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Stratigraphy and structural framework of the Sub-Himalaya, Bagmati River region, Central Nepal*

T. P. Adhikary and L. N. Rimal
Department of Mines and Geology, Lainchaur, Kathmandu, Nepal

ABSTRACT

The Sub-Himalaya in the Bagmati River region of central Nepal consists of two groups of rocks very different in age and characters. The Bagmati Group, an assemblage of pre-Siwalik rocks are found within the Siwalik Group. The Bagmati Group consists of sedimentary rocks, metasediments and basic rocks. The Siwalik Group is divided into the Lower, Middle and Upper Siwaliks. The Upper Siwalik is further subdivided into the Gadhan Khola, Chiruwa Khola and Bhainse Khola Formations. Vertebrate fossils were found in the lower and middle part of the Upper Siwaliks. An index fossil identified as *Elephas planifrons* was discovered for the first time in this region from a massive sandstone bed belonging to the upper part of the Upper Siwaliks. A conglomerate horizon with predominantly Siwalik sandstone clasts occur at the uppermost level of the Siwalik Group exposed in the southern belt. They in turn are unconformably overlain by flat lying younger Dun gravels.

The Sub-Himalayan rocks are distributed into the northern and the southern belts, separated by the Chaura-Marin Thrust. The northern belt is characterised by a number of thrusts and faults resulting in the cropping out of the Bagmati Group sediments and the repetition of the formations of the Siwalik Group. The southern belt shows largely north dipping sequences from the Lower to the Upper Siwaliks. Both the belts show plunging folds in the vicinity of the thrusts. Several NW-SE, NE-SW and N-S trending faults have cut across the entire Siwalik Range.

INTRODUCTION

A number of workers have taken traverses in the past across the Sub-Himalaya of Nepal (Fig.1). Based on the lithology most of them (Auden, 1935; Gansser, 1964; Itihara et al, 1972; Nakajima, 1982 and others) have accepted a three fold subdivisions of the Siwalik Group in Nepal. The upward coarsening litho-units and the repetition of these units due to thrusting have been widely recognised. Until 1986, it was considered that the Sub-Himalaya of Nepal consisted of only the terrestrial molasse type of Mid-Miocene to Lower Pleistocene sediments. Herail et al.(1986) first pointed out the occurrence of Muree type rocks (pre-Siwalik rocks) and associated dolerites in the Bagmati River basin of central Nepal. Kaphle and Pant (1988), reported the occurrence of a small body of basic rock (dolerite) in Dawar Khola (Fig.3). Later Kaphle and Einfalt (1992) carried out petrological and geochemical analysis of the basic rocks of the same area and concluded that they are volcanites having basaltic composition. They, however, thought that the volcanites occur within the Lower Siwaliks. Schelling (1992) constructed the balanced cross section of the Siwaliks in the Bagmati River region and estimated the crustal shortening of the Siwaliks in this area in the order of 20 km.

The stratigraphy of the Siwalik Group was primarily based on lithological comparison with the known sequences in India and Pakistan. The stratigraphy of the Siwalik Group in Nepal and the boundary between Lower, Middle and Upper Siwaliks have remained a subject of discussion till today, although sporadic cases of the discovery of index fossils (Sharma, 1977; West and Munthe, 1981; Munthe et al., 1983) have been reported from time to time in different parts of Nepal Sub-Himalaya. Studies of the paleomagnetic polarity carried out by

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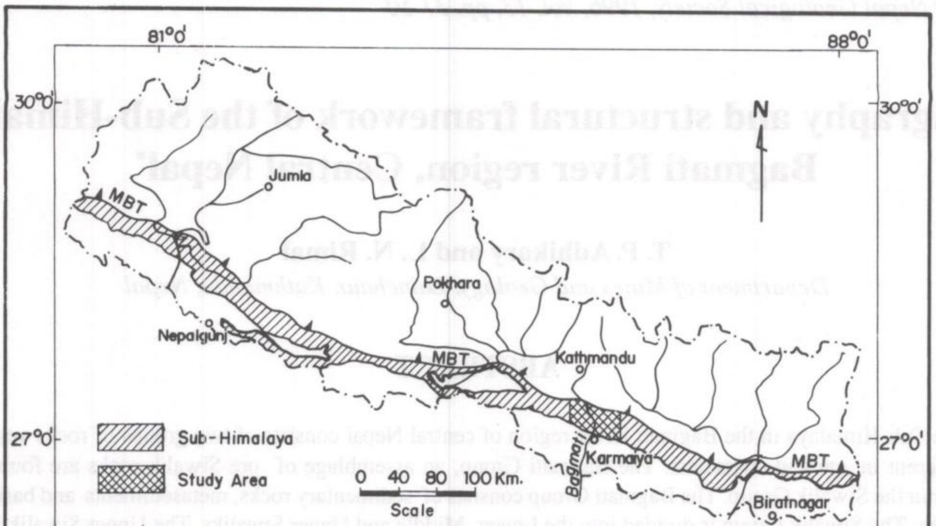

Fig. 1: Location map of the study area.

Tokuoka et al. (1986), Appel et al. (1991), Gautam and Appel (1994) etc. and the systematic paleontological study carried out by Corvinus (1993) in Dang, south western Nepal have redefined the position of boundaries between the Lower and the Middle as well as the Middle and the Upper Siwalik Formations. The Siwalik Group belongs to Upper Miocene to early Pleistocene age.

STRATIGRAPHY

The geological map and the cross sections of the Sub-Himalayan belt of the Bagmati River region is shown in Fig. 2 and 3 and the generalized columnar section is shown in Fig. 4.

The Bagmati Group

This group occurs only in the northern belt on the southern slope of the Churia Ridge (Fig. 2). It forms a 1-4 km wide zone and can be traced for about 35 km along the strike. It has a tectonic contact on both sides with the rocks of the Siwalik Group. It is represented by undifferentiated sedimentary rocks and metasediments in association with sills of basic rocks.

The Bagmati Group dominantly consists of sedimentary rocks such as sandstones, quartzitic sandstones of red brown to light brown and grey white and brown micaceous quartzites (Fig. 4,5). These rocks are moderately to thickly bedded and fine grained. Cross laminations are common in the red brown sandstones. Ripple marks and mud cracks are also occasionally seen. Beds of sandstones and shales intercalations with thickness of a few metres to tens of meters are also present. These grey, violet, and brown coloured rocks are intensly folded exhibiting tight isoclinal to chevron folds. A number of medium to coarse grained basic rocks of dull green occasionally of reddish brown colour are also noted. These basic rocks are about 30 to 100 m thick and show roughly concordant relation with the sedimentary rocks. These basic rocks are present in the vicinity of the faults and are accompanied by thin, gritty sandstones and by 2-3 meter thick sheared hematite beds.

The basic rocks are also exposed along the upper and the lower contacts of the Bagmati Group rocks, east of the Bagmati River. An excellent exposure of the basic rock was encountered at the left bank of the Bagmati River (Fig. 2,4,5). The Dowar Khola and the Basan Khola sections reveal a number of basic rock bodies; at the lower, middle and the upper part of the sequence. To the west of the Bagmati River, a single band of the basic rock was encountered in the upper part of the Bagmati Group, exposed in the upper reaches of the Devjhar Khola.

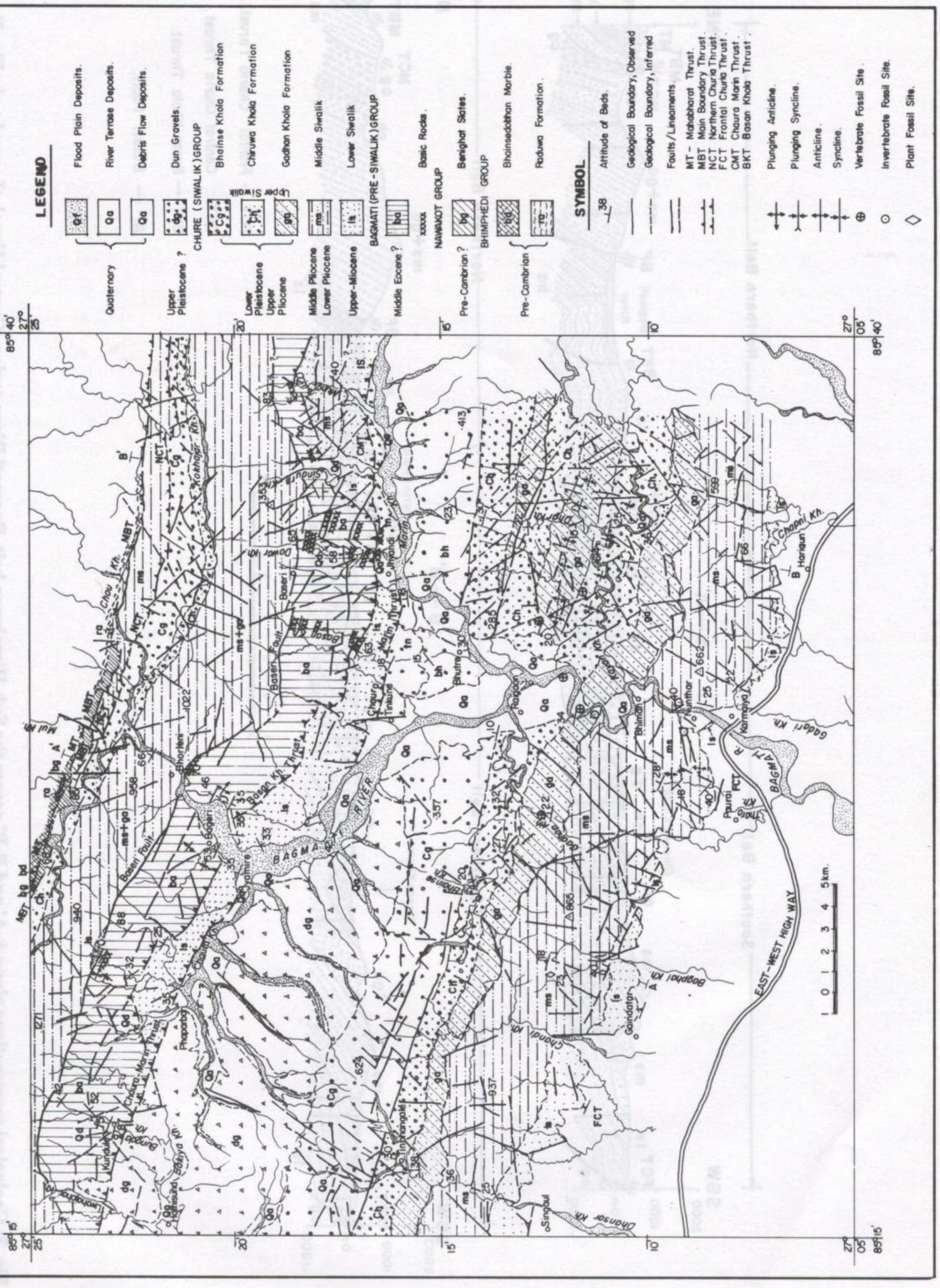

Fig. 2: Geological map of the Sub-Himalayan belt, Bagmati River region, Central Nepal.

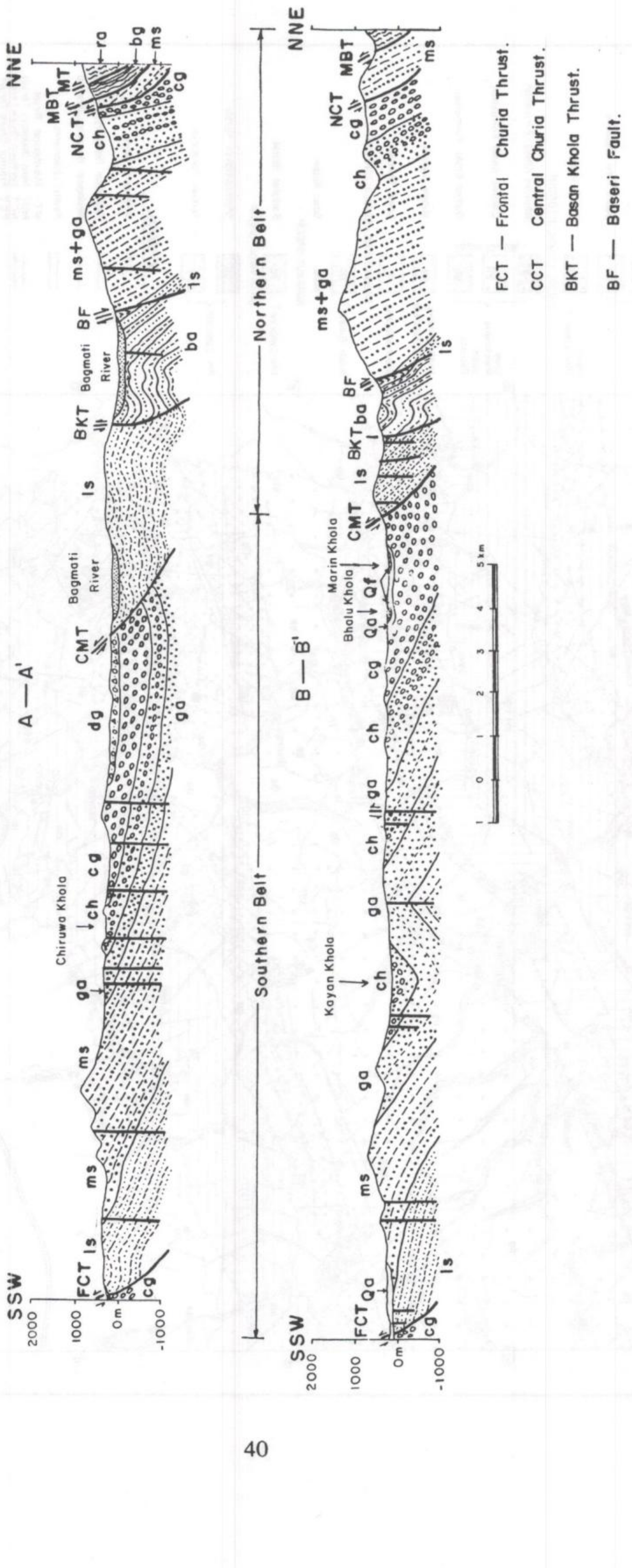

Fig. 3: Geological crosssections along A-A' and B-B' across the Sub-Himalayan belt, Bagmati River region, Central Nepal. (Legend as in Fig. 2)

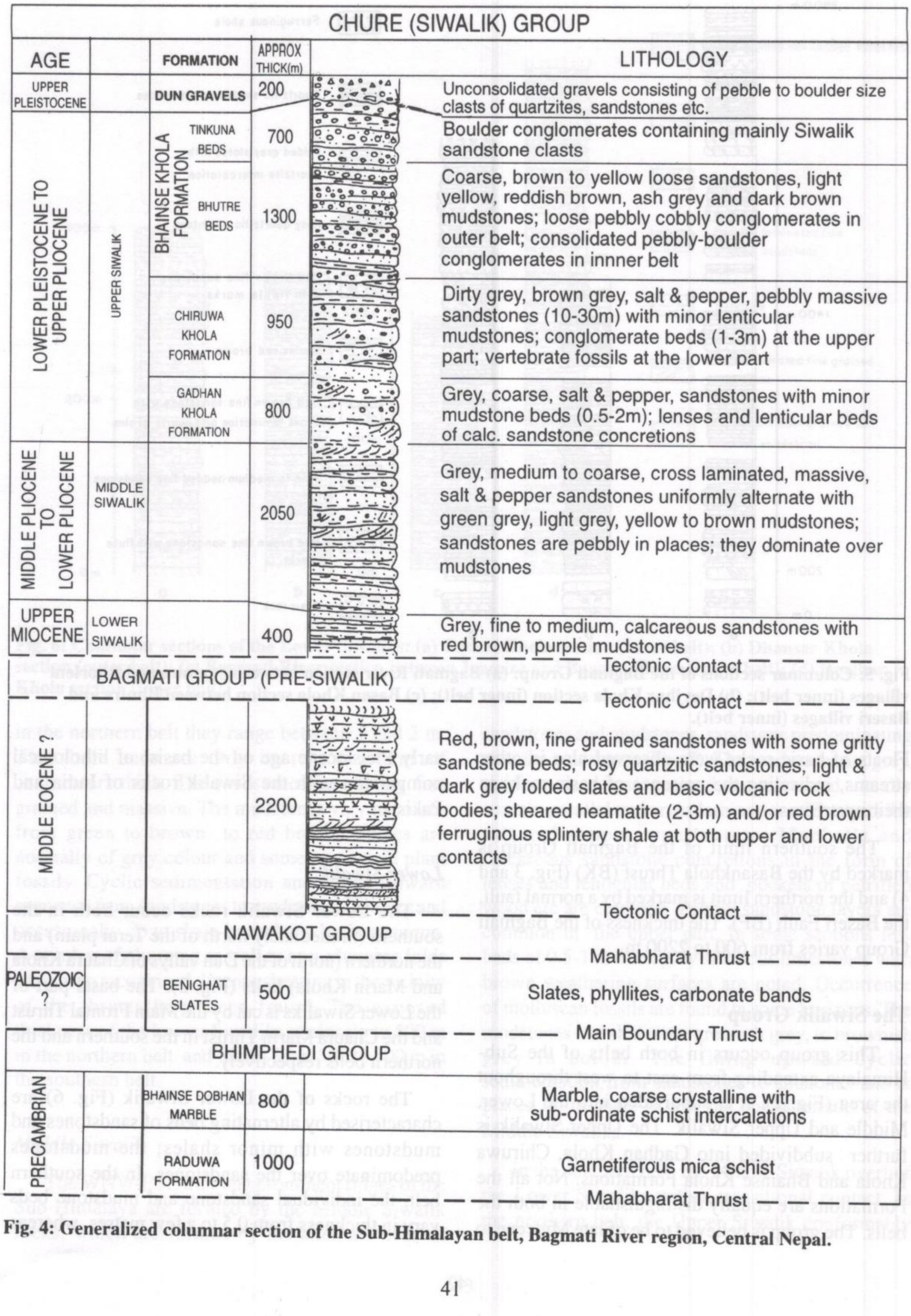

Fig. 4: Generalized columnar section of the Sub-Himalayan belt, Bagmati River region, Central Nepal.

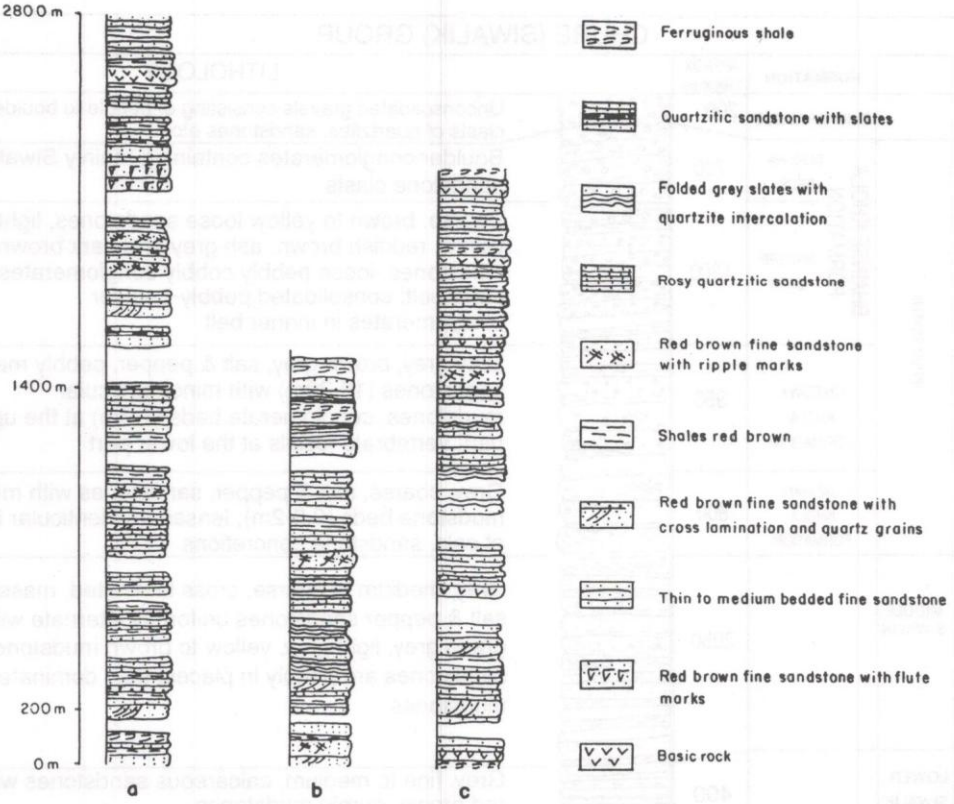

Fig. 5: Columnar sections of the Bagmati Group: (a) Bagmati River section between Jyamire and Bhorleni villages (inner belt); (b) Devjhar Khola section (inner belt); (c) Basan Khola section between Bhutre and Baseri villages (inner belt).

Floats of basic rocks were observed also in other streams, indicating the presence of basic rocks in their upstreams.

The southern limit of the Bagmati Group is marked by the Basankhola Thrust (BK) (Fig. 3 and 4) and the northern limit is marked by a normal fault, the Baseri Fault (BF). The thickness of the Bagmati Group varies from 600 to 2200 m.

The Siwalik Group

This group occurs in both belts of the Sub-Himalaya extending from east to west throughout the area (Fig. 2). It is subdivided into the Lower, Middle and Upper Siwalik. The Upper Siwalik is further subdivided into Gadhan Khola, Chiruwa Khola and Bhainse Khola Formations. Not all the Formations are equally distinguishable in both the belts. The group is believed to be of late Miocene to early Pleistocene age on the basis of lithological comparison with the Siwalik rocks of India and Pakistan.

Lower Siwalik

The Lower Siwalik rocks occur both in the southern (immediately north of the Terai plain) and the northern (north of the Dun vallys of Chaura Khola and Marin Khola) belts (Fig. 2). The basal part of the Lower Siwaliks is cut by the Main Frontal Thrust and the Chaura Marin Thrust in the southern and the northern belts respectively.

The rocks of the Lower Siwalik (Fig. 6) are characterised by alternating beds of sandstones and mudstones with minor shales; the mudstones predominate over the sandstones. In the southern belt, the individual sandstone and mudstone beds vary in thickness from 0.5 to a few metres, whereas

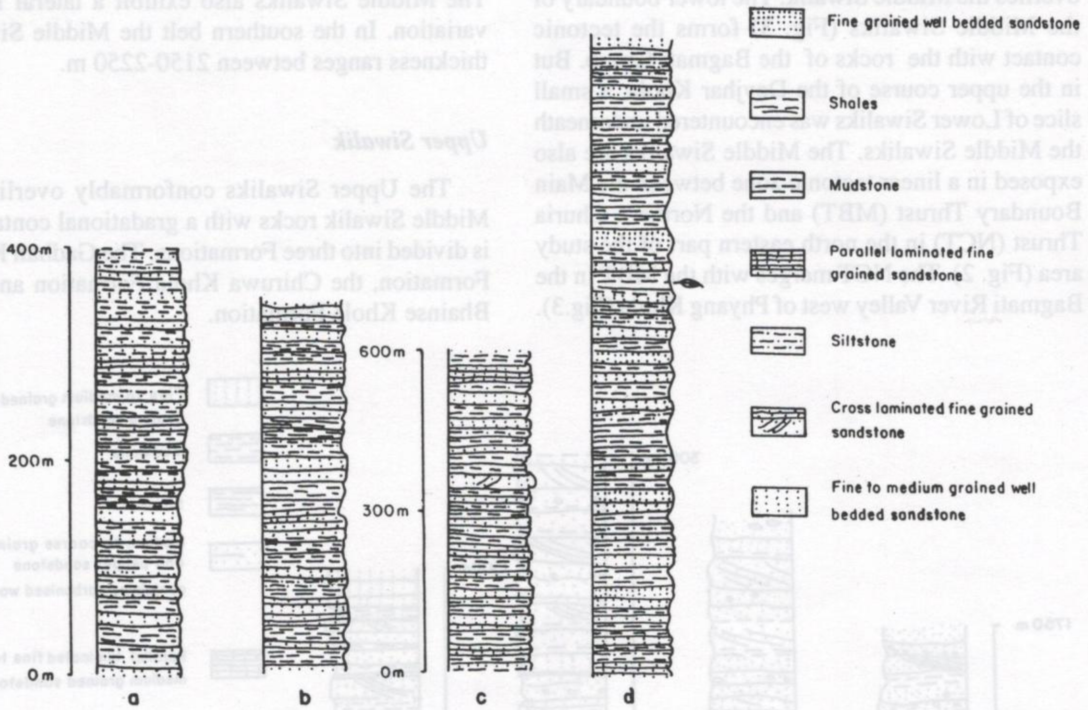

Fig. 6: Columnar sections of the Lower Siwaliks: (a) Gaderi Khola section (outer belt); (b) Dhansar Khola section (outer belt); (c) Bagmati River section between Jyamire and Bageri villages (inner belt); (d) Devjhar Khola section (inner belt).

in the northern belt they range between 1 and 2 m. The shale beds are only up to a few tens of centimeters thick. The sandstones are usually fine grained and massive. The mudstones vary in colour from green to brown to red brown. Shales are normally of grey colour and sometimes yield plant fossils. Cyclic sedimentation and fining upward sequence from sandstones to mudstone/siltstones and occasionally up to shale in each cycles is common. A number of plunging as well as non-plunging folds have been recognized. Intense shearing in the vicinity of the thrusts have been found. The exposed thickness of the Lower Siwaliks attains up to 500 m in the northern belt and varies from 300 to 400 m in the southern belt.

Middle Siwalik

The WNW-ESE trending prominent ridges of the Sub-Himalaya are formed by the Middle Siwalik rocks, which are formed by the alternate beds of sandstones and mudstones, sandstone predominating over the mudstones (Fig. 7). The sandstones are grey, medium to coarse grained, massive and usually contain parallel and cross laminations. They exhibit salt-and-pepper type texture. Mudballs and calcareous sandstone concretions in the form of lenses and lenticular beds and pockets of petrified wood etc are common. Pebbly sandstone layers are common in the upper part. In some sections few beds of 0.5-1 m thick grey siliceous limestones with brown weathering surfaces are noted. Occurrence of molluscan fossils are found in some horizons. The mudstones and shales are greenish grey, to brownish grey in colour. The fining upward cyclic sedimentation from sandstones to siltstones and at places up to shale is also the characteristic of the Middle Siwaliks.

In the southern belt, the Middle Siwalik overlies the Lower Siwaliks with a transitional contact. In the northern belt, the Upper Siwalik conformably overlies the Middle Siwalik. The lower boundary of the Middle Siwaliks (Fig. 3) forms the tectonic contact with the rocks of the Bagmati Group. But in the upper course of the Devjhar Khola, a small slice of Lower Siwaliks was encountered underneath the Middle Siwaliks. The Middle Siwaliks are also exposed in a linear tectonic zone between the Main Boundary Thrust (MBT) and the Northern Churia Thrust (NCT) in the north eastern part of the study area (Fig. 2). The NCT merges with the MBT in the Bagmati River Valley west of Phyang Khola (Fig.3). The Middle Siwaliks also exhibit a lateral facies variation. In the southern belt the Middle Siwalik thickness ranges between 2150-2250 m.

Upper Siwalik

The Upper Siwaliks conformably overlie the Middle Siwalik rocks with a gradational contact. It is divided into three Formations: The Gadhan Khola Formation, the Chiruwa Khola Formation and the Bhainse Khola Formation.

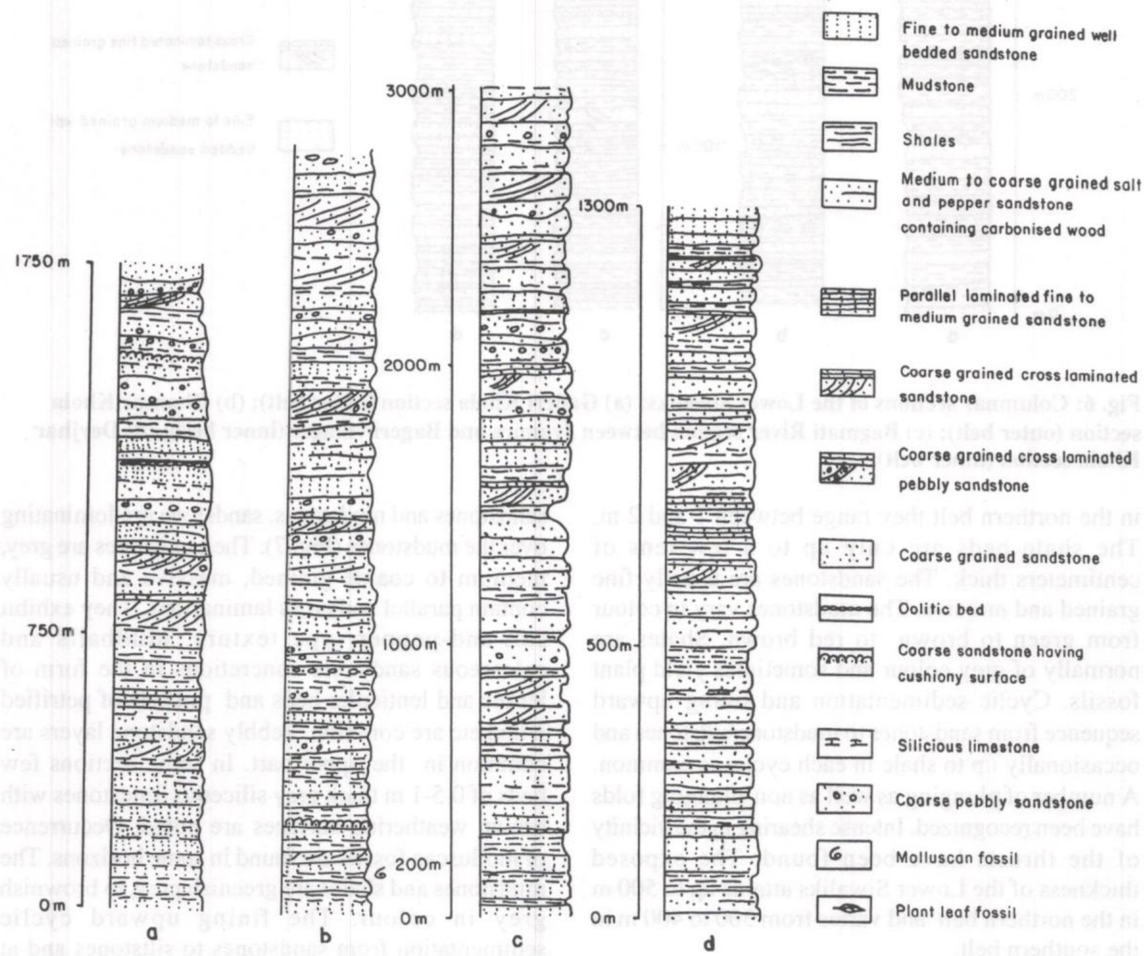

Fig. 7: Columnar sections of the Middle Siwaliks: (a) Dhansar Khola section (outer belt); (b) Bagmati River section between Nunthar and Bhiman villages (outer belt); (c) Bagmati River section between Bhorleni and Hatisar villages (undifferentiated Middle Siwaliks and the Gadhan Khola Formation of the Upper Siwaliks)(inner belt); (d) Mul Khola section (inner belt).

The Gadhan Khola Formation: This formation is named after the Gadhan Khola, a southern tributary of the Bagmati River (Fig. 2). It has a thickness of about 700-1000 m and forms the lowest unit of the Upper Siwaliks. It is represented only in the southern belt. This formation is characterised by thick sandstone beds intercalated with thinner mudstone beds (Fig. 8). The sandstones are coarse grained, calcareous, cross laminated, and show a salt-and-pepper appearence. They are often pebbly and contain calcareous sandstone concretions in the form of lenses and lenticular beds. A bovid tooth was found in one of the puddingstone beds. A few vertebrate fossil fragments and coalified wood pieces were recorded from the sandstones.

The Chiruwa Khola Formation: This formation is named after the Chiruwa Khola lying in the southern belt. It has been recognised in both the belts. The formation is 800-1000 m thick in the southern belt, and about 500 m in the northern belt. It conformably overlies the Gadhan Khola Formation. This formation can be recognised in the Kayan Khola area, east of the Bagmati River, occupying the core of the Kayan Khola Syncline, and also in the flanks of the corresponding Kashbagar anticline (Fig. 2). It mainly consists of coarse, pebbly sandstones and thin conglomerate horizons.

The absence of the calcareous sandstone concretions in the Chiruwa Khola Formation indicates its non-calcareous environment of deposition and it is an important criteria for distinguishing this formation from the underlying Gadhan Khola Formation. In the southern belt, this formation is characterised by very thick (upto 30 m) sandstone beds. Minor lenticular greenish mudstones (1-3 m thick) are present at the basal part of the formation (Fig. 9). In the upper part of the unit, the conglomerate beds (1-3 m thick) with pebble to cobble size clasts of mostly quartzites alternate with coarse, salt-and-pepper sandstone beds. The sandstones and mudstones commonly show cross-laminations. Several vertebrate fossil remains of post-cranial bones and teeth have been found within the pebbly sandstones, including a maxilla of a proboscidae identified as *Elephas planifrons* (size 0.31 m x 0.19 m x 0.15 m) and second and third molars of a *Hexaprotodon sivalensis*. The above fossils were identified by Dr. A.C. Nanda of Wadia Institute of Himalayan Geology, India.

In the northern belt, the Chiruwa Khola Formation conformably overlies the underlying Gadhan Khola Formation (Fig. 2). In the Bagmati River section, this formation begins with a pebbly conglomerate bed (Fig. 9c).The formation is characterised by the presence of thick sandstone beds (6-15 m) interbedded with mudstones (1-2 m thick). The sandstones are medium to coarse grained, and show salt-and-pepper texture. The pebbly sandstones (2.5- 4 m thick) are common in the middle part, which gradually pass upward to thicker beds of pebbly conglomerates.

The Bhainse Khola Formation: This formation with a thickness of 900-1300 m in the southern belt, and 500-1500 m in the northern belt, is the uppermost member of the Upper Siwaliks. It conformably overlies the Chiruwa Khola Formation with a sharp contact and is marked by the appearence of the thick conglomerate beds (about 10 m) in both the belts. In the southern belt, to the east of the Bagmati River, this formation has been subdivided into: a) Bhutre Member and b) Tinkuna Member (Fig. 2). To the west of the river, they are not differentiable.

Bhutre Member: It consists of conglomerate beds with rounded to sub-rounded pebbles, cobble and boulder size clasts of quartzites and occasionally granites with a silty sand and calcareous sandy matrix (Fig. 10b). The conglomerates contain lenticular beds (0.1-2 m) of sandstones and mudstones.

Tinkuna Member: This member forms the upper part of the Bhainse Khola Formation. It can be claearly identified in the Marin Khola section (Fig. 2) by the presence of unsorted and unconsolidated conglomerates with boulder size clasts of exclusively Siwalik sandstones in a silty sand matrix. (Fig. 10b).

The northern belt of the Sub-Himalaya exhibits undifferentiated Bhainse Khola Formation, which is clearly recognised in the Chau Khola, Kokhajor Khola, Mul Khola and in the Bagmati River upstream from Hatisar village (Fig. 2). The formation is represented by alternating beds of conglomerates and sandstones at the lower part, which gradually passes upward into the monotonous conglomerate.

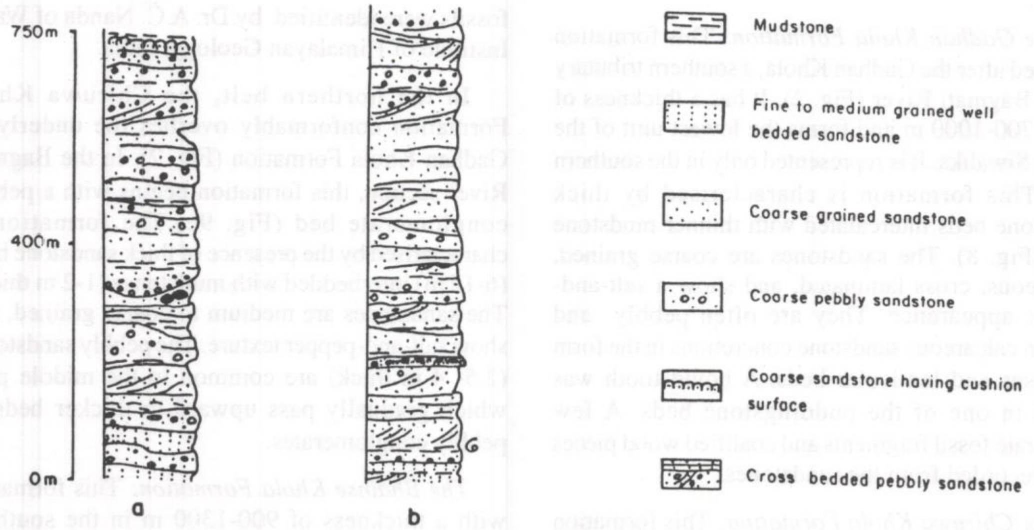

Fig. 8: Columnar sections of the Gadhan Khola Formation, Upper Siwaliks: (a) Dhansar Khola section (outer belt); (b) Bagmati River section between Bhiman and Raigaon villages (outer belt).

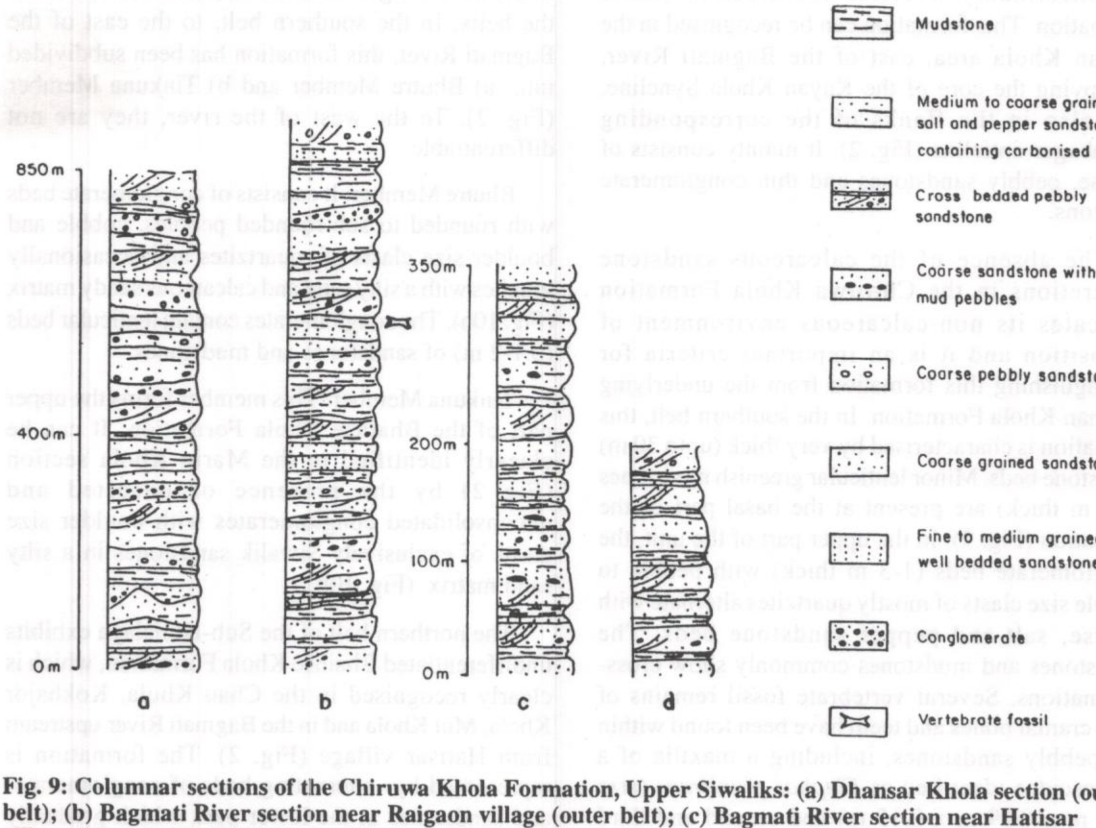

Fig. 9: Columnar sections of the Chiruwa Khola Formation, Upper Siwaliks: (a) Dhansar Khola section (outer belt); (b) Bagmati River section near Raigaon village (outer belt); (c) Bagmati River section near Hatisar village (inner belt); (d) Kokhajor Khola section (inner belt).

The conglomerates are composed of pebble to boulder size clasts of mainly quartzites, and occasionally granites (Fig. 10c). The conglomerates with predominantly Siwalik sandstone clasts similar to the Tinkuna Member of the southern belt are not developed in the northern belt.

POST SIWALIK SEDIMENTS

In the southern belt, the post Siwalik sediments are represented by Dun gravels and alluvial deposits, whereas in the northern belt they consist of debris flow and alluvial deposits. About 200 m thick Dun gravel deposit occupies a vast area of the wide valley between the two major Churia Ridges. They unconformably overly the Bhainse Khola Formation (Fig. 2). They form unconsolidated, nearly horizontal deposits of pebble to boulder size clasts of quartzites, sandstones and some granites in a silty sand matrix (Fig. 3) as well as angular blocks of fine grained Siwalik sandstones. Stratification is very weak to absent. The rounded to sub-rounded quartzite clasts seem to have derived from the Bhainse Khola Conglomerate whereas the sub-rounded to sub-angular clasts of sandstones may have originated from the lower part of the Siwalik sediments.

A clear erosional and depositional history can be observed in the area. The area previously occupied by the very weakly consolidated conglomerates of the Upper Siwaliks was extensively eroded to a well stablished base level. The lateral streams draining the area then redeposited these eroded conglomeratic material from the Upper Siwaliks into the Dun basin to form the Dun gravels.

TECTONICS

The Main Boundary Thrust (MBT) separates the Siwaliks from the Lesser Himalaya whereas the Himalayan Frontal Thrust (HFT) separates the Terai Plain (Indo-Gangetic plain) from the Siwaliks. The Siwalik Zone has a distinct tectonic architecture characterised by simple homoclinal structure. The Chaura-Marin Thrust (CMT) has divided the Sub-Himalayan domain into two main structural units: the southern belt and the northern belt (Fig. 3). A series of almost east-west trending tight folds are present near the southern margin of each belt. They are mainly asymmetrical plunging folds with the

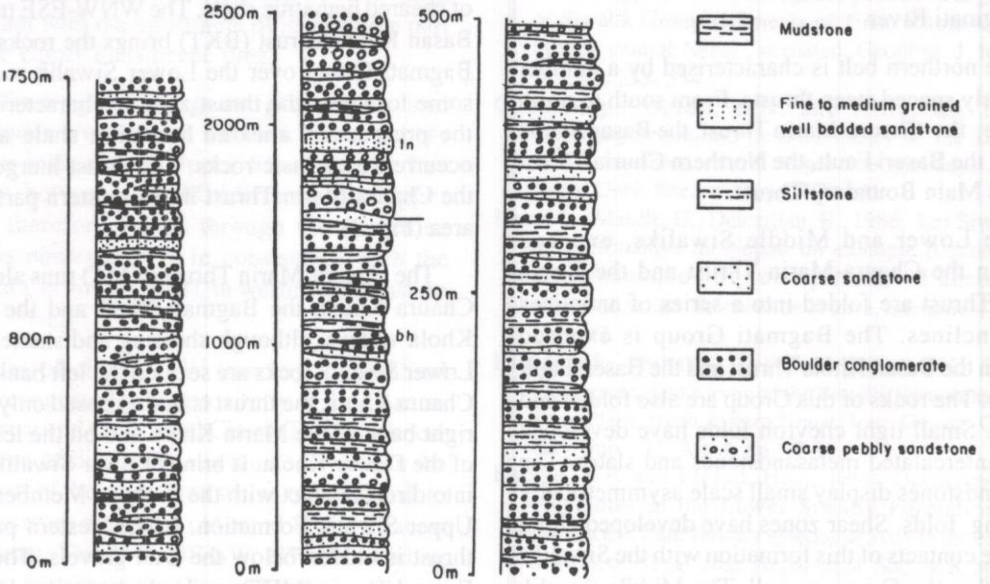

Fig. 10: Columnar sections of the Bhainse Khola Conglomerate, Upper Siwaliks: (a) Bhainse-Khahare Khola section (outer belt); (b) Basan Khola section (outer belt) showing Bhutre Member (BH) and Tinkuna Member (TN); (c) Mul Khola section (inner belt).

axial plane inclined towards the north. The interpretation of the aerial photographs has revealed a number of lineaments with WNW-ESE, N-S, NW-SE and NE-SW trends. The WNW lineament corresponds to longitudinal thrusting and reverse faulting, whereas the other three are transverse faults which cut across the entire Siwalik Range. The drainage of the region mostly follows these fault systems (Figs. 2).

The southern belt is characterised by a continuous sequence of monoclinally north dipping Siwalik beds which gradually change their dips from 45-50° in the Lower Siwalik to 10-15° in the Upper Siwalik leading to open broad syncline filled with Dun gravel deposits. Towards east of the Bagmati River in the central part of the area, the Gadhan Khola and Chiruwa Khola Formations of the Upper Siwaliks are folded into an open, west plunging syncline named as the Kayan Khola Syncline which forms a negative relief. The corresponding Kashbagar anticline forms a positive relief. Both folds are almost symmetrical with very gently dipping beds of 11-16° and plunge 20° towards west. The two Upper Siwalik formations are further repeated to the north due to thrust faulting. These folds and thrust structures however, do not continue westward from the Bagmati River.

The northern belt is characterised by a number of closely spaced steep thrusts. From south to north they are: the Chaura-Marin Thrust, the Basan Khola Thrust, the Baseri Fault, the Northern Churia Thrust and the Main Boundary Thrust.

The Lower and Middle Siwaliks, exposed between the Chaura-Marin Thrust and the Basan Khola Thrust are folded into a series of anticlines and synclines. The Bagmati Group is exposed between the Basan Khola Thrust and the Baseri Fault (Fig. 2). The rocks of this Group are also folded and faulted. Small tight chevron folds have developed in the intercalated metasandstones and slates. The metasandstones display small scale asymmetrically plunging folds. Shear zones have developed along both the contacts of this formation with the Siwaliks and within the Group as well. The Middle Siwalik rocks crops out three times along the linear tectonic zones between the Chaura Marin Thrust and the Main Boundary Thrust. The zone is wider in the north east and gradually narrows westward.

Major Tectonic Elements

The Main Boundary Thrust (MBT) runs mainly along the northern hillslopes of the Bagmati River and the Chau Khola bringing the Lesser Himalayan rocks in juxtaposition with Middle and Upper Siwalik sediments (Fig. 2). The thrust zone is 10-15 m wide. Near the thrust the steepening of beds and even overturning in some places, are common. At places it is displaced by N-S and NE-SW trending transverse faults. The Northern Churia Thrust (NCT) extends almost parallel to the Main Boudary Thrust in the north-east part of the study area and merges with the MBT in the Bagmati River Valley west of Phyang Khola (Fig. 2). It has brought Middle Siwaliks over the Bhainse Khola Conglomerate of the Upper Siwaliks. The thrust is characterised by a a few meters wide shear zone.

The Baseri Fault (BF) is a steeply north dipping normal fault which separates the rocks of the Bagmati Group (foot wall) from the northern homoclinal sequence of Middle to Upper Siwalik rocks (hanging wall). In the Devjhar Khola, a slice of the Lower Siwalik rocks is in juxtaposition along the fault with the rocks of the Bagmati Group. The shearing along this fault is marked by the occurrence of sheared hematitic shale. The WNW-ESE trending Basan Khola Thrust (BKT) brings the rocks of the Bagmati Group over the Lower Siwalik rocks. At some locations the thrust zone is characterised by the presence of sheared hematitic shale and the occurrence of basic rocks. The thrust merges with the Chaura-Marin Thrust in the western part of the area (Fig. 2).

The Chaura-Marin Thrust (CMT) runs along the Chaura Khola, the Bagmati River and the Marin Khola valleys, although shearing and shattering of Lower Siwalik rocks are seen on the left bank of the Chaura Khola, the thrust is best exposed only on the right bank of the Marin Khola and on the left bank of the Dawar Khola. It brings Lower Siwalik rocks into direct contact with the Tinkuna Member of the Upper Siwalik Formation. In the western part, the thrust is hidden below the Dun gravels. The Main Frontal Thrust (MFT) marks the boundary between the Churia hills and Terai Plains. The thrust itself was not observed on the surface. However, the effects of the thrusting on the rocks of the hill front are clearly pronounced. The thrust gives rise to the longitudinal folding, shearing and back-thrusting, which involves the rocks of the Lower and the Middle Siwaliks.

DISCUSSION AND CONCLUSIONS

The Bagmati Group is a distinct lithological unit of pre-Siwalik age. It lies within a tectonic zone bounded on both sides by thrusts. These pre-Siwalik group of rocks are exposed only in the northern belt. They are sandwitched between the underlying Lower Siwaliks and overlying Middle Siwalik rocks. Basic rock bodies are identified within this unit. Herail et al., (1986) suggested the Bagmati Group to be equivalent to the Muree Formation. However, the palaeomagnetic study of the dolerites found within the Bagmati Group of Dowar Khola area (Gautam et al., 1995) indicates an age between Eocene and Early Oligocene. To the present authors the rocks of the Bagmati Group could be even older than Eocene.

The lithostratigraphic units of the Lower to Upper Siwalik rocks of the study area has been traced for nearly 40 km. The facies of the Siwalik sequences in the northern belt are not well comparable with the sequences of the southern belt, though the overall lithology of both the belts is similar. The restricted occurrence of the Siwalik sandstone clast dominated conglomerates of the Upper Siwaliks in the southern belt indicates a southward migrating Siwalik basin concomitant with the upliftment of its northern part during the Upper Pleistocene time.

The finding of *Elephas planifrons* and *Hexaprotodon sivalensis* in the thick coarse pebbly sandstone indicate an Upper Siwalik age. The boundary between the Middle and the Upper Siwaliks therefore passes through the sandstone beds. This observation is in consistency with the findings of Corvinus (1993), in western and eastern Nepal.

A series of almost E-W trending longitudinal folds are recognized in the proximity of the Chaura-Marin Thrust and the Frontal Churia Thrust. A linear arrangement of discontinuous fault scarplets in the western part of the study area seems to be related to the rejuvenation along the old trend of the Chaura-Marin Thrust. The N-S, NE-SW, NW-SE trending lineaments cut across the Churia Range.

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