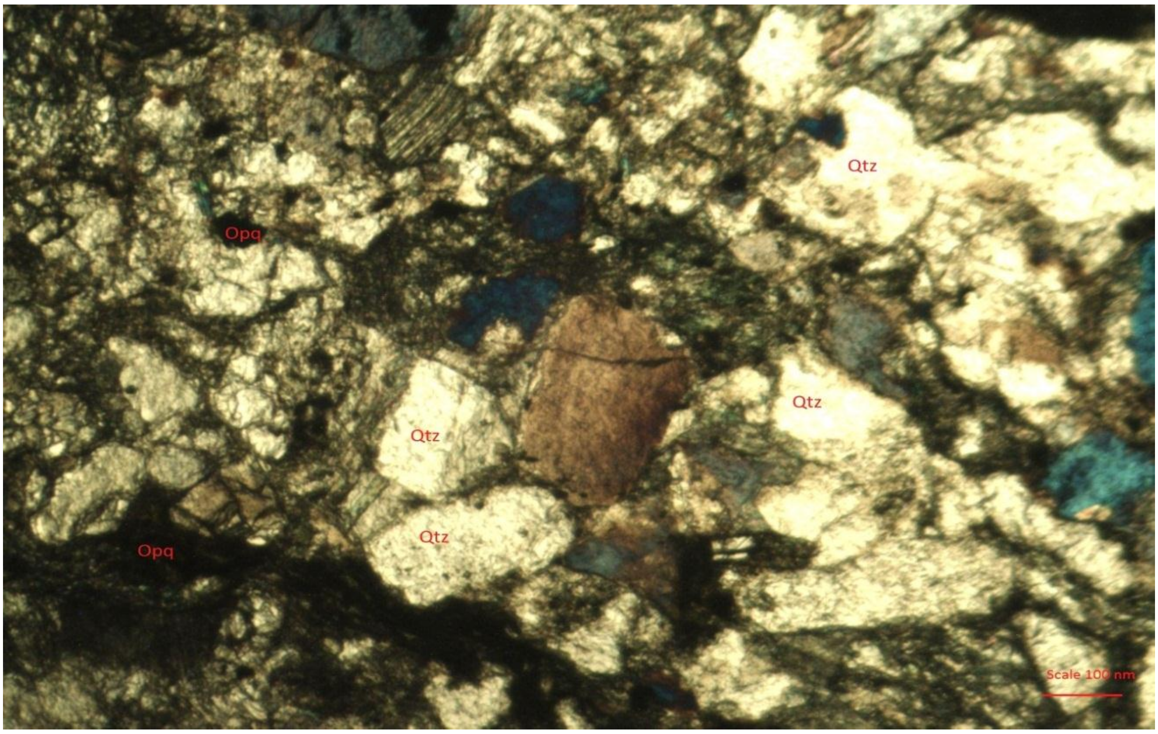


Figure 15 : Photomicrograph of the Upper Member of the Arung Khola Formation.

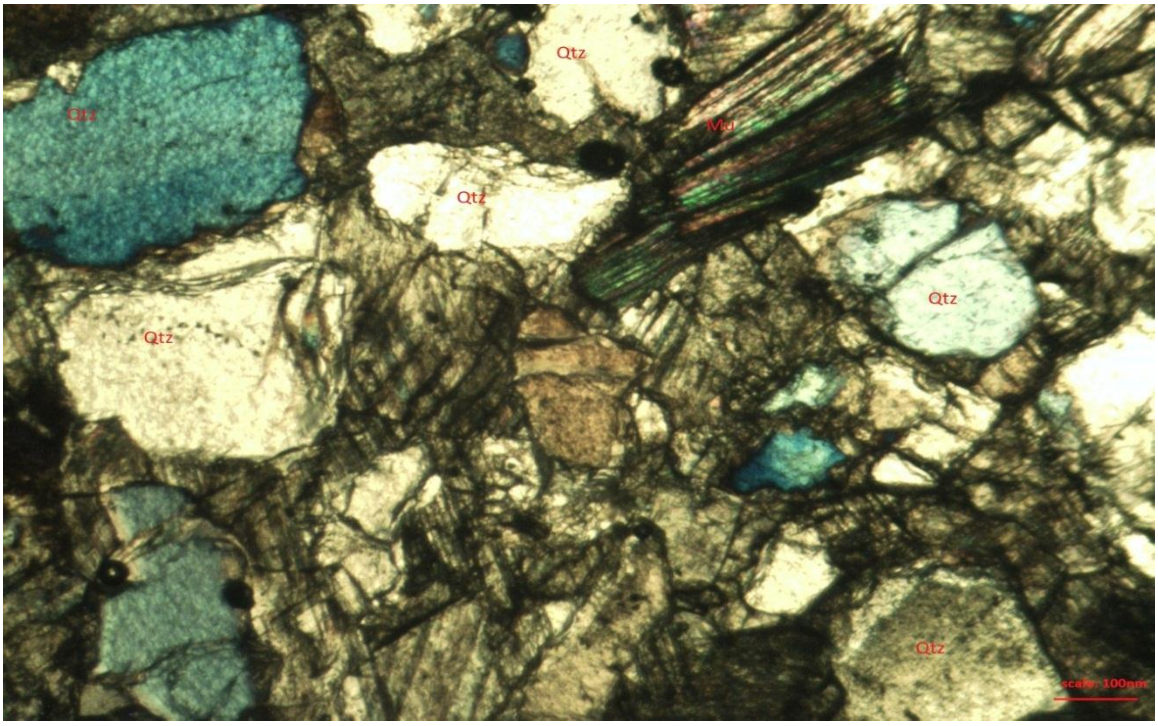


Figure 16 : Photomicrograph of the Lower Member of the Binai Khola Formation.

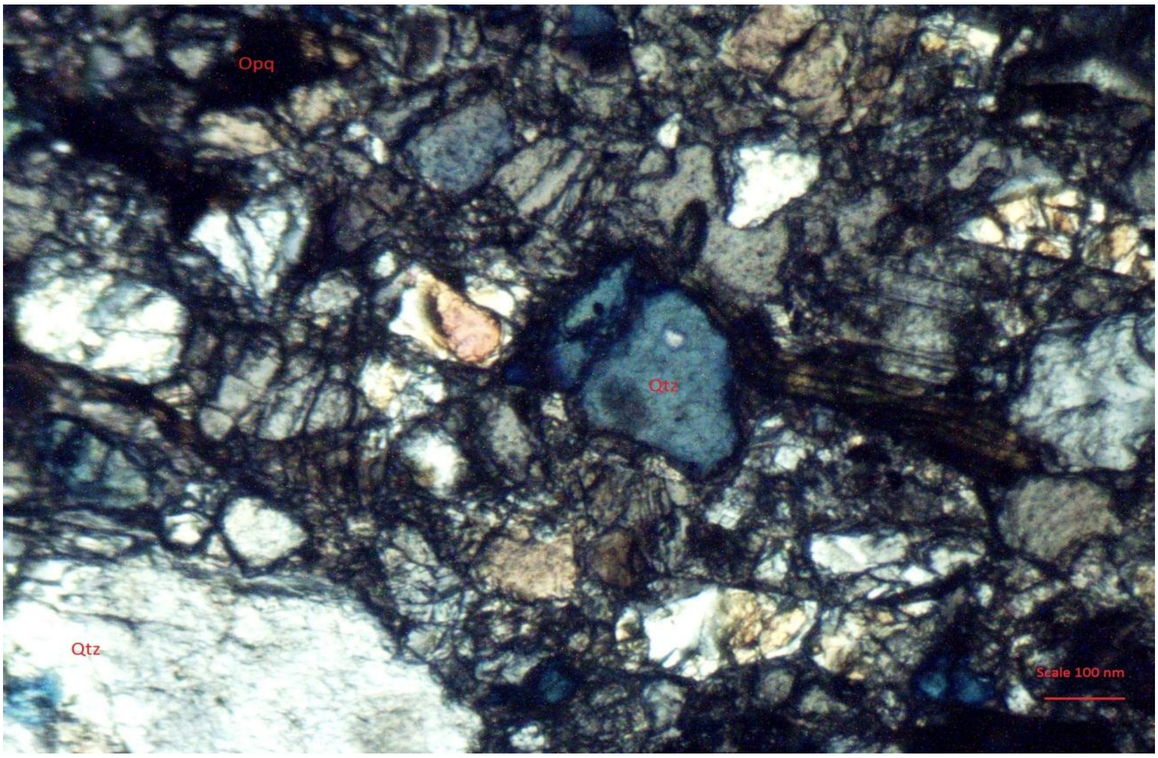


Figure 17: Photomicrograph of the Middle Member of the Binai Khola Formation near MBT zone.

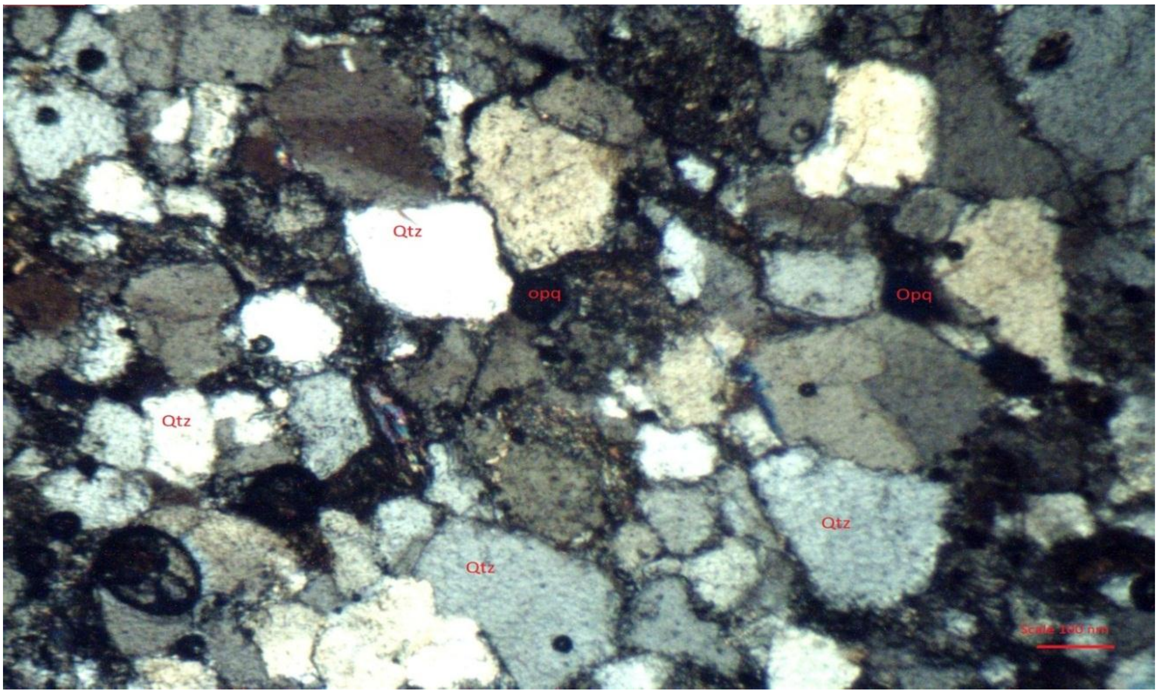


Figure 18: Photomicrograph of the Middle Member of the Binai Khola Formation.

4.3.5 Deorali Formation

This Formation is exposed only in the Southern part of the Binai Khola area at the South of CCT. During the field work the exposure were noted along the Khursani Khola about 500 m upstream from the Sonai village, along the Khorandi Khola about 200 m downstream from the confluence of Khorandi and Dharodi Khola and upper section of Binai Khola. CCT separate the older Al member (stratigraphically upper) with the younger Deorali Formation (stratigraphically lower) so it has thrust contact. The conglomerate is ill sorted, subanguler to elongated, highly lithified, matrix supported and of cobble to boulder size matrix. The clast are of the same composition that of the Arung Khola Formation (Sandstone, mudstone and marl). Sandstone and mudstone are rarely found indicating debris flow deposit (Tokuoka at el. 1988). The total thickness of this formation is about 600 m.

4.4 Structure of the study area.

The study area consists of many geologic structures. The primary sedimentary structures are represented by bedding plane, ripple marks, mud cracks, trough cross bedding and planar cross bedding. The secondary or tectonic structures such as fault, fold, thrust are also common. The structures of the study area are described in the following sections.

4.4.1 Geological Structure

Major geological structures such as faults, thrusts and folds were observed during the field work. They are Main Boundary Thrust (MBT), Central Churia Thrust (CCT), Himalayan Frontal Thrust (HFT) and Sonai Khola Anticline.

4.4.1.1 Main Boundary Thrust (MBT)

The Main Boundary Thrust (MBT) separates the older rocks of lesser Himalayan metamorphic sequence in the North from the younger sedimentary rocks in the South. It is steeply dipping ($150^0/65^0$ NE) toward the North. In the study area it is well exposed about 1km upstream along the Murali Khola from the confluence Arun Khola and Murali Khola, around the Lame Damar Village, 500 m upstream from the confluence of stream from the Khani Damar and Arun Khola along the small stream, around the Mudabas and Ritha Pani area. The middle member of the Binai Khola Formation lies on the footwall of the MBT and Lesser Himalayan rocks consisting of purple shale (Murali Khola), alternation of dolomite, pink and smoky quartz and slate (Khani Damar area) on the the hanging wall. The exposures are highly fractured and crushed on the MBT zone (figure: 20) Small scale fold is common on this zone. The topographycal changes from gentle to steeper. Small pressure ridge are also prominent. Big landslides are also common. Detail columnar was also prepared on the MBT zone figure: 19.

4.4.1.2 Central Churia Thrust (CCT)

Churia Group is divided into two belts by the Central Churia Thrust (CCT) as Northern Belt (Older sequence) above Southern Belt (Younger sequence). In the Northern Belt, the three members of Arung Khola Formations (Al, Am, Au) and two members of the Binai Khola Formation (Bl, Bm) are exposed in normal sequence upto MBT which lies above the younger Chitwan and Deorali Formations of southern belt. During the field work CCT was traced around the Damargau along the Arun Khola above the Chitwan Formation but in the Binai Khola section it lies above the Deorali formation in Khoorsani and Khorandi Khola. Variagated mudstone and the fine grained sandstone of lower member of the Arung Khola Formation is exposed adjacent to the CCT. The strike of the rock of Southern belt (WNW-ESE) and Northern belt (E-W) sequence is little difference. No exact thrust plane was traced but the geomorphologic features; topography, large landslides and highly crushed sandstone give the clear evidence of the thrust around this area.

4.4.1.3 The Sonai Khola Anticline

The anticlinal fold with axis along the Sonai Khola was described by (Tokuoka et al. 1986). The dipping of the beds were NW and SE (N10^{0}E/32^{0}NW and N20^{0}E/24^{0}SE) on the beds of the upper member of Binai Khola Formation. Repetition of the same strata was noted on the way from the Sardi to Dumkibas. Lower Member of the Binai Khola Formation is in the core of this anticline (Tokuoka et al 1986).

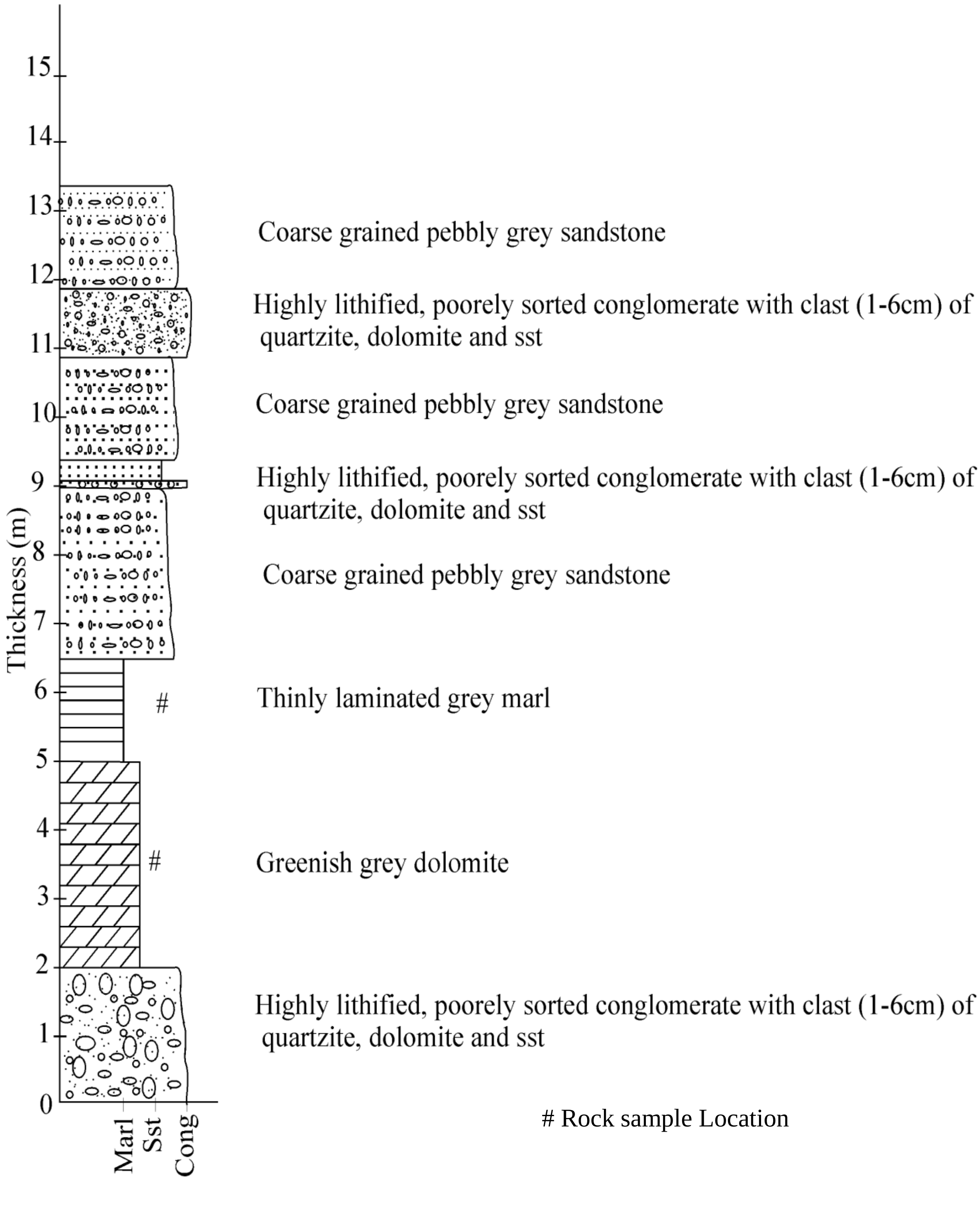


Figure 19: Detail Columnar Section of the MBT zone near KhaniDamar Gau.

4.4.2 Sedimentary (Primary) Structures

Primary sedimentary structure is well preserved on the sedimentary rock of the study area. The primary structures are indicators of the paleoenvironment and sedimentary succession. The structure like bedding, ripple marks, bioturbation are common in the study area.

4.4.2.1 Bedding

Most of the rock of the study area is well bedded because all the formations are formed in the sub-horizontal depositional basin. They were distinguished from each other by their colour, mineral composition and grain size. The laminations are also well preserved in some beds. The sedimentary unit whose thickness is less than 1 cm is called lamina and the unit which is greater than 1 cm is termed as bedding. The thickness depends on the sedimentary cycle of the deposition. The bedding or lamina which makes some angle with the depositional surface is called cross-lamination or cross bedding. Bedding may be planner, undulating, parallel, sub-parallel, continuous or discontinuous. Trough cross bedding were formed due to the migration of the three dimensional sand dunes and have erosional relationship with the underlying beds. Cross beddings help to reconstruct the paleoflow direction and flow type. The trough cross bedding were found on the sandstone of the lower and upper members of the Binai Khola Formation in the whole study area. Parallel laminations were well exposed on the sndstone of Jyemire Khola area. Cross lamination were observed on the bed of the middle member of the Binai Khola Formation figure: 21. The figure shows the clear younging direction towards the north as arrow in the given photograph shows.

4.4.2.2 Ripple

Ripple are undulation seen on the bedding and formed due to the movement of different phase of the water current. Formation of ripples depends on the velocity of the current flow and the depth of water. Many types of ripples such as current ripple (due to low water current), mega ripple (high current on deep depositional basin), wave ripple (due to back and forward movement of the current) and wind ripple (due the air current in sandy terrian) are found in nature according to depostional environment. We observed oscillation ripple on the fine grained sandstone of the lower member of the Arung Khola Formation (Al) figure: 27.

4.4.2.3 Lateral Accretion

The pinching of the bedding with in the short distance is called lateral accretion. It is generally of wedge shaped. It shows the tilting of the depositional horizon. It is well exposed on the sandstone of various locations within the Arung Khola Formation.

4.4.2.4 Biogenic Structure

Biogenic structures are the imprint of activities of plant and animals in the depositonal process of the sediments. Majority of such structures are syn-sedimentary in nature. Biogenic structures like bioturbation, track and trails, burrows, foot prints and worm trails are common in the rocks of the Siwalik Group. Many bioturbations are found in Arung Khola Formation in the form of concretions figure: 26. Worm trails are also documented from different parts of the study area. This indicates the water in the depositional basin was shallow with plenty of animal and plant activities.

Figure 20: Highly Fractured Sequence of Lesser Himalaya about 500 m upstream from Khani Damar

Figure 21: Cross lamination on the exposure of the Bm in Arun Khola area (arrow show younging direction)

Figure 22: Convolute bedding observed near the confluence of Murali and Arun Khola**.**

Figure 23: Bedding Structure of Arung Khola middle member (Am) exposed along the Arung Khola (facing west).

Figure 24: Exposure of the Deorali Formation along the Dhoradi Khola (facing east).

Figure 25: The mud ball on the lower member of the Binai Khola Formation at Gogadi Khola.

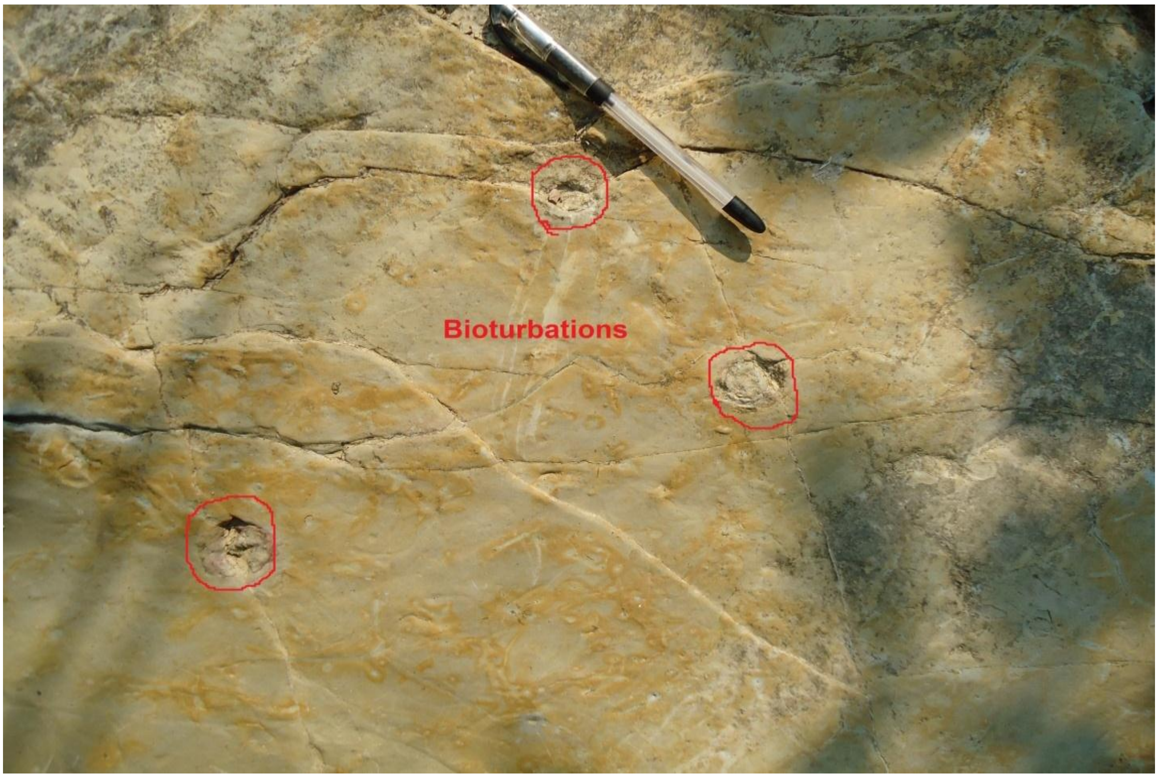


Figure 26: The bioturbation seen on the Al member near Damargaun..

Figure 27: The Ripple marks on the Al member near Damargaun on the right bank of Arun Khola.

4.5 Paleocurrent analysis

Paleocurrent analysis was done with pebble orientation data which were collected from the exposure which is about 250m upstream from the confluence of Arun Khola and Churibas Khola. 54 pebble's orientation measured and furthered proceeds for tilt correction. The azimuths are taken as follow after tilt correction. The attitude of regional bedding plane is N20^{0}E/60^0 NW.

Table 2 Pebble orientations taken from confluence between Arun and Churibas Khola after Tilt correction.

S.N	Azimuth (θ)	Sinθ	Cosθ	S.N	Azimuth (θ)	Sinθ	Cosθ
1	153	0.454	-0.891	28	241	-0.875	-0.485
2	155	0.423	-0.906	29	242	-0.883	-0.469
3	161	0.326	-0.946	30	245	-0.906	-0.423
4	168	0.208	-0.978	31	246	-0.914	-0.407
5	188	-0.139	-0.990	32	245	-0.906	-0.423
6	196	-0.276	-0.961	33	247	-0.921	-0.391
7	191	-0.191	-0.982	34	247	-0.921	-0.391
8	206	-0.438	-0.899	35	248	-0.927	-0.375
9	207	-0.454	-0.891	36	251	-0.946	-0.326
10	212	-0.530	-0.848	37	250	-0.940	-0.342
11	213	-0.545	-0.839	38	257	-0.974	-0.225
12	210	-0.500	-0.866	39	258	-0.978	-0.208
13	216	-0.588	-0.809	40	256	-0.970	-0.242
14	218	-0.616	-0.788	41	257	-0.974	-0.225
15	218	-0.616	-0.788	42	261	-0.988	-0.156
16	219	-0.629	-0.777	43	259	-0.982	-0.191
17	225	-0.707	-0.707	44	263	-0.993	-0.122
18	225	-0.707	-0.707	45	265	-0.996	-0.087
19	230	-0.766	-0.643	46	266	-0.998	-0.070
20	231	-0.777	-0.629	47	268	-0.999	-0.035
21	231	-0.777	-0.629	48	270	-1.000	0.000
22	234	-0.809	-0.588	49	271	-1.000	0.017
23	239	-0.857	-0.515	50	279	-0.988	0.156
24	239	-0.857	-0.515	51	278	-0.990	0.139
25	157	0.391	-0.921	52	276	-0.995	0.105
26	228	-0.743	-0.669	53	281	-0.982	0.191
27	280	-0.985	0.174	54	270	-1.000	0.000
				Total		-37.650	-25.490

$\sum Sin\ \theta$ = - 37.650 and $\sum Cos\ \theta$= - 25.49

Or, Tanθ = ($\sum Sin\ \theta\ /\sum Cos\ \theta$)

Or, $\theta = Tan^{-1}$ (- 37.650 / -25.490)   Or. $\theta = 56^0$

Vector mean is calculated as $\theta = 56^0$ so the paleocurrent direction is $S56^0W$

For Vector Magnitude R = $\sqrt{\sum(Sin\theta)^2 + \sum(Cos\ \theta)^2}$

Generally R is express as percentage as $\frac{R}{n} \times 100 = \sqrt{\sum(-37.650)^2 + \sum(-25.490)^2} \times \frac{100}{54}$

Where n is number of poles.

$= (\sqrt{1417.52 + 649.74} \times 100/54)$ %

Vector magnitude = 84%

Hence the paleoflow direction of the Arun Khola is on the Mudabas-Khani Damar area is $S56^0$ W and Vector magnitude is 84%.

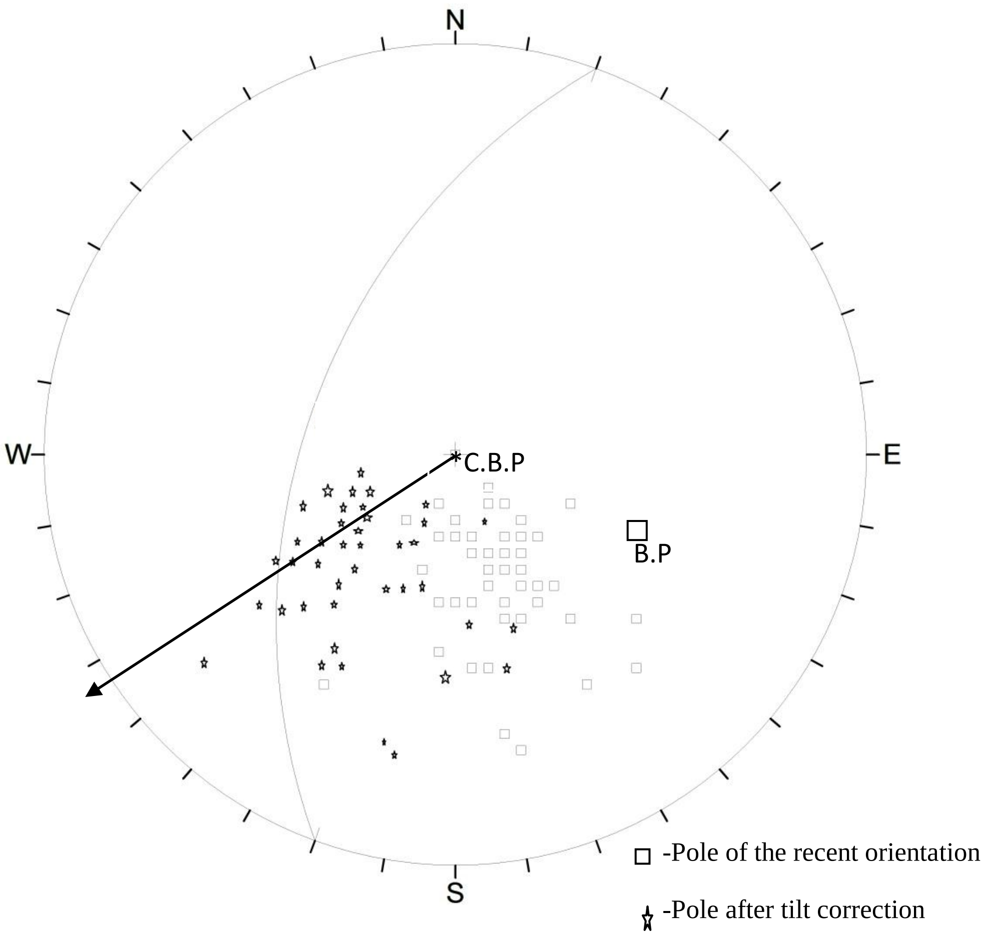
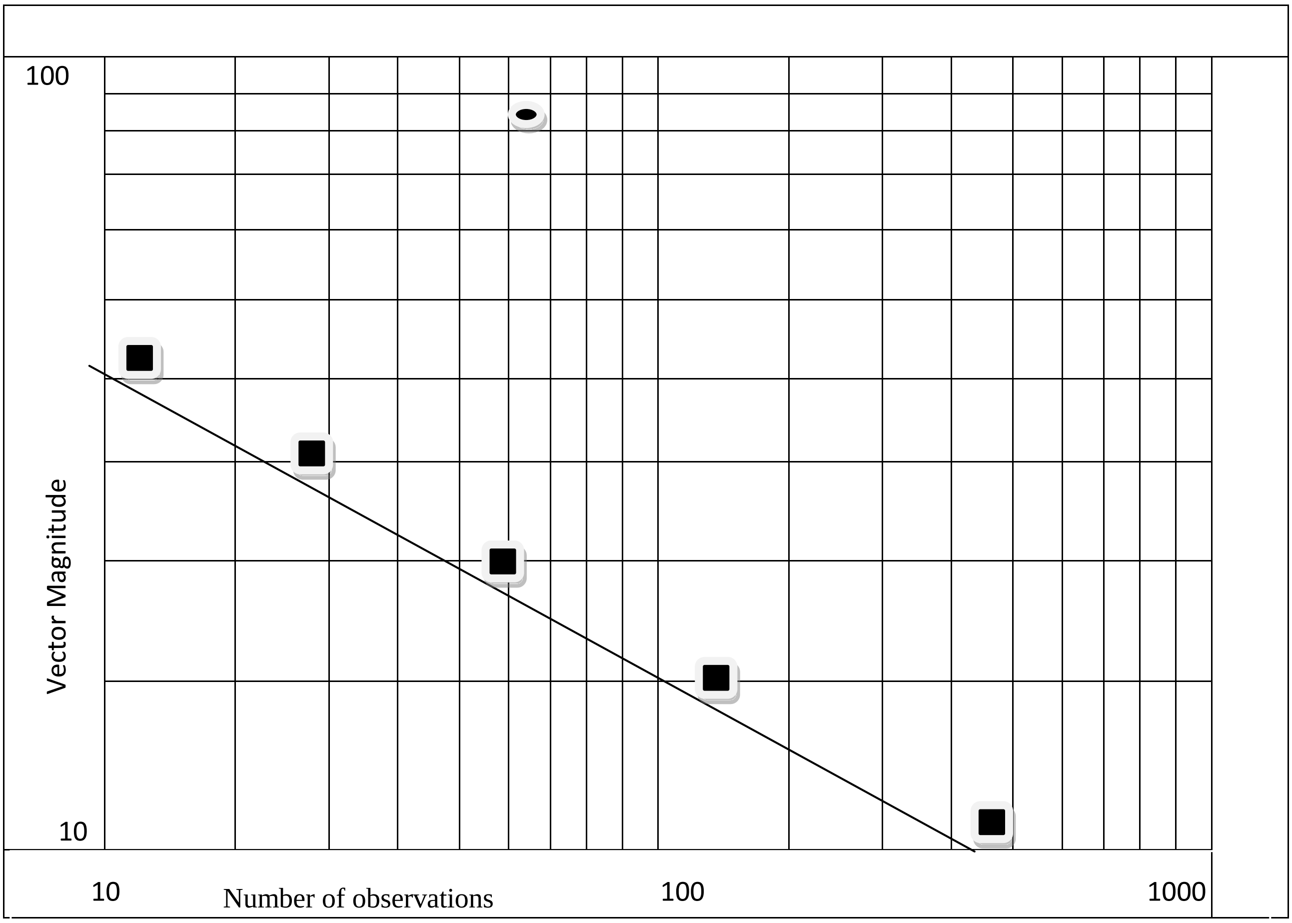


Figure 28: Show the paleocurrent direction. B.P= bedding plane, C.P.B= Corrected Bedding Plane.

Table 3: Plot of the Vector Magnitude and number of observation to evaluate significant of a vector mean using Rayleigh test



The calculated value is greater than that of critical line for the given number of the observation; therefore it is stastically valid for the calculation.

4.6 Palynological investigations

The pollen analysis is a proxy which gives an idea about paleovegetation and thus climate existed during the deposition of the geological deposits. Three samples were collected from Al, Am and Au members of the Arung Khola Formation for palynological investigation. The sample (A1) collected from the Lower Member of the Arung Khola Formation is found to be barren while samples A2 and A3 collected from Middle (Am) and Upper (Au) contain a significant amount of palynological assemblages. The major taxa discovered from the samples A2 and A3 belonging to the middle (Am) and upper (Au) members of the Arung Khola Formation are listed below (see also PLATE-I to PLATE-IV).

Table : List of pollen taxa from the Arung Khola section, Siwalik Group, central Nepal.

Plant Group	**Family**	**Genera**	**Sample nr.**
Gymnosperm	Pinaceae	*Pinus*	A3
	Pinaceae	*Tsuga*	A3
Angiosperms (Dicotyledon)	Acanthaceae	*Strobilanthes*	A3
	Betulaceae	*Alnus*	A3
		Betula	A3
	Compositae	Indet.	A2/A3
	Ericaceae	*Rhododenron* ?	A3
	Euphorbiaceae	indet.	A3
	Fagaceae	*Quercus*	A3
Angiosperms (Monocotyledon)	Palmae	indet.	A2
	Poaceae	indet.	A2/A3
	Potamoganaceae	*Potamogeton*	A2/A3
Pteridophytes	Lycopodiaceae	*Lycopodium*	A2/A3
	Polypodiaceae	indet. (3 species)	A2/A3
	Parkeriaceae	*Ceratopteris* (4 species)	A2/A3
	Pteridaceae	indet. (2 species)	A2/A3
Algal Cyst	Zygnemataceae	*Zygnema* (4 different types)	A2/A3
Fungal spores		*Glomus* sp.	A2/A3

4.6.1 GYMNOSPERMS

Family: Pinaceae

Genus: *Pinus* sp. (Plate I, Fig. 1)

Description:

Shape: Bisaccate, Size: 94.3 x 67.2 µm, Aperture: Inaperturate, Exine: Cappa regulate and thick, saci coarsely rugulate, micro-reticulate.

Locality: Arung Khola Formation (upper member)

Age: Late Miocene

Genus: *Tsuga* sp. (Plate I, Fig. 2)

Description:

Shape: Monosaccate, saccus in annular form, Size: 65.6 x 67.2 µm, Aperture: Inaperturate, Exine: Rugulate with some spiny projection.

Locality: Arung Khola Formation (upper member)

Age: Late Miocene

4.6.2 ANGIOSPERMS

a. Dicotyledons

Family: Acanthaceae

Genus: *Strobilanthes* sp. (Plate I, Fig. 3)

Description:

Shape: Prolate, Size: 37.2 x 72.9 µm, Aperture: Tricorpolate, colpi shallow and distinct, Exine: Sexine thicker than nexine, striate and micro- reticulate.

Locality: Arung Khola Formation (upper member).

Age: Late Miocene.

Family: Betulaceae

Genus: *Alnus* sp. (Plate I, Fig. 4)

Description:

Shape: Oblate, Size: 25.7 x 22.8 µm, Aperture: Pentaporate, Exine: Regulate and microechinate.

Locality: Arung Khola Formation (upper member).

Age: Late Miocene.

Genus: *Betula* sp. (Plate I, Fig. 5)

Description:

Shape: Oblate, circular in polar view, Size : 31.2 x 28.6 µm, Aperture: Colporate, Exine: scabrate with micro-echinate processes, granulate.

Locality: Arung Khola Formation (upper member).

Age: Late Miocene.

Family: Compositae

Genus: Indet. (Plate I, Fig. 6)

Description:

Shape: Circular in equatorial view, Size: 31.4 x 28.6 µm, Aperture: Tri-colporate, Exine: Echinate, echinae are longer than 1 µm.

Locality: Arung Khola Formation (middle and upper members).

Geological Age: Late Miocene.

Family: Ericaceae

Genus: *Rhododendron* sp.? (Plate II, Fig. 7)

Description:

Shape: Tetrad, semi-circular in equatorial view, Size: 57.2 x 40 µm, Aperture: Colporate, Exine: Scrabate and Granulate.

Locality: Arung Khola Formation (upper member).

Geological Age: Late Miocene.

Family: Euphorbiaceae

Genus: Indet. (Plate II, Fig. 8)

Description:

Shape: Prolate, semi-circular in equatorial view, Size: 21.4 x 30 µm, Aperture: Tri-colporate, Exine: Thick, granulate and microreticulate.

Locality: Arung Khola Formation (upper member)

Geological Age: Late Miocene.

Family: Fagaceae

Genus: *Quercus* sp. (Plate II, Fig. 9)

Description:

Shape: Prolate, Size: 18.6 x 30 µm, Aperture: Tri-olporate, Exine: Scrabate, granulate.

Locality: Arung Khola Formation (upper member)

Geological Age: Late Miocene.

b. Monocotyledons

Family: Palmae

Genus: Indet. (Plate II, Fig. 10)

Description:

Shape: Elliptical in outline, Size: 54.2 x 30 µm, Aperture: Sulcate (mono)

Exine: Reticulate or verucate.

Locality: Arung Khola Formation (lower member).

Geological Age: Late Miocene.

Family: Poaceae

Genus: Indet. (Plate II, Fig. 11)

Description:

Shape: Circular or globular in outline, Size: 54.2 x 30 µm, Aperture: porate (mono), Exine: scabrate, granulate, microechinate.

Locality: Arung Khola Formation (middle and upper members).

Geological Age: Late Miocene.

Family: Potamoganaceae

Genus: *Potamogeton* sp. (Plate II, Fig. 12)

Description:

Shape: Tetrad, monad circular in outline, Size: 54.3 x 40 µm, Aperture: Porate (mono), Exine: finely reticulate.

Locality: Arung Khola Formation (middle and upper members).

Geological Age: Late Miocene.

4.6.3 PTERIDOPHYTES

Family: Lycopodiaceae

Genus: Indet. (Plate III, Fig. 13)

Description:

Shape: Triangular, Size: 51.4 x 40 µm, Aperture: Trilete, Exine: Coarsely coarsely reticulate and with costae.

Locality: Arung Khola Formation (middle and upper members).

Geological Age: Late Miocene.

Family: Parkeriaceae

Genus: *Ceratopteris* sp. 1 (Plate III, Fig. 14)

Description:

Shape: Subtriangular, Size: 77.2 x 80 µm, Aperture: Trilete, Exine: 2 m, with granulate perine and thick forming rich parallel ridges on surface.

Locality: Arung Khola Formation (middle and upper members)

Geological Age: M. Miocene.

Family: Parkeriaceae

Genus: *Ceratopteris* sp. 2 (Plate III, Fig. 15)

Description:

Shape: Subtriangular, Size: 70 x 65.7 µm, Aperture: Trilete, Exine: 2 µm, with sub-parallel coarse strations and ridges.

Locality: Arung Khola Formation (middle and upper members)

Geological Age: M. Miocene.

Family: Parkeriaceae

Genus: *Ceratopteris* sp. 3 (Plate III, Fig. 16)

Description:

Shape: Triangular**,** Size: 57.2 x 57.2 µm**,** Aperture: Trilete, Exine: 1.5 µm, verrucate, striate and ridged, granulate.

Locality: Arung Khola Formation (middle and upper members)

Geological Age: M. Miocene.

Family: Parkeriaceae

Genus: *Ceratopteris* sp. 4 (Plate III, Fig. 17)

Description:

Shape: Triangular to Sub-rounded, Size: 72.9 x 65.7 µm, Aperture: Trilete

Exine: 1.5 µm, verrucate, striate and ridged, granulate.

Locality: Arung Khola Formation (middle and upper members)

Geological Age: M. Miocene.

Family: Polypodiaceae

Genus: Indet. 1 (Plate III, Fig. 18)

Description:

Shape: Elliptical (bean shaped), Size: 97.1 x 68.6 µm, Aperture: Monolete, Exine: 1.5 µm,micro-verrucate and granulate.

Locality: Arung Khola Formation (middle and upper members)

Geological Age: M. Miocene.

Family: Polypodiaceae

Genus: Indet. 2 (Plate IV, Fig. 19)

Description:

Shape: Subtriangular, Size: 64.3 x 40 µm, Aperture: monolete, Exine: 2 µm, verrucate, granulate.

Locality: Arung Khola Formation (middle and upper members)

Geological Age: M. Miocene.

Family: Polypodiaceae

Genus: Indet. 3 (Plate IV, Fig. 20)

Description:

Shape: Elliptical, Size: 57.14 x 31.4 µm, Aperture: monolete, Exine: 2 µm, verrucate, granulate.

Locality: Arung Khola Formation (middle and upper members)

Geological Age: M. Miocene.

Family: Pteridaceae

Genus: Indet. 1 (Plate IV, Fig. 21)

Description:

Shape: Triangular , Size: 44.3 x 35.7 µm, Aperture: Trilete, Exine: 1.5 µm, verrucate and granulate.

Locality: Arung Khola Formation (middle and upper members)

Geological Age: M. Miocene.

Family: Pteridaceae

Genus: Indet. 2 (Plate IV, Fig. 22)

Description:

Shape: Triangular, Size: 40 x 37.14 µm, Aperture: Trilete, Exine: 1.5 µm, verrucate and granulate.
Locality: Arung Khola Formation (middle and upper members)
Geological Age: M. Miocene.

Altogether 22 taxa belonging to 14 families of plant are documented from the Arung Khola Formation. Samples A2 and A3 mainly yielded Pteridophyte spores, algal and fungal cysts indicating humid and warm climatic conditions. Palm pollen are common in the A2 sample which indicate tropical-subtropical climatic existing at that time. Few gymnosperm (*Pinus* and *Tsuga*) and angioperm (*Alnus, Betula, Rhododendron, Quercus*) pollen recovered from sample A3 belonging to Upper member (Al) of the Arung Khola Formation. The gymnosperm pollen are very rare and supposed to be travelled from long distace from High altitudes. Plant like *Alnus* might have been growing in riverine gullies where wet environment was existed. Near water wet land plants such as *Potamogeton* is common indicating shallow water condition in the depositional basin. Plenty of warm loving Pteridophytes such as Parkeriaceae indicate the climate existed during the deposition of Arung Khola Formation was humid and warm as experienced in Terai area of Nepal today.

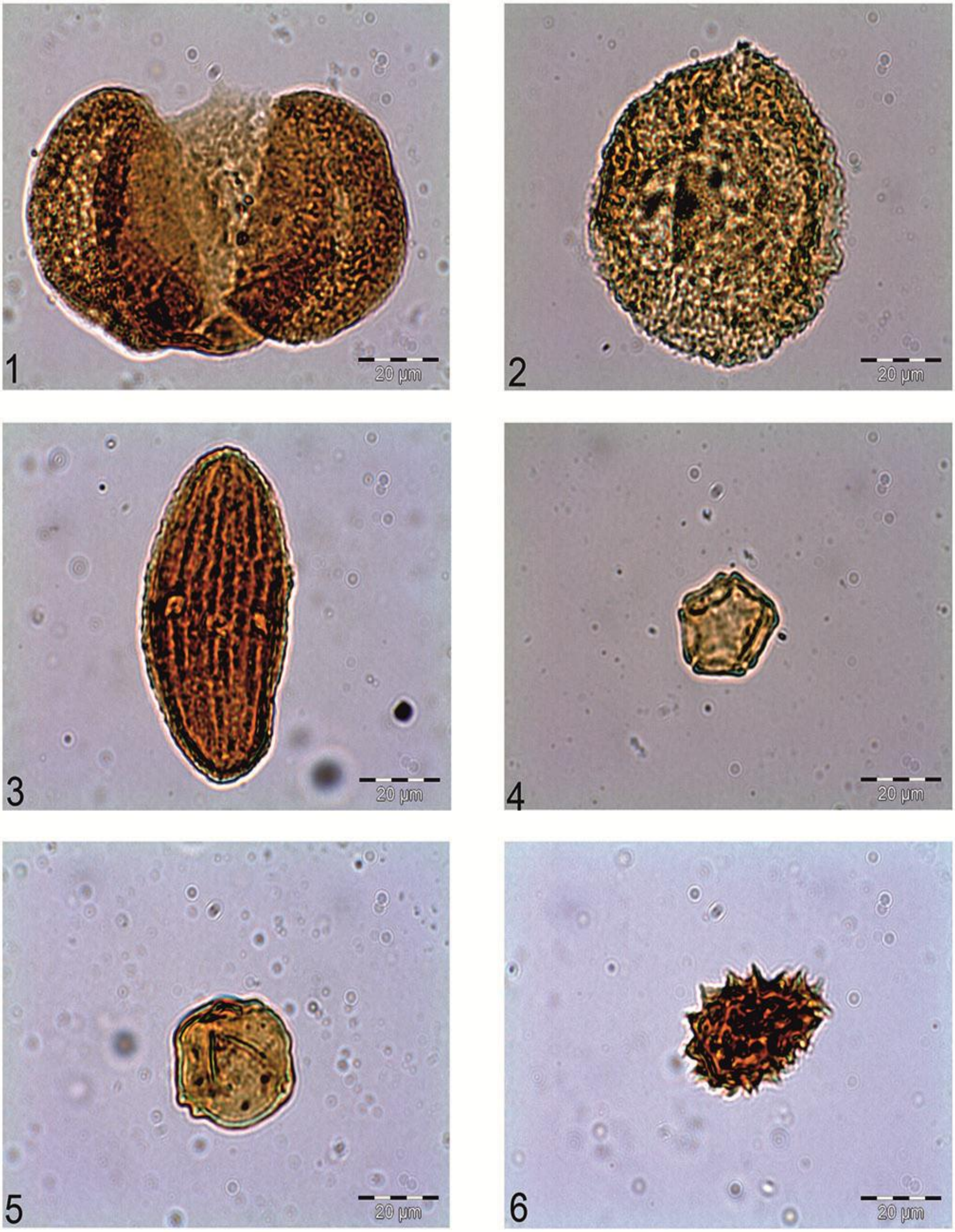


PLATE-I. 1. *Pinus* sp. (Family Pinaceae), 2. *Tsuga* sp. (Family Pinaceae), 3. *Strobilanthes* sp. (Family Acanthaceae), 4. *Alnus* sp. (Family Betulaceae), 5. *Betula* sp. (Family Betulaceae), 6. Family Compositae gen. indet.

PLATE-II. 7. Ericaceae gen. indet., 8. Euphorbiaceae gen. Indet., 9. Quercus sp. (Family Fagaceae), 10. Palmae gen. indet., 11. Poaceae gen. indet., 12. Potamogetonaceae gen. indet.

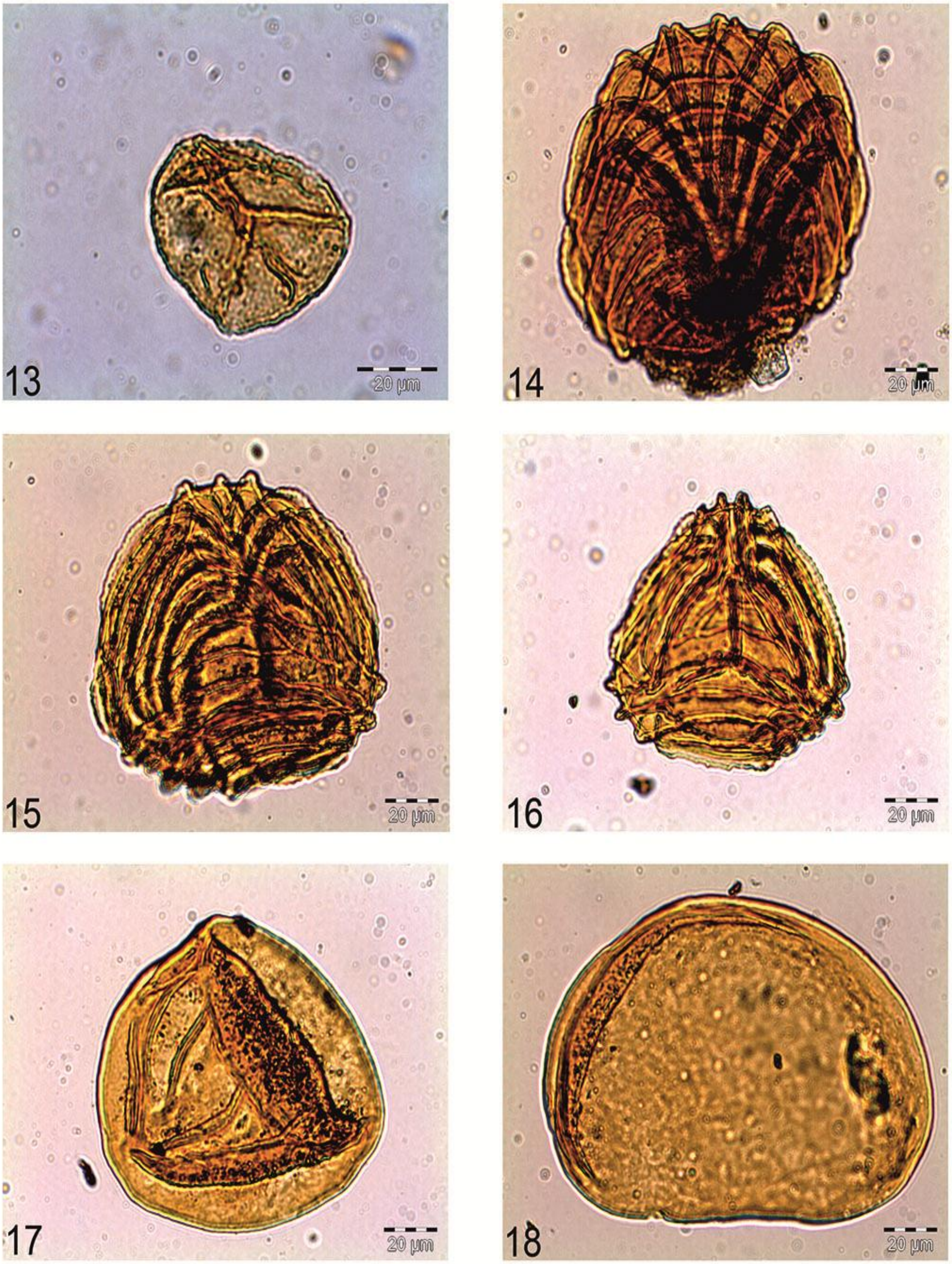


PLATE-III. 13. Lycopodiaceae, 14. Parkeriaceae sp. (1), 15. Parkeriaceae sp. (2), 16. Parkeriaceae sp. (3), 17. Parkeriaceae sp. (4), 18. Polypodiaceae sp. (1).

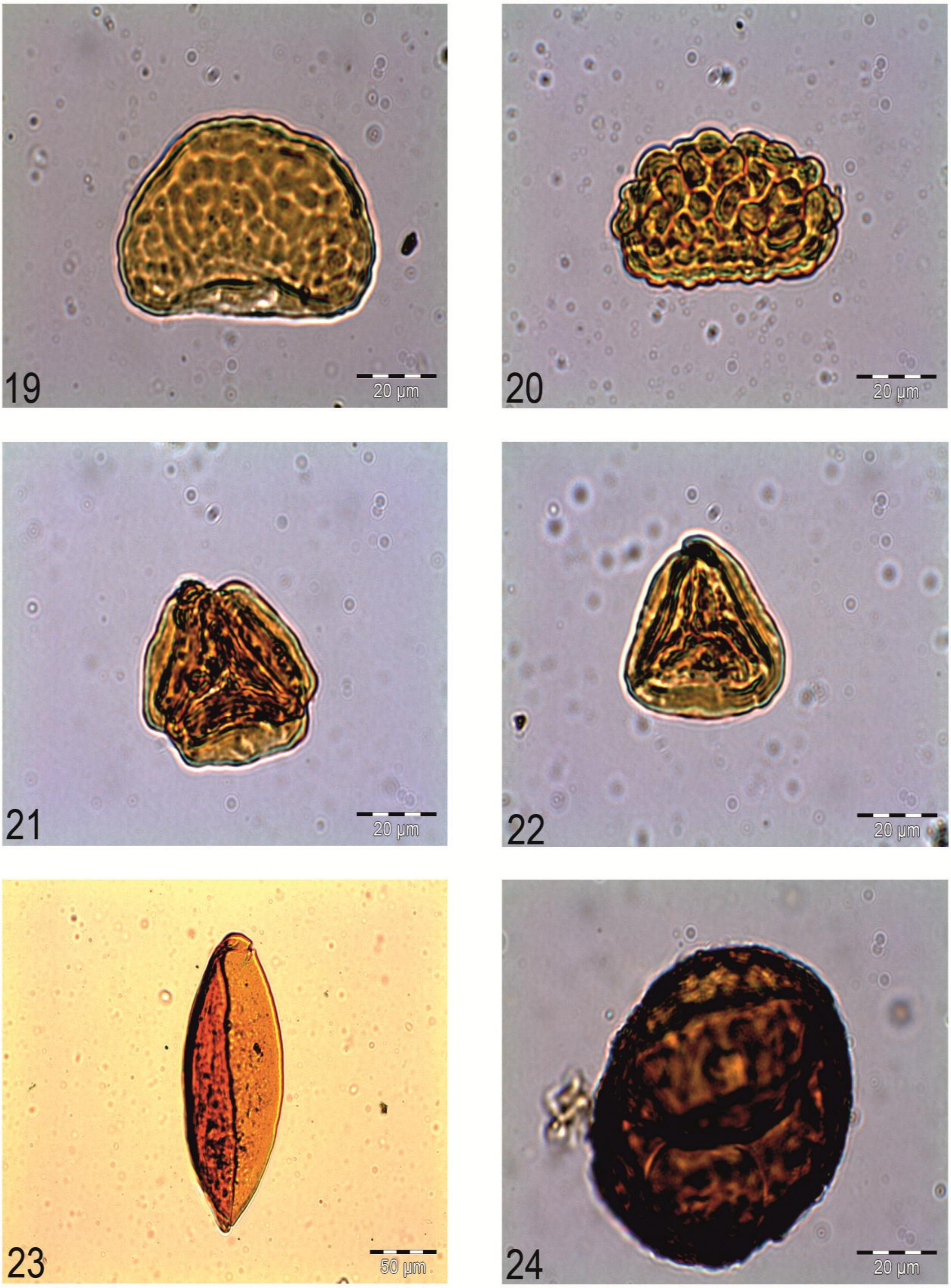


PLATE-IV. 19. Polypodiaceae sp. (1), 20. Polypodiaceae sp. (2), 21. Pteridaceae sp. (1), 22. Pteridaceae sp. (2), 23. Algal cysts (*Zygnema* sp.), 24. Fungal spore (*Glomus* sp.).

CHAPTER V
DISCUSSION

The Siwalik rocks in the Arun Khola area can be divided in to two belts separated by the CCT in the northern and southern belt. Arung Khola Formation is the oldest and Deorali Formation is the youngest formation of that area. MBT divides the Lesser Himalayan rocks from the Siwalik rocks. CCT is the thrust which separates the older Arung Khola Formation in the north and younger Deorali Formation is on the south. The both formations are north dipping.

Rock composition is very complicated in the study area due to similar texture and properties. The grain size and proportion of the sandstone and mudstone is different in different members. Grain size is increasing from the older to younger. At the bottom of the sequence the grain size is very small but at the top (younger) heavy boulder conglomerate. Mudstone of Arung Khola Formation is variegated sandstone is fine grained and calcareous.

Pollen sample of the Arung Khola Formation shows the shallow depositional environment, Binai Khola Formation is deposited by the meandering river system under humid climate. Chitwan and Deorali Formation were deposited in the shallow debris and flash flow. Deurali Formation consists of the clasts derived from the Siwalik Group rocks too.

Paleocurrent analysis from the pebbles orientation was done along the Arun Khola near the Khani Damar village on the bed of the consolidated pebbly conglomerate. The pebbles are of quartzite, marble, sandstone and dolomite. They are of the size ranging from 3 cm–10 cm. The bed has the dip amount 40^0 so the azimuth was taken after the tilt correction. The paleocurrent direction calculated in this area is S56W.

Pollen of Gymnosperm, Angiosperm, Pteridophytes, Algal cyst and Faunal spores were dicovered from the Arung Khola Formation of the study area. The palynological assemblage shows the warm loving vegetation and the climate was quite warm and humid. The Palm and Pteridophyte belonging to different species of *Ceratopteris* are the most dominant elements indicating the warm climate.

Thin section of the different sample was show they are sublitharenite to feldspathic type. The percentage of the quartz is greater than that of other in the sample. Rock of the Arun

Khola Lower is of the litharenite type. The percentage of rock fragment is greater than quartz and less amount of feldspar. But the rock sample of Binai Khola Formation is of the sublitharenite type.

Rock near the MBT zone is highly fractured and crushed. Small pressure ridge, huge landslide, sudden change in topography and lithology is the evidence of the thrust fault. MBT brings the older Lesser Himalayan rock above the Siwalik. Similarly CCT is intra Siwalik thrust, which brings older Arung Khola Formation over the younger Deorali Formation.

CHAPTER VI
CONCLUSION AND RECOMMENDATION

6.1 Conclusion:

The study area is of the part of (Sub-Himalayan) Zone of Nepal Himalaya. The study covers mainly the part of the Siwalik between the CCT and the MBT. The lithological and palaeontological study carried in the area concluded as:

1. As a whole has coarsening upward Sequence with individual fining up cycle. Rock units are classified into the four formations as Arung Khola Formation, Binai Khola Formation, Chitwan Formation and Deorali Formation. Arung Khola and Binai Khola Formations are again divided into lower, middle, and upper members respectively. Arung Khola is the oldest and the Deorali Formation is the youngest formation.

2. Arung Khola composed of variagated Mudstone, fine-grained sandstone. The sandstones are somewhere calcareous. Binai Khola Formation is consist of Coarse to very coarse grained salt and pepper sandstone to pebbly sandstone, Chitwan Formation consist of semi-consolidated clast supported pebbly conglomerate and Deorali Formation consist of matrix supported boulder conglomerate.

3. Petrographic study of the Sandstone shows they are of arkose, lithic arenite and feldspathic types.

4. Altogether 22 taxa belonging to 14 families of plant are documented from the middle and upper members of Arun Khola Formation. These plant are of the age Middle-Miocene to Early-Pleistocene. Plam are common vegetation showing the tropical to sub tropical climatic condition.

5. Paleocurrent analysis from the pebble imbrication show the flow is toward S56^{0}W around Khani Damar area.

6.2 Recomendations

The Siwalik Group of rocks is best for study the lithological and biological aspect of the geology. The compositional and textural variation of rock units can be observed in small effort. Presence of pollen makes easy to predict the paleo-environment. Field work of the Siwalik is more danger in the summer and warmer time due to the flood and snake problems. Rock of Siwalik is dominantly of coarse grained and dull with almost same compositional character so need great care on the minor properties of the sample. Tectonic features like the MBT, CCT, and HFT should be carefully documented since they are obscured sometimes.

CHAPTER VII
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Annex I: Terminology Used in The pollen Description.

Apex: A general term applied for the tip of an organ. In fossil spores applied to the tip or corner of a trilete spores.

Apocolpium: A region at the pole of a zonocolpate pollen grain delimited by lines connecting the apices of the colpi.

Apolar: Describing pollen and spores without distinct polarity.

Areola: A feature of ornamentation in which the ectexine/sexine is composed of circular or polygonal areas separated by grooves which form a negative reticulum.

Atectate: Describing pollen grains that have an exine with little or no internal structures.

Atrium: A space within the aperture of a compound pore that has a much larger endopore than the ectopore, so that the pore canal widens towards the interior of the grain.

Baculum: A cylindrical, free standing exine element more than 1µm in length and less than this in diameter.

Bilateral: Describing pollen and spores having a single principle plane of symmetry.

Bisaccate: Describing pollen with sacci.

Cappa The thick-walled proximal side of the corpus of a saccate pollen grain.

Cappula: The thin walled distal side of the corpus of a saccate pollen grain (synonym of leptoma).

Caput: The expanded head (apex) of a columella.

Cingulum: A thick outer structure of a spore that projects at the equator, but does not extend over the distal or proximal face.

Colporus: A compound aperture consisting of an ectocolpus with one or more endoapertures. (adj. Colporate)

Colpus: An elongated aperture with a length/breadth ratio greater than 2.

Colpus membrane: The aperture membrane of a colpus.

Columella: A rod like element of the ectexine/sexine, either supporting a tectum or caput. (pl. Columellae)

Commissure : A slit or line of dehiscence in the laesure.

Concordant pattern: A pattern in a tectate pollen grain in which the arrangement of the columellae is the same as that of the elements upon the tectum.

Contact area: Area on the proximal face of a spore interpreted as having been formed in contact with other membrane of the tetrad.

Conus: Cone-shaped elements on the surface of spores in which the height is less than two times the basal diameter and the apex is pointed, blunt and rounded (more or less synonym to spine).

Corona: An equatorial or subequatorial extension of a spore, resembling a cingulum, but divided into fringe-like elements.

Corpus: The body of a saccate pollen grain or camerate spore.

Costa: A thickening of the endexine/nexine bordering an endoaperture or following the outline of an ectoaperture.

Crescentic: Describing a pollen grain in polar view with a very thick exine in the medium of intercolpium, gradually thinning towards the colpi.

Crista: A crest like ornamentation element, taller than it is wide, characterized by a narrowly curved base and a sharp upper edge.

Discordant pattern: A pattern in a tectate pollen grain in which the arrangement of the columellae is different from that of the elements on the tectum.

Distal: A common descriptive term used in contrast to proximal, applied in palynology to features on the surface that face outward in the tetrad stage.

Distal face: The part of a palynomorph that faces outwards the centre of the tetrad, between equator and distal pole.

Distal pole: The centre of the surface of the distal face.

Ectexine: The outer part of the exine. Ectexine consists of foot layer, columella, tectum and sculpture elements.

Ectoaperture: An aperture in the outer layer of the sporoderm.

Endexine: The inner part of the exine.

Endoaperture: An aperture in the inner layer of the sporoderm often the inner aperture of the compound aperture.

Endospore: The innermost layer of a spore wall.

Equator: The dividing line between the distal and the proximal face of a pollen grain or spore.

Equatorial diameter: A line, lying in the equatorial plane, perpendicular to the polar axis and passing through it.

Equatorial outline: General description of the equator when a pollen grain is seen in polar view.

Equatorial plane: The plane perpendicular to the polar axis and lying midway between the poles.

Equatorial view: The view of a pollen grain or spore where the equatorial plane is directed towards the observer.

Exine: The outer layer of the wall of a palynomorph, which is highly resistant to strong acids and bases, and is composed primarily of sporopollenin.

Exospore: The outer layer of a spore wall.

Fissura: A sharp, straight split that appears during germination in certain inaperturate pollen grains (*Taxodium, Cupressus*).

Foot layer: The inner layer of the ectexine.

Fossula: A feature of ornamentation consisting of an elongated, irregular groove in the surface.

Foveola: A feature of ornamentation consisting of more or less rounded depressions or lumina more than 1µm in diameter. The distance between foveolae is greater than their breadth.

Furrow: A common word for an elongate aperture.

Gemma: A sexine element which is constricted at its base, higher than 1µm, and that has approximately same width as its height.

Granule: General word for a small rounded element.

Haploxylon type: Bisaccate pollen in which the outline of the sacci in polar view is more or less continuous with the outline of the corpus, so that the grain appear a more or less smooth ellipsoidal form.

Heterobrochate: Describing a reticulum with brochi of different sizes.

Inaperturate: Describing a pollen grain or spore without aperture.

Intectate: Describing pollen grains without a tectum but with sculpturing.

Intine: The innermost of the major layers of the pollen grain wall underlying the exine and bordering the surface of the cytoplasm.

Laevigate: A general term for smooth, as if polished (syn: psilate)

Leptoma: A thin area at the distal pole of a pollen grain, presumed to function as an aperture.

Laesura: The arm of a proximal fissure or scar of a spore.

Lobate: Describing an equatorially aperturate pollen grain with a lobed shape in polar view.

Lophate: Describing a pollen grain in which the outer exine is raised in a pattern of ridges (lophae) surrounding depressions (lacunae).

Lumen: The space enclosed by the muri.

Megaspore: A general term for large spores of heterosporous vascular plants.

Mesocolpium: The area of a pollen grain surface delimited by lines between the apices of adjacent colpi or margins of adjacent pores.

Microreticulum: A reticulate ornamentation consisting of muri and lumina smaller than 1μm.

Monad: A pollen grain or spore dispersed as an individual unit, rather than in association with others, such as in a dyad, tetrad or polyad.

Mono-aperturate: Describing a pollen grain or spore with a single aperture.

Monolete: Describing a spore with a single laesura.

Monosaccate: Describing a pollen grain with a single saccus.

Murus: A ridge that is part of the ornamentation and, for example, separates the lumina in a reticulate pollen grain or the striae in striate pollen grain (pl. muri).

Nexine: The inner, non-sculptured part of the exine which lies below the sexine.

Oblate: Describing the shape of a pollen grain or spore in which the polar axis is shorter than the equatorial diameter.

Palynofacies: The assemblages of phytoclasts found in a particular sediment, such as palynomorphs, wood fragments and cuticles.

Palynology: The study of pollen and spores and of other biological materials that can be studied by means of palynological techniques.

Palynomorphs: A general term for all entities found in palynological preparations.

Panto-aperturate: Describing a pollen grain with apertures spread over the surface sometimes forming a regular pattern.

Perforate: A general adjective indicating the presence of holes, applied in palynology to holes less than 1μm in diameter and generally situated in tectum.

Pitted: A general term for small depressions (syn. foveolate).

Polar view: A view of a pollen grain or spore in which the polar axis is directly towards the observer.

Pollenkitt: A sticky material, produced by tapetum that may hold pollen grains together during dispersal.

Pore: A general term, applied in palynology to a circular or elliptic aperture with a length breadth ratio less than two.

Prolate: Describing the shape of a pollen grain or spore in which the polar axis is larger than the equatorial diameter.

Proximal face: The part of a palynomorph which faces towards the centre of the tetrad, between equator and proximal pole.

Proximal pole: The centre of the proximal face.

Psilate: Describing a pollen or spore with a smooth surface.

Reticulum: A network-like pattern consisting of lumina or other spaces wider than 1µm bordered by elements narrower than the lumina.

Rugulate: Describing a type of ornamentation consisting of elongated sexine element more than 1µm long, arranged in an irregular pattern that is intermediate between striate and reticulate.

Saccus: An expanded sac formed by a local separation within the exine of a pollen grain and at least partly filled with an alveolate infrastructure.

Scabrate: Describing elements of ornamentation, of any shape, smaller than 1µm in all direction (*e.g. Quercus, Artemisia*).

Sculpturing: The surface relief, or topography, of a pollen grain or spore.

Sexine: The outer, sculptured layer of the exine, which lies above the nexine.

Spheroidal: Describing the shape of a pollen grain or spore in which the polar axis and the equatorial diameter are approximately equal.

Spine: A general term applied in palynology to long tapering pointed elements.

Sporoderm: The entire wall of a pollen grain or spore.

Sporomorph: A general term for spore-like palynomorphs.

Striate: A general descriptive term applied in palynology to elongated, generally parallel elements separated by grooves.

Striato-reticulate: Describing a pattern in which parallel or subparallel muri are cross-linked to form a reticulum in the grooves. The connection of muri lie on a single level or different level.

Tectum: The layer of sexine, which forms a roof over the columellae.

Tetrad: A general term for a group of four pollen grains or spore, either as dispersal unit or as a developmental stage.

Tetrahedral tetrad: A multiplanar tetrad in which each member is in contact with three others, so that the centres of the grains define a tetrahedron. (e.g. Ericaceae)

Tricolpate: Describing pollen grains with three ectocolpi, three compound apertures or three pores.

Trilete: Describing a spore with laesurae, thus showing a trilete mark.

Trilete mark: The triradiate mark of a trilete spore.

Velum: A feature of a monosaccate pollen grain in which the saccus is convoluted.

Verruca: A wart-like sexine element, more than 1µm wide, that is broader than it is high and is not constricted at the base.

Vestibulum: A separation between two layers of the exine forming a cavity between the inner and outer pores. (*e.g. Betula*)

Viscin thread: A general botanical term applied in palynology for an acetolysis resistant, sporopollenin thread arising from the exine of a pollen grain, usually from the proximal surface (e.g. Ericaceae).

Zono-aperturate: Describing a pollen grain with apertures situated only at the equator.

Annex II : Geological Map of the study Area