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# *Lithostratigraphy and structures of the Siwaliks rocks in the southern part of Dang and its surrounding area, Southwestern Nepal*

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## Abstract

Late Cainozoic fluvial sedimentary sequences of the Siwalik Group is extensively accumulated in the southern frontal part of the Himalaya and well exposed along southern part of Dang and in all sides of the Deukahari Valley of west-central Nepal Himalaya. Lithostratigraphy of the succession consists of the Bankas Formation, Chor Khola Formation, Suria Khola Formation, Dobata Formation, and the Dhan Khola Formation in an ascending order. The Bankas Formation is represented by an interbedding of red-purple mudstones, shales, and fine-to very fine-grained sandstones. The Chor Khola Formation shows a gradual increase of sandstone grain size as well as thickness of beds. The sandstones are calcareous and rich in plant fossils. The mudstones are variegated in the lower part and gray-green in the upper part. The Surai Khola Formation is mainly represented by multi-storied, coarse-to very coarse-grained 'salt and pepper' sandstones. The beds yield a great amount of petrified wood in the form of steams, branches, and roots. The Dobata Formation is predominated by mudstones with a minor amount of sandstones and conglomerates. The Dhan Khola Formation comprises compact and hard boulder-and pebble-bearing conglomerates with yellow mudstones in the lower part and not well cemented conglomerates with yellow mudstones in the upper part. The sandstones of the study area mostly belong to the litharenite and subordinately to the sub-litharenite. The rocks show coarsening-upward succession in general but many fining-upward fluvial successions on a scale from several to tens of meters is established in each lithological unit. The Siwalik rocks show a coarsening-upwards sequence, evidencing a continuous uplift of the Himalayas. However, the individual depositional units show a fining-upwards sequence reflecting the fluvial depositional environment. The

detailed lithostratigraphic study and geological mapping of the area show that the rocks of the present study area are lithostratigraphically similar to those of the Surai Khola area located in the east of the study area.

The rocks distributed in the study area are highly deformed. The persistence of shortening between Indian Plate and Asian Plate involves their deformation. This deformation is expressed in the form of faults and folds which succeed one another in both space and time. The study area is subjected to more than one phase of deformational process. Series of faults such as the Bheri Thrust, Mali Khola Thrust, Babai Back Thrust, Tui Khola Back Thrust, and Rapti Back Thrust and also a number of folds as Baijapur Anticline, Bhaisahi Anticline, Khairi Khola Anticline, and Malai Khola Anticline, Agaiya Syncline, Satbariya Syncline, and Masot Khola Syncline delineate the study area. The pattern of thrusting here is related to the thin -skin tectonic model. The thrusts show the ramp-flat geometry and the thrusting is related to the piggy-back propagation pattern. Due to this thrusting the rocks here are repeated more than five times. The Dang Valley is located in a triangle zone bounded by the thrusts, which seems to be generated by retardation of faulting, thrusting and folding.

## Introduction

The study area is situated about 338 km west of Kathmandu, Nepal. It occupies a small part of the Sub-Himalaya in Mid-Western Nepal (Fig. 1) lying between the Main Boundary Thrust (MBT) in the north and the Himalayan Frontal Thrust (HFT) in the south. The area is located in the Dang and Banke Districts, and is bounded by latitudes 27° 522' 303'' and 28° 152' N, and longitudes 81° 522' 303'' and 82° 302' E with an area of about 1350 sq km.

A systematic study of the Siwaliks began at the end of the nineteenth century. A

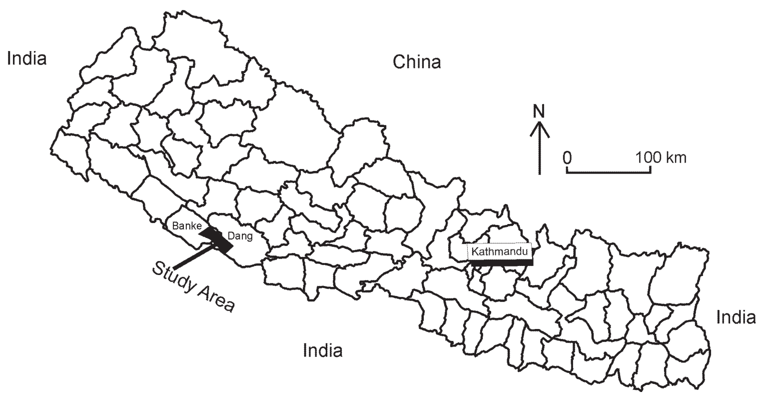


Fig. 1 : Location map of the study area.

brief review of the previous works on the Siwaliks of Pakistan, India, and Nepal is given below.

While working in the Potwar Plateau, Pilgrim (1913) divided the Siwalik succession into three units and assigned them the Middle Miocene, Late Miocene to Early Pliocene, and Late Pliocene to Early Pleistocene ages, respectively. Wadia (1928, 1957) and Colbert (1935) further subdivided the lower unit into Kamalial and Chinji Zones, the middle unit into Nagri and Dhok Pathan Zones, and the upper unit into Tatrot, Pinjor, and Boulder Conglomerate Zones.

Auden (1935) investigated the Siwaliks of central Nepal around Hetauda and Udaipur Garhi. He classified them into the Lower Siwaliks (Nahans) of brown-weathering sandstones, chocolate clays, and some inconsistent beds of impure limestone, the Middle Siwaliks of thick beds of feldspar and mica-rich sandstones, and the Upper Siwaliks consisting of conglomerates.

Hagen (1969) followed the three-fold subdivision of the Siwaliks. According to it, the Lower Siwaliks are composed of siltstones, red shale facies with minor sandstones, and pseudo conglomerates, the Middle Siwaliks consists of sandstone and siltstone facies with minor conglomerates and red shales, and the Upper Siwaliks are composed of conglomerate facies. He subdivided the rocks into the inner thrust Siwaliks and the outer folded Siwaliks.

Glennie and Ziegler (1964) classified the Siwaliks of Nepal into the lower Sandstone Facies and the upper Conglomerate Facies, owing to the difficulty in applying three-fold subdivision over the whole country. According to them, the sandstone facies corresponds to the Lower and the Middle Siwaliks and is composed of fine-grained sandstone, conglomerate and pebble bearing sandstone. The upper portion of the sandstone facies consists of claystone or siltstone and contains leaf imprints and shell fragments. Similarly, the conglomerate facies corresponds to the upper Formation and is composed of very coarse and massive conglomerate with layers of sandstone in between.

According to Chaudhari (1982), the sandstones of the Lower Siwaliks of Nepal are represented by quartz arenites, the Middle Siwaliks are characterised by lithic arenites, and the Upper Siwaliks are composed of boulder conglomerates with subangular to subrounded metamorphic and crystalline rock fragments.

West and Munthe (1981) reported some new fossils from the lower Siwaliks of the Babai Khola and Tinau Khola areas. Munthe (1983) reported the upper molar of Sivapithecus punjabicus from the Tinau Khola area. They also carried out palaeomagnetic studies in the Tinau Khola area. Later, Gautam and Appel (1984) established the detailed magnetostratigraphy in that area. According to them, the 1710 m thick Siwaik section between Butwal and the Dobhan Khola has an age ranged between 11.0 and 5.9 Ma. The age of the Sivapithecus horizon is about 8.5 Ma, which almost coincides with the boundary of the Arung Khola and Binai Khola Formations of Tokuoka (1986, 1988a, 1988b, 1990).

West (1984) made a detailed study of vertebrate fossils of Nepal Sub-Himalaya and drew a conclusion that the rocks cannot be correlated with the Siwaliks of India and Pakistan on the litholigical basis.

Tokuoka (1988a, 1990) mapped the Siwaliks of Arung Khola area, West Nepal, and divided the rocks into the Arung Khola, Binai Khola, Chitwan, and Deurali Formations in ascending order. By the help of palaeomagnetic studies, the rocks were correlated with the stratigraphic sequences of the Potwar Basin.

Harrison (1993) made the palaeomagnetic studies of the Siwaliks in the Bakiya Khola section, south-eastern Nepal and established the depositional age of between 11. 2 and 4.9 Ma. They also established high sediment deposition rates (between 0.1 and 1. 5 mm/year) in a cyclic fashion with a period between 1.5 million and 400,000 years. According to them, it might reflect episodic thrusting events in the Himalaya. The palaeomagnetic polarity indicates the deposition period of the Siwalik Group in Nepal from 16 to 1 Ma ago (Tokuoka et al., 1986 ; Harrison et al., 1993 ; Gautam and Appel, 1994 ; Gautam and Fujiwara, 2000).

Corvinus (1988) studied the Surai Khola Siwaliks of the Surai Khola section located in east of the present study area. Based on vertebrate fossil occurrence, she classified the rocks into the Bankas Beds, Water Spring Beds, Chor Khola Beds, Surai Khola Beds, Dobatta Beds and Dhan Khola Beds in an ascending order. Later on, Corvinus (1993) and Corvinus and Nanda (1994) modified the above divisions into the Bankas Formation, Chor Khola Formation, Surai Khola Formation, Dobatta Formation and the Dhan Khola Formation.

Dhital (1995) made a detailed study of the Siwaliks of the Mid Western Nepal around the Rapti River and established a detailed stratigraphy of that area and divided the area into the Bankas, Chor Khola, Dobata, and Dhan Khola Formations, in an ascending order. The Bankas Formation is represented by the alternating beds of red -purple mudstones, shales, and fine-to very fine-grained sandstones. The Chor Khola Formation is divided into Jungali Khola Member and Shivagarhi Member. The mudstones are variegated in the Juagli Khola Member, but are predominantly of gray -green color in the Shivagarhi Member of the Chor Khola Formation. The Surai Khola Formation is composed mainly of multi-storied course-to very coarse-grained 'salt and pepper' sandstones. The beds yield a great amount of petrified wood in the form of steams, branches, and roots. The Dobata Formation is predominated by mudstones with a minor amount of sandstones and conglomerates and is rich in vertebrate as well as molluscan fossils. The Dhan Khola Formation is the youngest rock unit and comprises well cemented and hard boulder and pebble bearing conglomerates with yellow mudstone in the lower part, and poorly cemented conglomerates with yellow-brown mudstones in the upper part. The Siwalik sandstones belong to lithiarenite, feldspathic lithiarenite, and lithic graywacke.

Mugnier (1995) studied the structural and thermal evolution of the Siwaliks of Western Nepal. It reported that the persistence of shortening between Indian plate and Asian plate results into the mountain growth from at least 4 Ma ago. The presence of many thrusts, faults, and folds is due to this deformation.

## Purpose of the study

The main purpose of the present study was to establish the geology of the Siwaliks constituting the hills surrounding the Dang and Deukhuri valleys, to establish the lithostratigraphy of the study area and to correlate it to the established stratigraphy of the eastern area of the Surai Khola area, so that the geological map of the area could be prepared. For these purposes, objectives were set as follows.

— To study the lithology (megascopic and microscopic) and stratigraphy of the Siwaliks,

— To study the geological structures,

— To correlate the stratigraphic sequence of the study area with the established stratigraphy of the nearby regions, and

— To prepare a geological map of the area.

## Physiography

The study area consists of two intermountain (or dun) valleys. They are the Dang and the Deukhuri Valleys. The Deukhuri Valley is surrounded by the rocks of Siwaliks whereas the Dang Valley is bounded by the Lesser Himalayan rocks in the north and the Siwalik rocks in the other sides. The elevations of the Dang and the Deukhuri Valleys are about 700 m and 300 m above the sea level, respectively. The two valleys are arranged in en-echelon style (Fig. 2). The important settlement areas within the study area are Tulsipur, Ghorahi, Lamahi, Amiliya, Kusum, Agaiya, and Malai.

The Dang Valley lies about 10 km north of the Deukhuri Valley and closes about 30 km west of the Deukhari Valley. It is an oval shaped valley with the length of about 50 km and width of about 17 km and is filled up by the Quaternary fluvial sediments deposited essentially by the north-south flowing rivers. On the other hand, the Deukhuri Valley is about 50 km long in the east-west direction and about 12 km wide in the central part. It is like an elongated trough filled up by the Quaternary deposits of the Rapti River which is flowing from east to west almost through the middle part of the valley. The Siwaliks have altitudes ranging from 900 m to 1500 m and exhibit a very rugged topography with highly dissected gullies and steep slopes. The altitudes of the Dang and Deukhari valley floors are about 700 m and 300 m above the sea level, respectively.

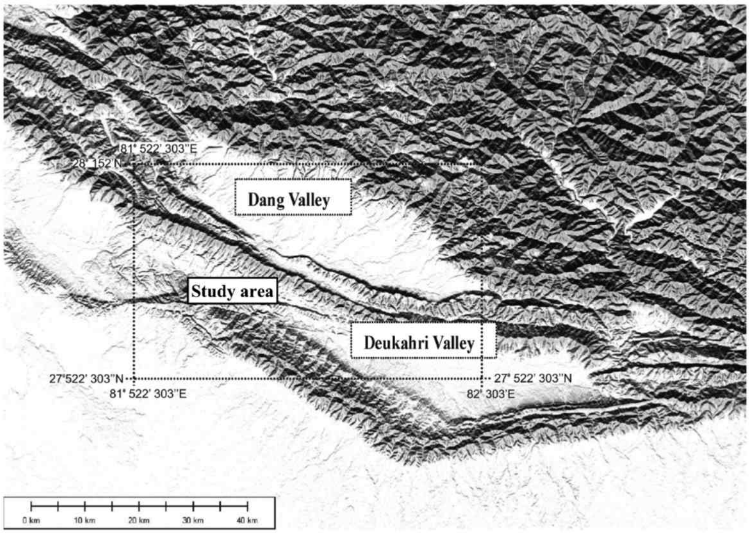


Fig. 2 : The physiographic map of the study area showing the Dang and the Deukahari vallys (SRTM DEM).

Most of the mountain ridges in the study area extend in the east-west direction, parallel to the main geological structures. The landforms of the study area are mainly controlled by the tectonic processes and subordinately by mass wasting and weathering. The erosional landforms predominate over the depositional ones. There are rugged hills, numerous deep gorges, steep slopes, cliffs, and active gullies representing the erosional landforms, whereas river terraces, alluvial fans, and talus cones are the examples of depositional landforms. The Dang and Deukhari valleys are drained by the Babai and the Rapti rivers, respectively.

## Llithostratigraphy of the study area

The distribution of different rock units are shown in Fig. 3, and the lithostratigraphy of the study area is given in Fig. 4. The formation nomenclature used in this study follows that of Dhital et al. (1995) from the Surai Khola-Bardanda area.

The lithology of the study area can be subdivided into the Bankas Formation, Chor Khola Formation, Surai Khola Formation, Dobata Formation, and Dhan Khola Formation in ascending order. Description of lithostratigraphy of all the formations is briefly discussed in the following section.

### Bankas Formation

The characteristic feature of the Bankas Formation is an interbedding of fine-to very fine-grained gray-green sandstone and red-purple, yellow-brown, and dark brown mudstone. Predominating color of the mudstone is red-purple. Palaeosol and calcrete are frequent and plant fossils occur in the mudstone of the upper part.

The Bankas Formation is exposed in many parts of the study area. The formation crops out all along the southern foothills of the mountain range in the Dang Valley, in the southern part of the Tui Khola Valley, to the south of the Malai River Valley, to the north of the confluence of the Babai and the Malai Rivers, and to the north of Hapure. The Bankas Formation forms the core of an anticline in the Khairi Khola. A periclinal closure consisting of the rocks of the Bankas Formation is seen at the confluence of the Babai River and the Malai Khola (Fig. 3).

A few sandstone samples were studied under the microscope for the determination of the mineralogy and the texture. The grain size is fine to medium which are sub-rounded, their sphericity is medium, and the grains are welded tangentially. The analysis revealed that the sandstone contains quartz, feldspar, muscovite, and certain opaque minerals. The thin-section study of the sandstone shows that the muscovite are deformed (Fig. 5) due to either tectonic or lithostatic pressure. Also, the studies show that the Bankas Formation is predominated by arenites. The amount of quartz is high and the amount of rock fragments is low in this formation. The micas in the Bankas Formation are rich in muscovite, and biotite is absent. Most of the samples of the Bankas Formation belong to the lithiarenite and subordinately to the feldspathic litharenite. All the above studies show that the lithology along with the petrography of the Bankas Formation is almost similar to that of the type locality. The sandstone also contains ripple marks (Fig. 6), parallel and cross laminations and concretion in almost all part.

The distribution of the Bankas Formation in different parts of the study area shows that the overall lithology is similar to that of the type locality. The thickness of the Bankas Formation is variable due to intense deformation and faulting. Below the Tui Khola Back Thrust, it is more than 250 m (Fig. 7), and it is about 730 m above the thrust, whose small portion is shown in Fig. 8. This shows that the thickness of the Bankas Formation is controlled by the thrusting in that area. As the area consists of many thrusts and back thrusts, some part of formation has been eliminated, while some part has been repeated.

## Chor Khola Formation

The main lithology of the Chor Khola Formation is cyclic deposition of thickly bedded, 'salt and pepper' sandstone, variegated (yellow, brown, red-purple, and gray-green) mottled mudstone. The top part of the Chor Khola Formation contains peat and organic debris with abundant leaves. In the sandstone beds, petrified wood fragments, tree trunks, and branches are observed. The mudstone may contain plant fossils.

The Chor Khola Formation is exposed in many parts of the study area (Fig. 3). It crops out in the Amiliya-Tulsipur road section, along the Masot Khola, along the

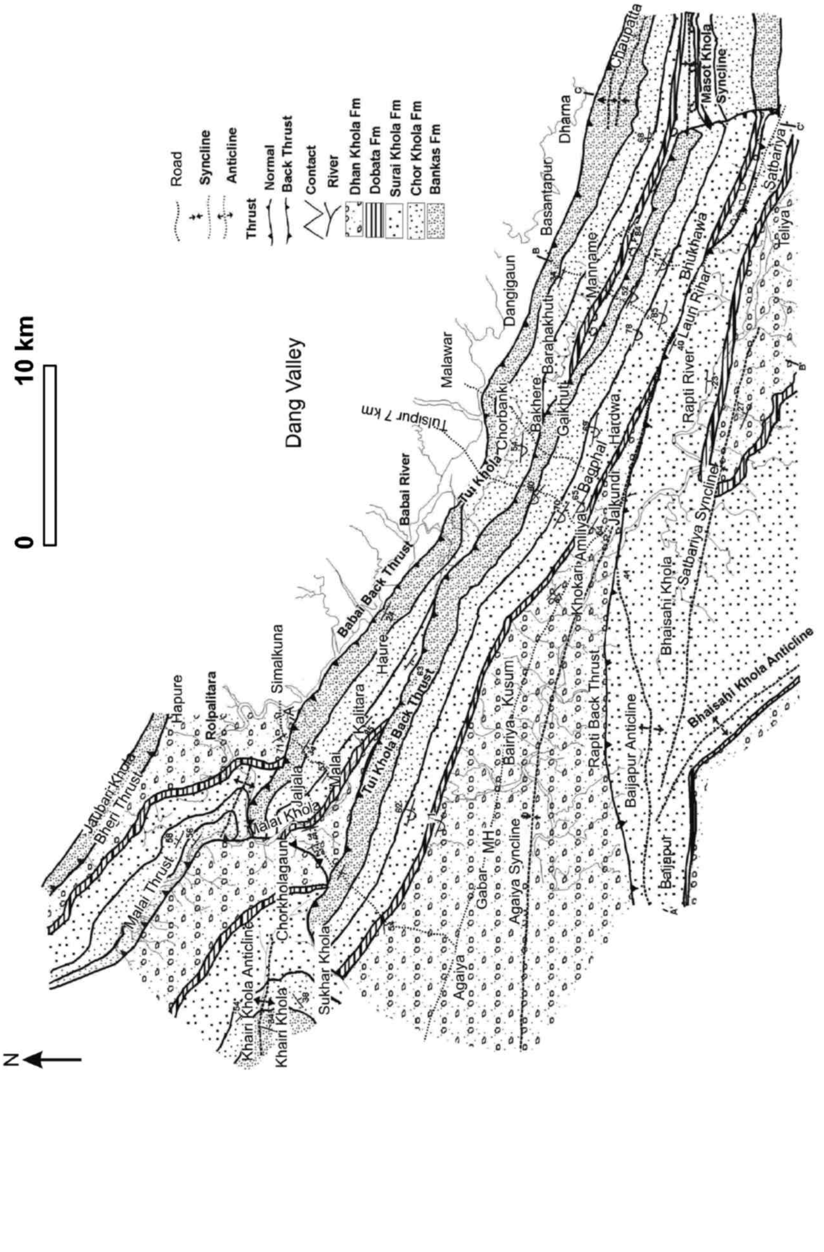


Fig. 3 : Geological map of the study area.

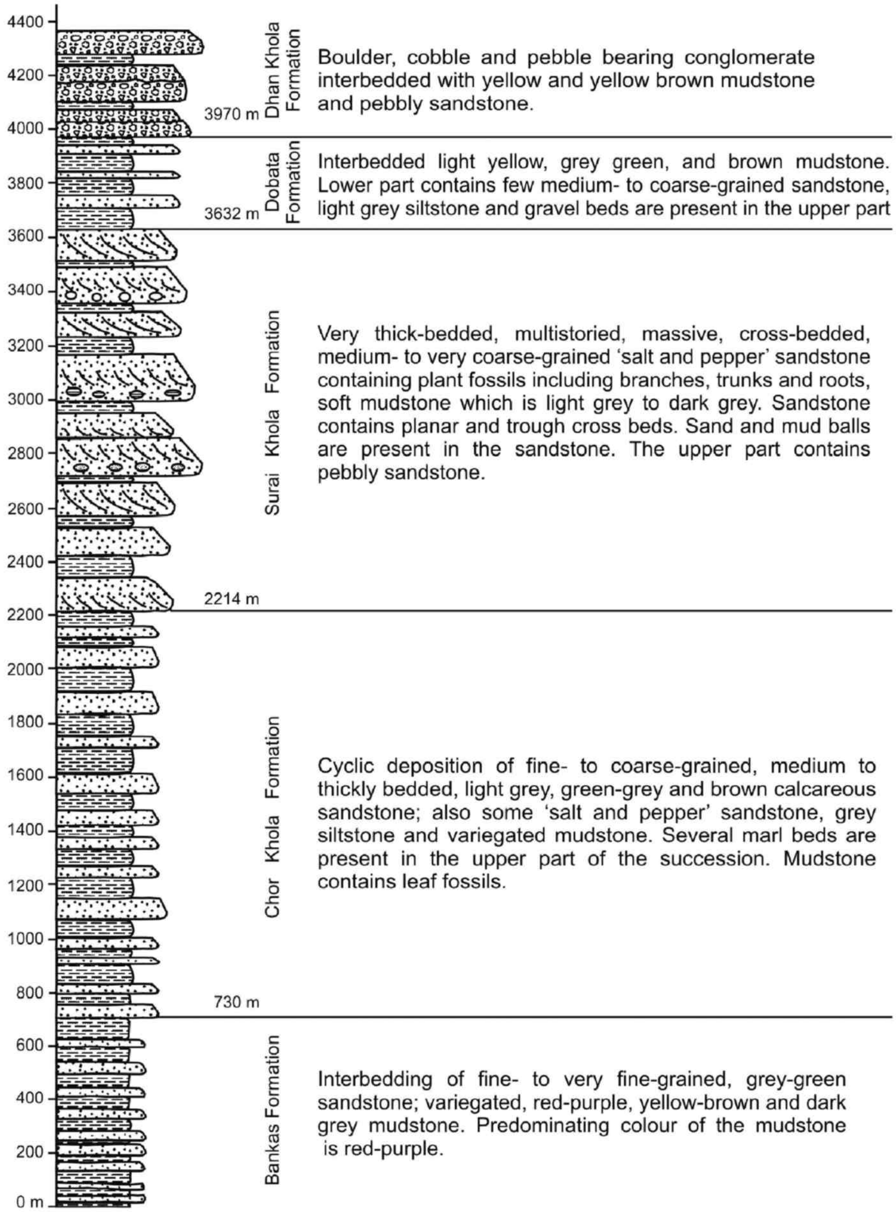


Fig. 4 : Generalized lithostratigraphic column of the Siwaliks in the Tulsipur–Amiliya road section.

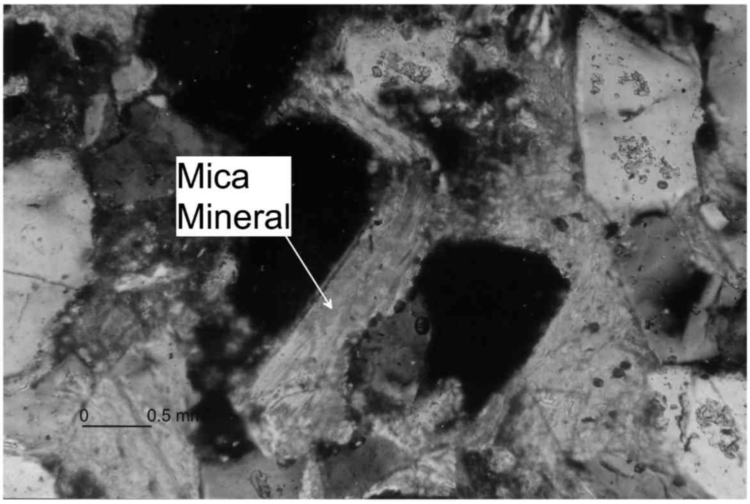


Fig. 5 : Sandstone from the Bankas Formation, showing the bending of the mica flake. This bending may be due to tectonic or lithostatic pressure prior to cementation.


Fig. 6 : Ripple marks observed on the fine-grained sandstone of the Bankas Formation in the Tui Khola.

Malai Khola, on the way to Simalkuna from Malai, between Jaljala and Agaiya, in the Khairi Khola, on the way to Bagphal from Malawar and on the way from Basantapur and Dangigaun to Bhaukhawa.

The sandstone of the Chor Khola Formation consists of medium to coarse grains.

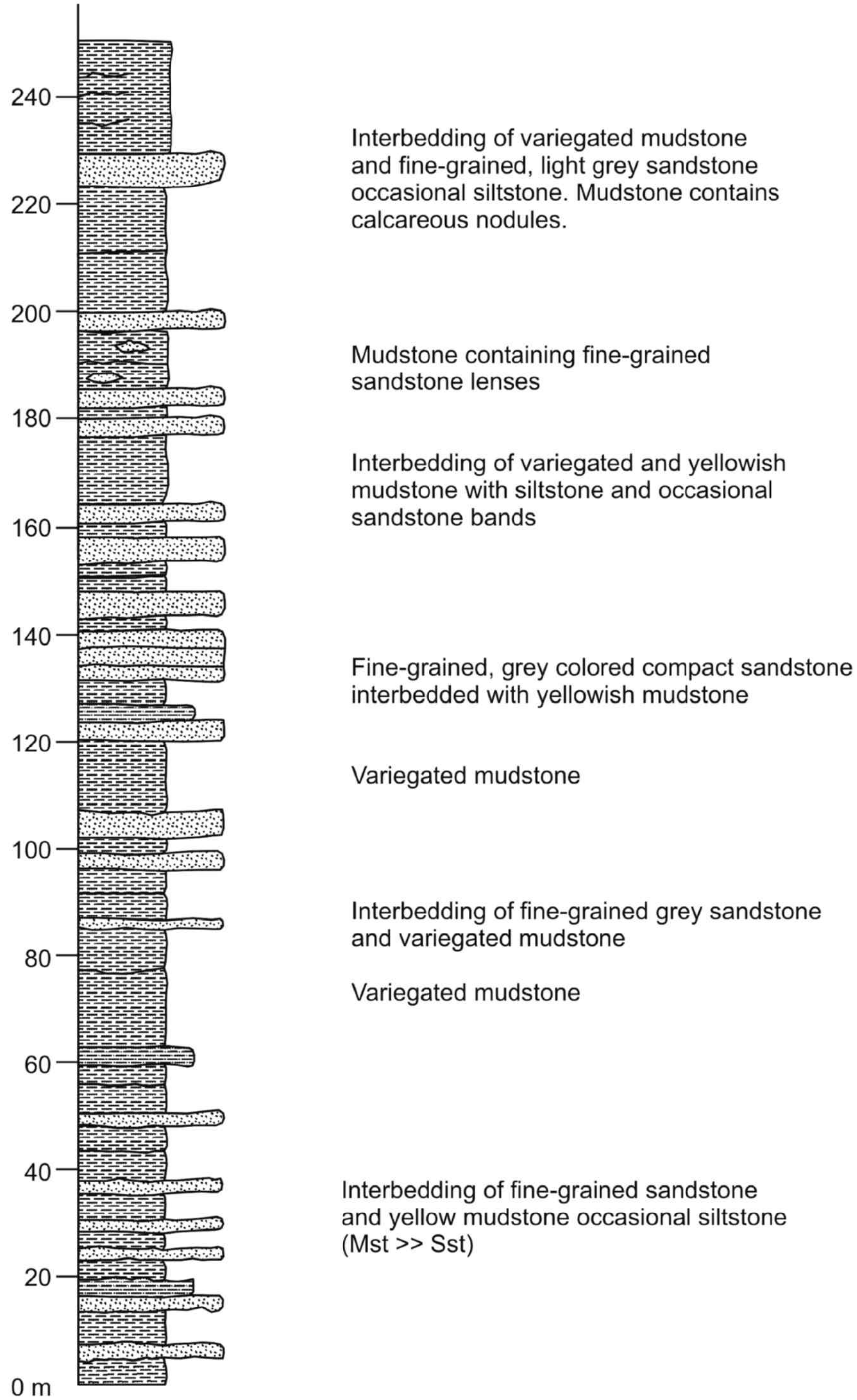


Fig. 7 : Detailed columnar section showing the rocks of the Bankas Formation from the north of the Tui-Khola Back Thrust.

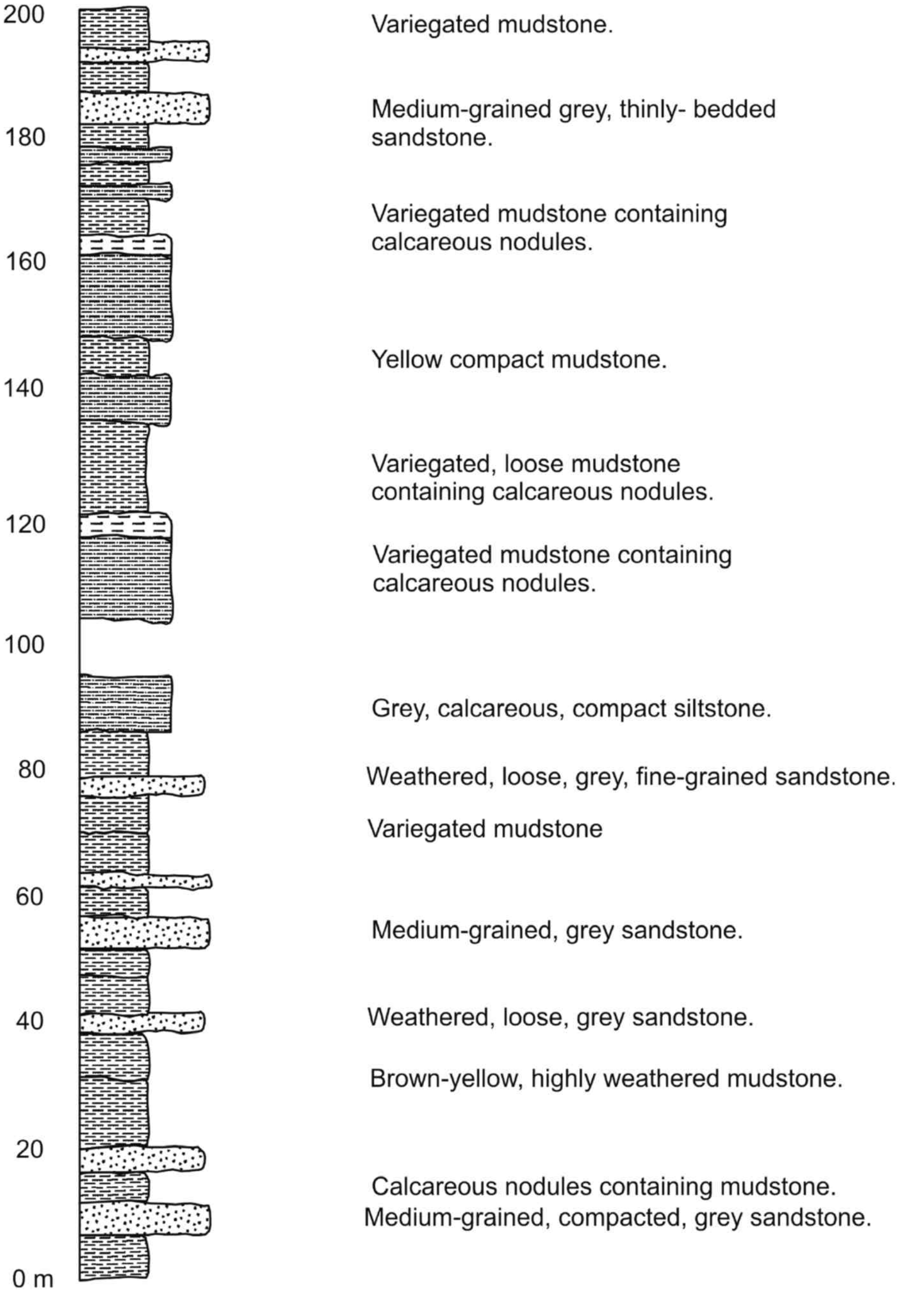


Fig. 8 : Detailed Columnar section showing the Bankas Formation at the south of the Tui-Khola Back Thrust.

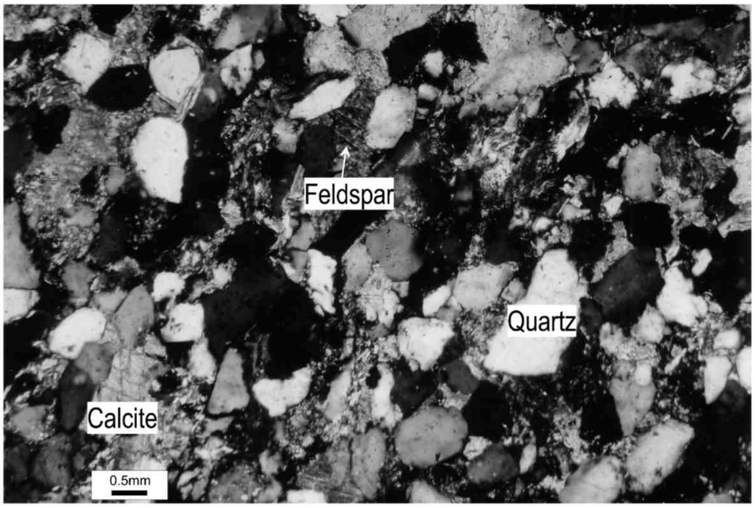


Fig. 9 : Sandstone from the Chor Khola Formation showing calcite, quartz, feldspar, muscovite and biotite.

The roundness is from sub-rounded to sub-angular, the sphericity is medium, and the contact between the grains is welded tangentially. The mineralogy of the Chor Khola sandstone is quartz, feldspar, muscovite, biotite and certain opaque minerals (Fig. 9). The biotite appears only with the start of Chor Khola Formation. The sandstones are belonging to the litharenites and lithic grewakes.

The boundary of the Chor Khola Formation and the Bankas Formation is detected by noting the change in the color of the mudstone, and the thickness of the sandstone beds. The red-purple color, which is the predominant color of the mudstone in the Bankas Formation, is missed in the Chor Khola Formation and mudstone is colored by yellow, grey and green-gray. Also the thickness of the sandstone beds increases in the Chor Khola Formation. The bottom of the Chor Khola Formation is the first appearance of the sandstone bed with the thickness of greater than 4 m.

Detailed columnar sections of the Chor Khola Formation were prepared at both the north (Fig. 10) and south (Fig. 11) sections separated by the Tui Khola Back Thrust. The northern portion of the thrust is composed of fine-grained gray sandstone, thin-bedded gray mudstone, light gray siltstone, dark gray sandstone, yellow mudstone containing calcareous nodules, thick-bedded, dark gray mudstone with a few leaf fossils, and coarse-grained compact gray sandstone. Mudstone is the dominating lithology of this part. The lower portion of the Chor Khola Formation at the south of the thrust consists of variegated mudstone containing calcareous nodules, thick-bedded yellow mudstone with a few silt bands, and fine-grained gray sandstone, while the upper part consists mainly of compact gray calcareous siltstone, thickly bedded fine-grained sandstone, interbedding of yellow-brown mudstone and variegated mudstone,

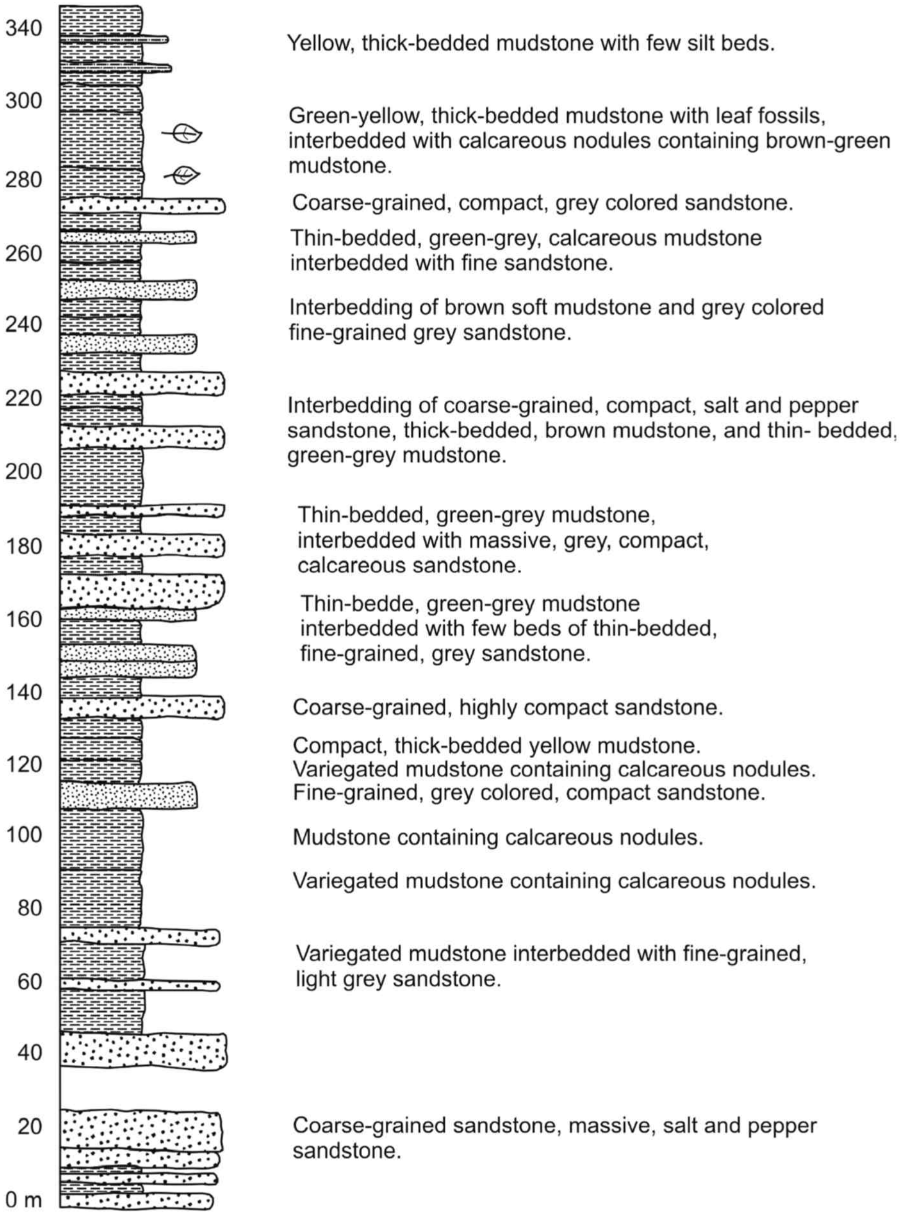


Fig. 10 : Detailed columnar section showing the Chor Khola Formation along the Tulsipur-Amiliya road section at the north of the Tui Khola Back Thrust.

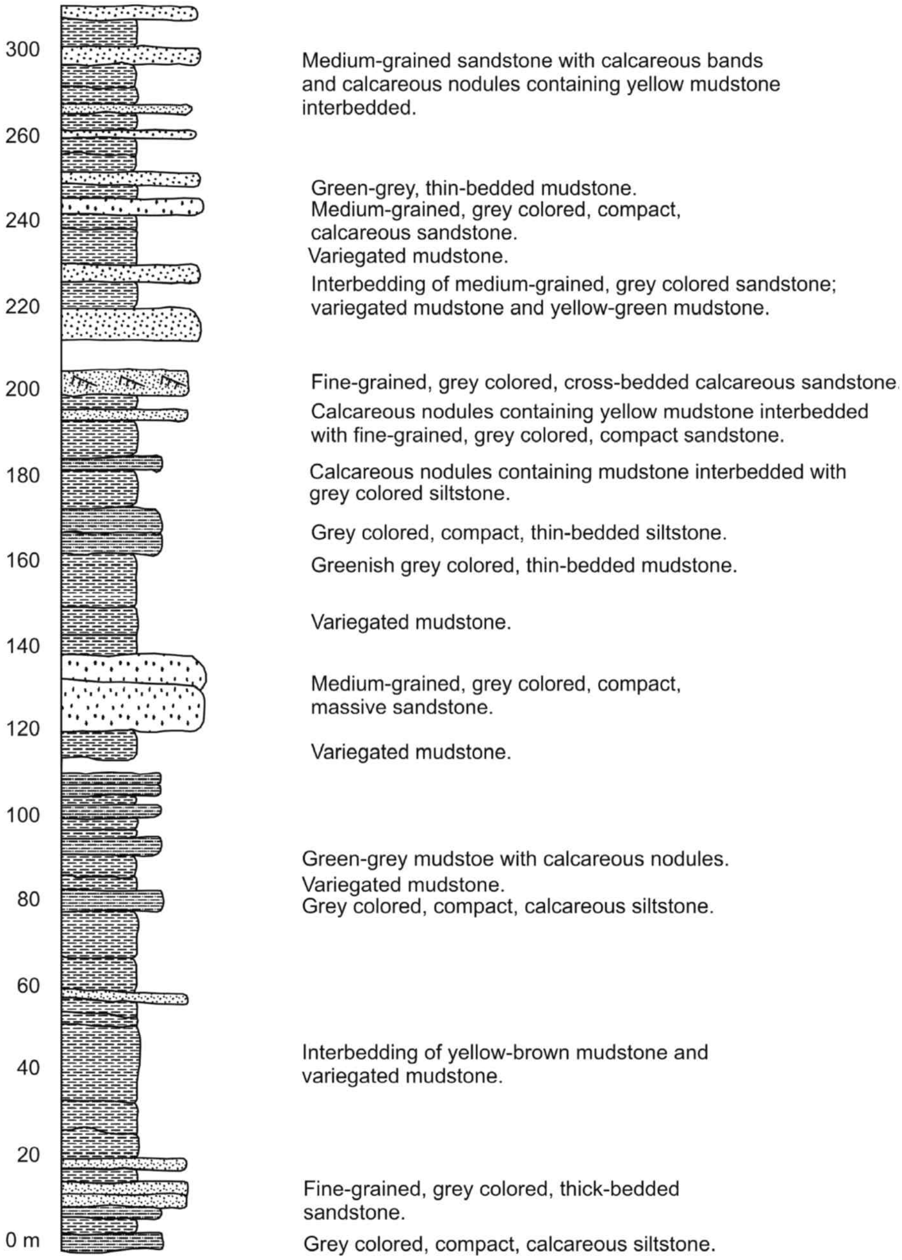


Fig. 11 : Detailed columnar section showing the upper part of the Chor Khola Formation.

Fig. 12 : Spheroidally weathered sandstone interbedded with mudstone from the Chor Khola Formation on the way to Sitalpur from Raniapur.

green-gray mudstone with calcareous nodules, and medium-to coarse-grained gray sandstone with some calcareous bands. The fine-grained sandstone here shows cross-bedding. The proportion of sandstone increases from the lower part to the upper one of the Chor Khola Formation. However, the overall proportion of sandstone and mudstone is almost equal. The Chor Khola Formation is about 1,485 m thick in the Tulsipur-Amiliya road section.

Though the Chor Khola Formation is exposed in several parts of the study area, they show minor difference in the thickness of the formation, as well as in the lithology. The sandstone of the Chor Khola Formation in the northern part consists mainly medium grains while in the southern part both medium-grained and coarse-grained sandstones are present. Sand-pipes as well as spheroidal weathering pattern are observed in the sandstone of the northern part (Fig. 12). Several siltstone bands are also found in the Chor Khola Formation in the northern part, which are very few in the southern part and the sand-pipes are lacking here. The color of the mudstone is also variable. It is mainly yellow and light gray in the northern part of the study area, while it is green-gray and dark gray in the southern part. Also, the thickness of the formation is variable. It is mainly due to the presence of great number of geological structures in the study area.

## Surai Khola Formation

The Surai Khola Formation is extensively distributed in the study area. It is exposed in the Amiliya-Tulsipur road section, in the Masot Khola, in the Malai Khola, on the way from Malai to Simalkuna, on the way to Jaljala from Agaiya, along the Khairi Khola, between Bagphal and Malawar, between Bhaukhawa and Basantapur and between Bhaukhawa and Dangigaun. It forms the core of the Masot Khola Syncline (Fig. 3).

The overall lithilogy the Surai Khola Formation is sandstone (about 80%) and mudstone (about 20%) with a subordinate amount of calcrete, marl, and shale. One of the characteristic features of the coarse-to very coarse-grained, multi-storied sandstones of the Surai Khola Formation is that they have 'salt and pepper' like appearance owing to the significant content of biotite and quartz grains. The grains are sub-angular, the sphericity of the grains is medium, and the contact between them is tangential. The main minerals contained in the sandstone of the Surai Khola Formation are quartz, feldspars, muscovite, and biotite (Fig. 13). Most of the sandstone samples from the Surai Khola Formation belong to litharenites, feldspathic litharenites, and lithic grewakes. The sandstones of this formation contain plant fossils including leaves, roots and steams. These fossilised plants are seen as petrified woods (Fig. 14). Besides it, the sandstones are thickly-bedded, massive, and feeble. The thickness of the sandstone beds ranges from 0.5 to 5 m.

The thickness of the Surai Khola Formation in the Amiliya-Tulsipur road section is estimated at 1,318 m, but it is not constant throughout the study area and keeps on changing due to deformation and faulting.

The columnar sections (Figs. 15 and 16) prepared in the Amiliya-Tulsipur road section show the detailed lithology of the Surai Khola Formation. Both the lower and the upper parts of the Surai Khola Formation are represented in the columns. The lower part of the Surai Khola Formation consists of interbedded yellow-brown and greenish-gray mudstone, coarse-grained cross-bedded 'salt and pepper' sandstone, light gray pebbly sandstone with calcrete bands and yellow to pale yellow or brown mudstone. The proportion of sandstone is greater in its middle part. The upper part consists of massive coarse-grained 'salt and pepper' sandstone with a few yellow mudstone beds intercalated with pebbly sandstone, a few pebble conglomerate bands and gray indurated calcareous sandstone interbedded with variegated gray-brown mudstone. The sandstones both in the lower and upper parts of this formation contain cross lamination and these cross lamination shows overturning (Fig. 17). The overall proportion of sandstone is significantly greater than that of the mudstone.

Though the Surai Khola Formation is exposed in several parts of the study area, they show change in thickness of the formation throughout the study area. This change

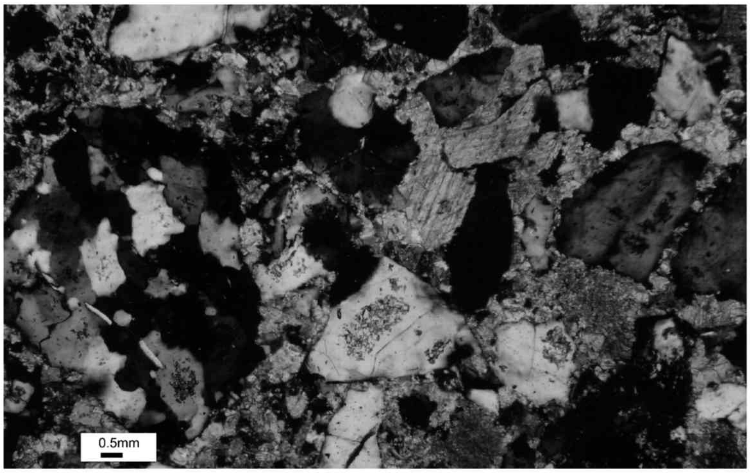


Fig. 13 : Sandstone (sample no : Sp2) from the Surai Khola Formation showing composite quartz grain viewed under the crossed polar. The detrital quartz grains are angular to sub-round.

Fig. 14 : 'Salt and pepper' sandstone of the Surai Khola Formation containing petrified tree trunks in the Simalsota Khola.

in thickness is mainly due to the presence of faults, thrust and folds. The changes in the thickness of the individual beds also occur in the southern and the northern part of the study area. The thickness of the sandstone beds in the southern part is greater than those of the northern part. A lot of plant fossils as branches, trunks, steams which are present in the southern part of the study area are absent in the northern part. However,

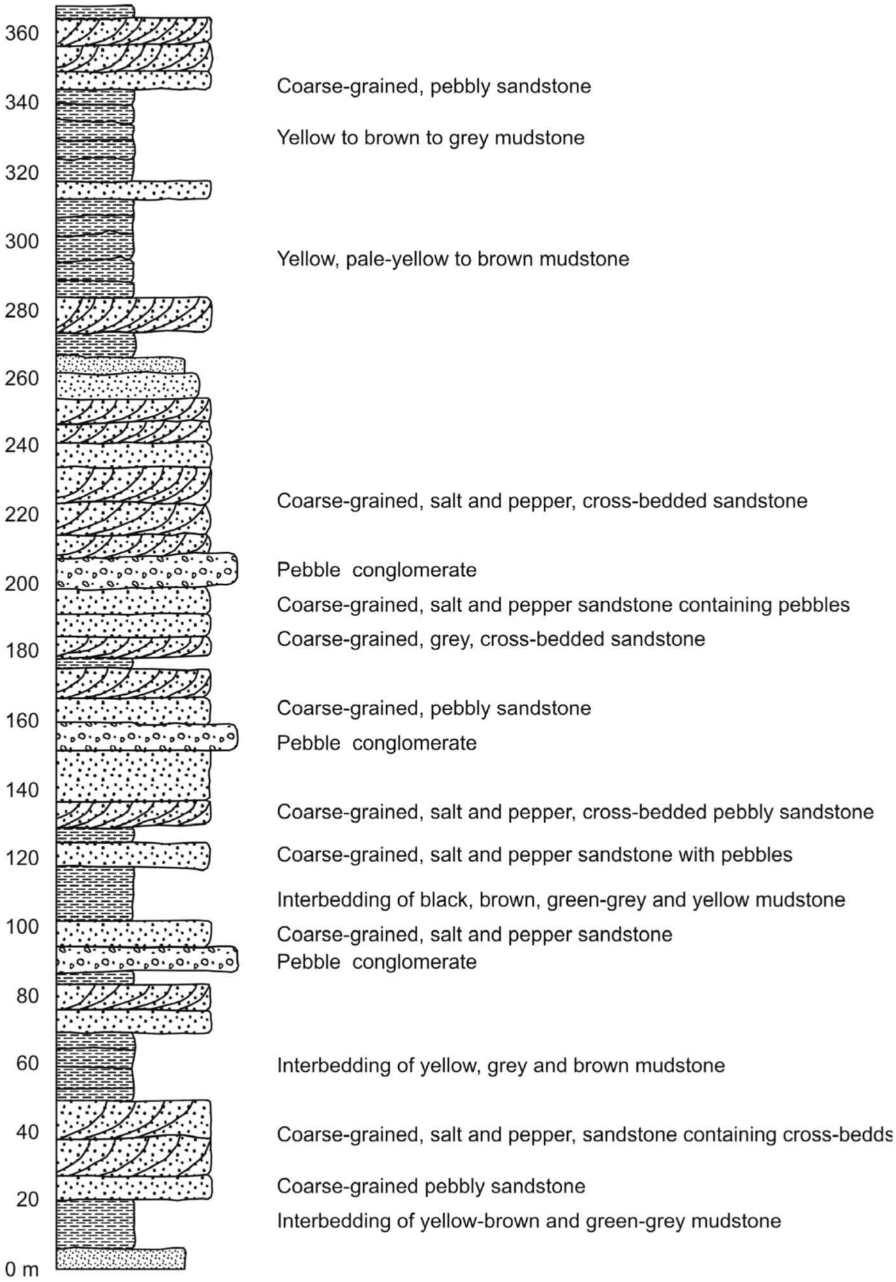


Fig. 15 : Detailed columnar section showing the lower part of the Surai Khola Formation in the Tulsipur-Amiliya road section

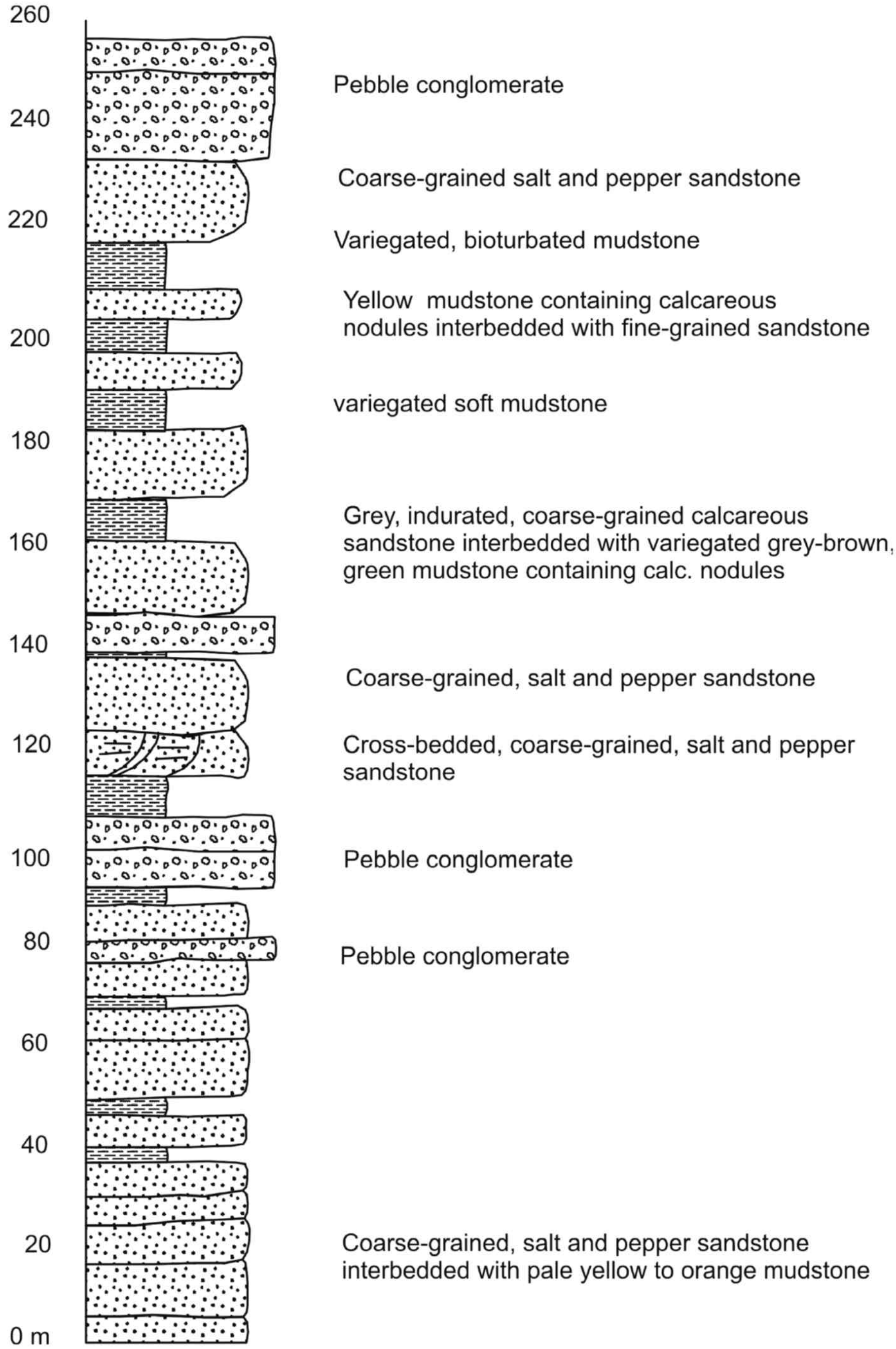


Fig. 16 : Detailed columnar section showing the upper part of the Surai Khola Formation in the Tulsipur–Amiliya road section.

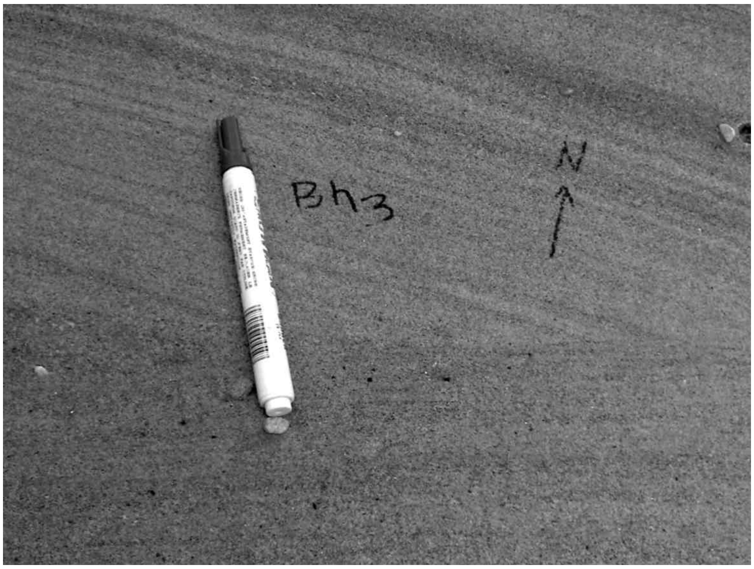


Fig. 17 : Cross-bedded 'salt and pepper' sandstone of the Surai Khola Formation showing the overturning.

the study shows that the overall lithology of the Surai Khola Formation in several parts of the study area is almost similar.

## Dobata Formation

The main lithology of the Dobata Formation is mudstone with a lesser amount of sandstone and conglomerate. The Dobata Formation follows the sandstone-predominating succession of the Surai Khola Formation and passes to the conglomerate-predominating succession of the Dhan Khola Formation gradually. The Dobata Formation occupies a special position in the stratigraphy of the study area. It consists predominantly of mudstone (63%) with lesser amounts of sandstone (23%) and conglomerate (14%).

The Dobata Formation is exposed in the five separate belts of the study area (Fig. 3). It overlies the Surai Khola Formation with a transitional contact. The Dobata Formation is exposed in the Masot Khola, at the Haure village of north Dang, to the south of Taliya, and in the upper reaches of the Khairi Khola.

The boundary between the Dobata and the Surai Khola Formation is noted by the increase in proportion of the yellow brown and gray mudstone in comparison to the sandstone. The mudstone which is also present in the Surai Khola Formation with very thin thickness becomes more than 20 m thick in the Dobata Formation, and the thickness of multi-storied sandstone of the Surai Khola Formation becomes less in the Dobata Formation.

The columnar section of the Dobata Formation prepared in the Phiringi Khola (Fig. 18) shows that the main rock types are yellow-brown, gray and dark gray mudstone (Fig. 19) ; and interbedding of soft, dark gray mudstone with a few bands of conglomerate. Coarse-grained 'salt and pepper' sandstone is also interbedded with the mudstone. The overall proportion of mudstone is relatively very high in comparison with that of sandstone and conglomerate. The thickness of the Dobata Formation at this rive section is 385 m.

The sandstones from the lower part of the Dobata Formation are light gray to gray, and medium-to very coarse-grained containing sand balls. In the middle portion, the sandstones become medium-to coarse-grained and they are intercalated with very thick mudstones. The upper portion of the Dobata Formation consists of coarse- to very coarse-grained, and cross-laminated sandstones. They become pebbly and also include conglomerate lenses. The thickness of the sandstone beds varies from 0.5 m to 20 m.

There are a few intercalated conglomerate beds in the upper part of the Dobata Formation. They range in thickness from 0.5 m to 15 m. The conglomerates are polymictic (quartzite, limestone, dolomite, and volcanic pebbles), matrix supported, and loose).

## Dhan Khola Formation

The Dhan Khola Formation is exposed in the Amiliya-Tulsipur road section, in the Masot Khola, in the Malai Khola, at Simalkuna, on the way to Jaljala from Agaiya, along the Khairi Khola, on the way to Bhaukhawa from Basantapur and from Dangigaun, in the many rivers which confluence with Rapti River from both south and north. It forms the core of a large syncline to the south of Rihar, to the south of Kusum, along the Masot Khola, and also the closure of an anticline in the Twang Khola.

The rocks of the Dhan Khola Formation consist of conglomerate (70%), mudstone (27%), and sandstone (3%). However the lithology of the Dhan Khola Formation is not the same in every part of the study area. The thickness of this formation is variable in each place. Its thickness is more than 450 m around the Amiliya-Tulsipur roadsection (Fig. 20). Both the thickness of the formation and the thickness of individual beds in the southern part of the study area differ from those observed in the northern part. The Dhan Khola Formation from the northern part of the study area consists of boulder conglomerate and the proportion of mudstone is also less than that in the southern part of the study area. The Dhan Khola Formation in the southern part of the study area is dominated by an interbedding of pebble-cobble conglomerate and mudstone. The boundary between the Dhan Khola Formation and the Dobata Formation is very distinct in the field. The Dobata Formation which is rich in mudstone is easily separable from the conglomerate dominant Dhan Khola Formation.

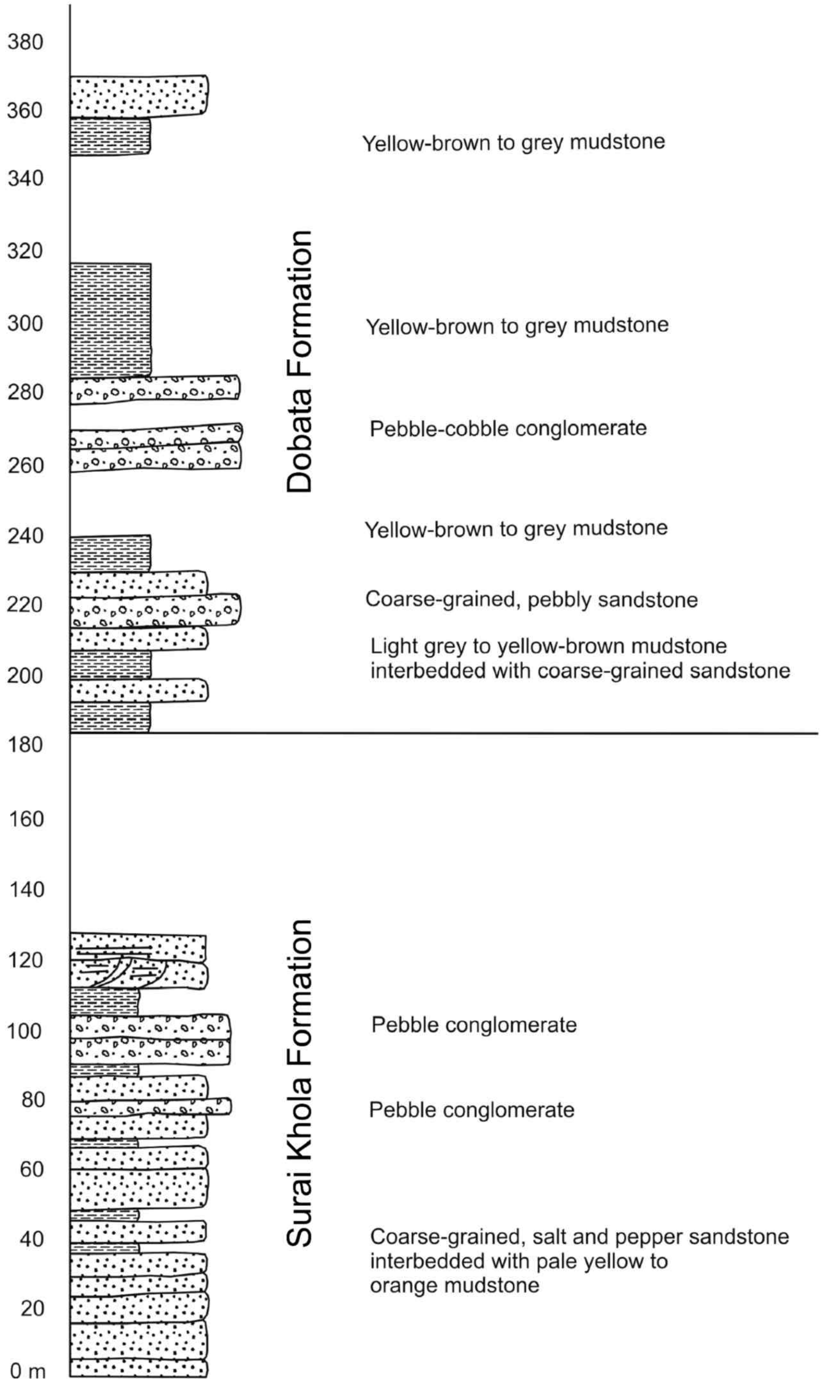


Fig. 18 : Detailed columnar section showing the contact between the Surai Khola Formation and Dobata Formation along the Phiringi Khola.

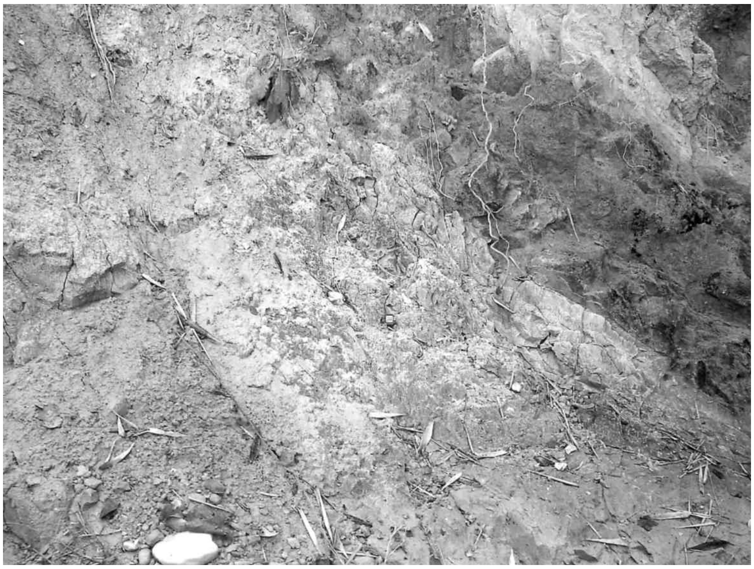

Fig. 19 : The dark grey and light grey mudstone of the Dobata Formation.

The columnar section of the Dhan Khola Formation prepared along the Phiiringi Khola comprises pebble-cobble and rarely boulder-bearing conglomerates interbedded with yellow mudstones. In the conglomerate, the pebbles of quartzite, limestone, dolomite, and sandstone are present. The conglomerates are moderately indurated and the matrix is composed of coarse-grained calcareous sandstone. Fining upward sequences of conglomerate and mudstone are frequent. The middle part of the formation is predominated by light yellow, gray, brown, and red mudstones.

## Correlation and comparison of the Siwaliks from different part of Nepal

The Bankas Formation in the study area consists of an interbedding of fine-to very fine-grained, gray-green sandstone and red-purple, yellow-brown, and dark brown mudstone. Predominating color of the mudstone is red-purple. Lithologically, this unit is comparable (Table 1) with the Lower Siwaliks (Auden, 1935 ; Hagen, 1969), Lower Churia Group (Sharma, 1990), Arung Khola Formation (Tokuoka et al., 1986), Bankas Beds and Water Spring Beds (Corvinus, 1988), Rapti Formation (Sah et al., 1994), Bankas Formation (Dhital et al., 1995).

The rocks of the Chor Khola Formation consist mainly cyclic deposition of thick bedded, 'salt and pepper' sandstone and variegated (yellow, brown, red-purple and gray-green) mottled mudstone. The upper part contains peat and organic debris with abundant leaves. The Surai Khola Formation consists of sandstone (about 80%), mudstone (about 20%) with a subordinate amount of calcrete, marl, and shale. Lithologically, these units are comparable (Table 1) with the Middle Siwaliks (Auden,

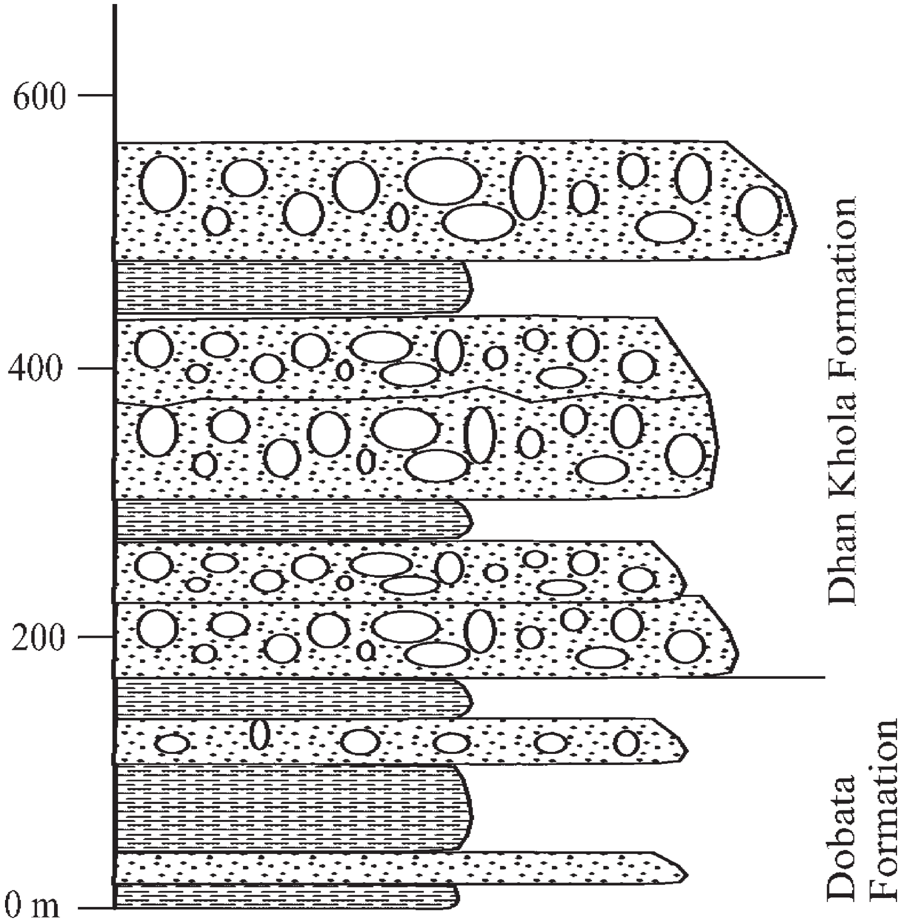


Fig. 20 : Detailed columnar section showing the contact between the Dhan Khola Formation and the Dobata Formation in the Phiringi Khola.

1935 ; Hagen, 1969), the upper part of the Lower Churia Group (Sharma, 1990), Binai Khola Formation (Tokuoka et al., 1986), Chor Khola Beds and Surai Khola Beds (Corvinus, 1988), Amlekhganj Formation (Sah et al., 1994), and Chor Khola Formation and Surai Khola Formation (Dhital et al., 1995).

The Dobata Formation is predominated by mudstones with a minor amount of sandstones and conglomerates and the Dhan Khola Formation consists of pebble-cobble-boulder conglomerates with yellow, brown and gray to dark gray mudstones and some coarse-grained sandstone beds. These units are lithologically comparable (Table 1) with the Upper Siwaliks (Auden, 1935 ; Hagen, 1969), Chitwan Formation (Tokuoka et al., 1986), Churia Khola Formation and Churia Mai Formation (Sah et al., 1994), Dobata Formation and Dhan Khola Formation (Dhital et al., 1995).

The lithology of the rock succession in the Surai Khola area and present study

Table 1. Table showing the Lithological correlation of the Siwalik from different part of Nepal

| Auden 1935 •(1) | Glennie and Zlegler 1964 (2) | Hagen 1969 (3) | Sharma 1973 (4) | Yoshida and Arita (5) | Tokuoka et a1 1986 (6) | Sah et al. 1994 (7) | Corvinus and Nanda 1994 and Dhital et a1 1995 (8) | Ulak and Nakayama 1998 (9) | Present Study Area |
|---|---|---|---|---|---|---|---|---|---|
| Upper Siwalik | Conglometate Facies | Upper Siwalik | Upper Churia Group | Upper Siwalik | Deorali Fm. | Churai Mai Fm. | Dhan Khola Fm. | Churai Mai Fm. | Dhan Khoia Fm. |
| | | | | | Chitwan Fm. | Churia Khola Fm. | Dobata Fm. | Churia Khola Fm. | Dobata Fm. |
| Middle Siwalik | Sandstone Facies | Middle Siwalik | Lower Churia Group | Middle Siwalik | Binai Khola Fm. | Amelkhganj Fm. | Suri Khola Fm. | Amlekhgunj Fm. | Suri Khola Fm. |
| | | | | | Arung Khola Fm | Rapti Fm. | Chor Khola Fm. | Rapti Fm. | Chor Khola Fm. |
| Lower Siwalik | | Lower Siwalik | | Lower Siwalik | | | Bankas Fm. | | Bankas Fm. |

area are similar (Fig. 21). However, there exist some minor differences in the thickness. These differences in thickness, as suggested by various researchers, may be attributed to the lateral variations in the depositional environment of the Siwalik rocks, as they were not deposited by a single river.

## Geological Structures

The rocks of the Siwaliks in the study area are complicated by many imbricate thrusts, faults, and various types of folds. There are folds ranging in scale from a few centimeters to many kilometers. A very large overturned block, of about 50 km in length and 4 km in width occurs in the study area. It is separated from other right-way-up sequences by back thrusts from all directions. There are three regional-scale back thrusts, which are all trending towards east-west and are nearly parallel to each other. Also, there are two regional-scale forward thrusts, which are dipping towards the

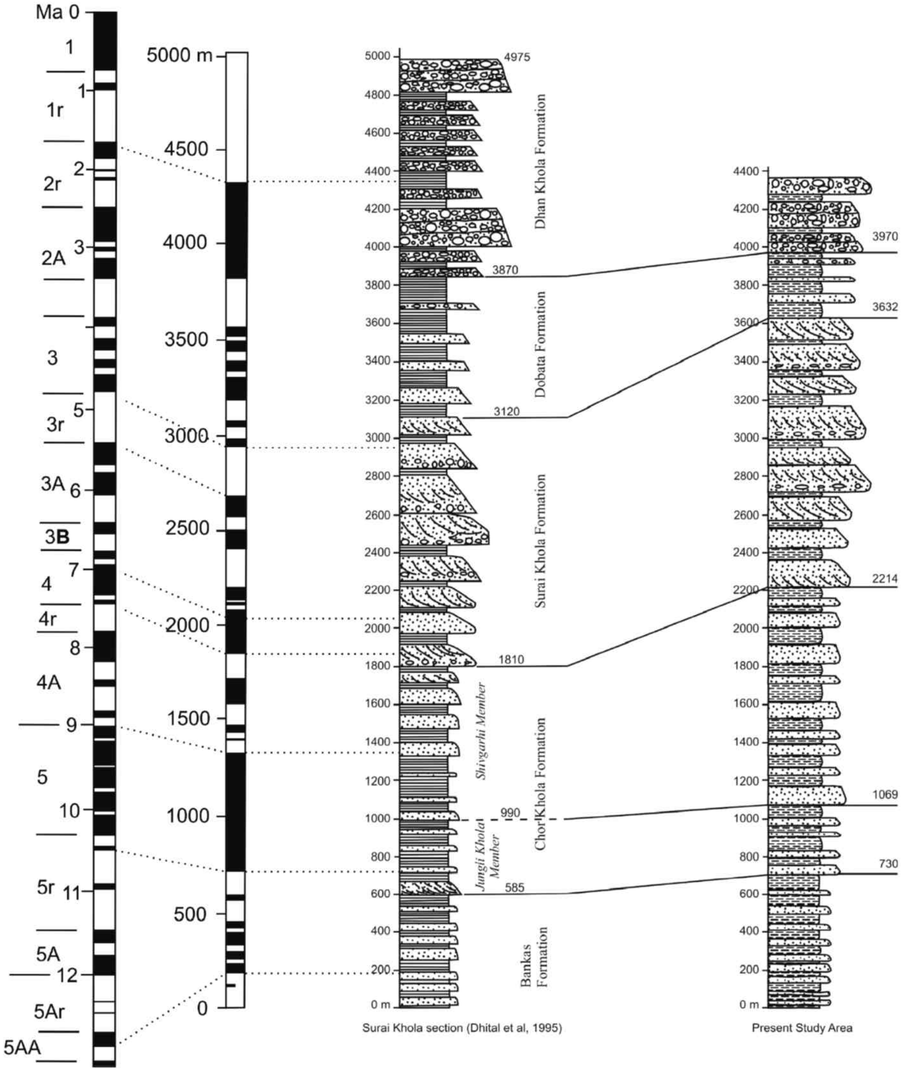


Fig. 21 : Lithostratigraphic correlation of the Siwaliks of the Surai Khola area with those of the Tulsipur-Amiliya road section.

north and are trending east-west.

On the map, the three regional scale faults are seen as the three parallel lines following the east-west trend. It is also seen that most of the faults inter into the fold, thus eliminating one of the fold limb. This situation is found in the Masot Khola area and also at Khokari.

The structure of the study area is interpreted on the basis of thin-skinned tectonics, and a short preview of the terms applied is given below.

## Thin Skin Tectonics

Dahlstrom (1970) classified the thrusts as contractional faults which cut up-section in the transport direction. The faults may have either smooth trajectory or staircase trajectory. In a staircase trajectory, the part of a fault, which passes with a relatively high angle through a layer, is known as ramp or step, and the section which is parallel to the bedding plane or any horizontal datum is known as a flat (Butler, 1982). Individual fault surfaces step from layer-parallel segments within soft, incompetent layering (flat) and cut obliquely across steep, competent beds en route to the next favorable incompetent unit (ramp). Where a thrust fault 'ramps' up through the bedding, it creates two cut-off angles, one with the hanging-wall strata and the other with the foot-wall strata. Cut-off lines mark the intersection of the thrusts with the stratigraphic horizon that is cut. The hanging-wall cut-off moves up and over the footwall cut-off progressively as the faulting proceeds. (Boyer and Elliott, 1982). Ramps which are cut-offs in the hanging wall are termed hanging wall ramps, and those cut-offs in the footwalls are termed as footwall ramps (Dalhstrom, 1970, Butler, 1982). Ramps which strike normal to the thrust transport direction are termed frontal ramps. They are characterised by dominantly reverse dip-slip displacement. Ramps with a strike oblique to the transport direction are called oblique ramps (Dahlstrom, 1970) and are characterised by elements of both strike slip and reverse dip-slip. Some ramps are lateral ramps. These represent places where a thrust "flat" abruptly cuts up -section laterally as a ramp until it reaches a higher horizon, where it once again becomes a flat. Basal decollements can be considered as very long flats. The sole thrust is the longest regional thrust surface (Elliot and Johnson 1980).

If a new thrust develops in the hanging wall of an older thrust, an over step or overlap sequence results (Elliot and Johnson, 1980). In such sequences, thrusts propagate towards the hinterland in a sense opposite to the transport direction. Hence, higher thrusts will represent the later movement across the array of faults (Butler, 1982).

## Structures found in the study area

The study area is located to the south of the Dang valley and in the Deukhari valley. There the rocks are all of sedimentary type belonging to the Siwaliks. The structures within the study are grouped into two, which are the minor one and major one.

### Minor structures

Though the study area consists of many minor structures, the important ones are given below.

## Fold

Many small-scale folds are observed during the field study. Both open and close folds are observed. Though there are many small-scale folds, one of them (Fig. 22) is shown below.

The main lithology of the outcrop making up the fold is thickly bedded, gray, and calcareous, cross laminated, 'salt and pepper' sandstone and yellow-brown calcareous mudstone. The orientation of bedding in one limb is 256°/81°S and in the second limb is 340°/60°N.

## Fault

The study area comprises many small-scale faults. These faults are mostly observed in the 'salt and pepper' sandstone of the Surai Khola Formation. Though there are many faults in the area, one of them (Fig. 23) is located at Jalakundi. Here the rock type is very coarse-grained, dark gray 'salt and pepper' sandstone interbedded with yellow-brown and bright green mudstone containing calcrete. Numerous mud clasts exist at the base of the sandstone.

## Joints

Joints form in tension (i.e. a pulling apart) in response to tectonic and thermal stress that forces the rock to extend ever-so-slightly perpendicular to the plane of


Fig. 22 : Open fold observed on the right bank of the Tiliya Khola, near the Dhawari road.

fracture. Figure 24 depicts the joint pattern observed in the fine-grained sandstone of the Chor Khola Formation from the south of the confluence of the Tui Khola with the Babai River.

## Slickenside

Slickensides are scratches into the surface of the rock formed as a result of the movement past each other. It testifies to origin by shear and discloses the direction of movement. Slickensides are observed at different part of the study area, some of them were on the right bank of the Tui Khola, about 500 m upstream from the confluence

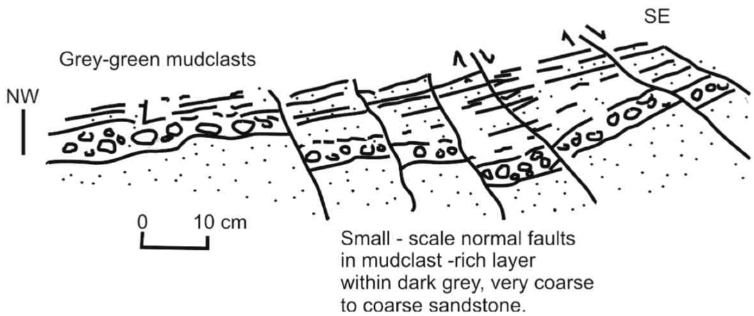


Fig. 23 : A series of small-scale faults observed on the left band of the Simalsota Khola.

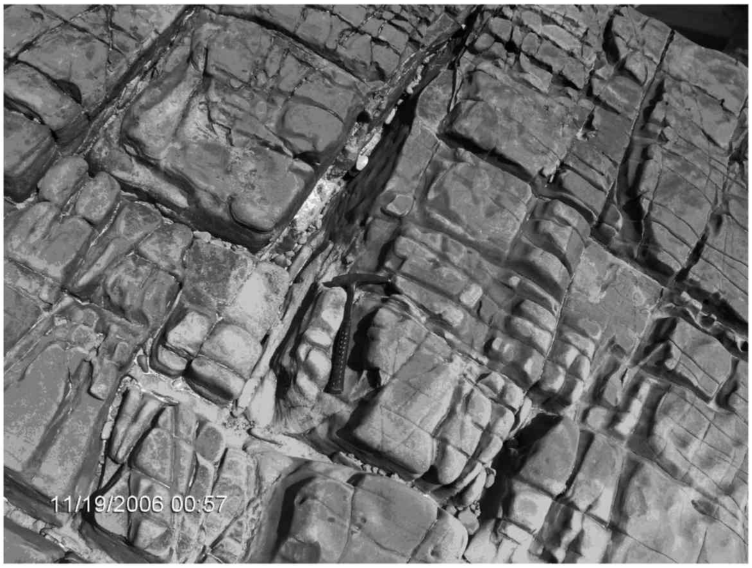


Fig. 24 : Joints observed in the fine-grained sandstone of the Chor Khola Formation, from the south of the confluence of the Tui Khola with the Babai River.

of the Tui Khola and Babai River (Fig. 25). The exposure making up the slickenside is yellow-green calcareous mudstone and greenish gray siltstone. From the observation of the slickenside, the sense of movement is found to be towards the northwest, i.e. opposite the dip direction. The attitude of bedding is 285°/17°SW and the trend and plunge of the slickenside are found to be 236°/19°, 265°/13°, 236°/18°, 244°/21°

## Major structures

The study area consists of a series of faults and folds indicating intense deformation in the past. The geological map and cross-sections of the study area show the geometry and pattern of thrusts and the folds. The main regional structures observed in the study area are briefly described below.

## Bheri Thrust

The name of the thrust is derived from the Bheri River in Mid-Western Nepal (Kyastha et al., 1999). It is a NW-SE trending and north-dipping thrust. In the study area it is located to the north of the Jaubari Khola (Fig. 3). In the footwall of the thrust the younger rocks of the Dhan Khola Formation are observed, while in the hanging wall, older rocks of the Bankas Formation are found.


Fig. 25 : Slickenside observed on the fine grained sandstone on the right bank of the Tui Khola, about 500 m upstream from the confluence of the Tui Khola and Babai.

## Malai Thrust

The name of the thrust is from the Malai Khola in Dang. It is a north-dipping thrust. In the study area, it is observed along the Babai River as well as to the east of the confluence with the Malai Khola (Fig. 3). From the east of the confluence, it takes the course of the Malai Khola and terminates at the Babai Back Thrust forming a branch line. In the hanging wall of the thrust older rocks of the Bankas Formation are observed, while in the footwall, younger rocks of the Dhan Khola Formation are observed. The thrust is almost parallel to the rocks of the hanging wall.

## Babai Back Thrust

The name of the thrust is derived from the Babai River, which flows form the southern part of the Dang Valley draining out the whole valley. In the study area the thrust passes through the entire length of the Babai River (from east to west) along the Dang Valley (Fig. 3), while it turns to the south after the termination of the Dang valley in the west. It is a northeast-southwest trending back thrust, and dips due south. To the north of the Babai thrust, the Quaternary deposits of the Dang Valley are observed, while to the south of the thrust, the Bankas Formation of the Siwaliks crop out. The back thrust is essentially parallel to the overlying Siwlaik rocks in most places. However to the western end of the Dang Valley, it obliquely cuts the rocks of the footwall, and also the rocks of the hanging wall forming the footwall and hanging wall ramps. This mainly happens in the vicinity of Jalajala, Simalkuna and Chorkholagaun and then the thrust terminates at the Tui Khola Back Thrust which is located to the south of it.

## Tui Khola Back Thrust

The name of the thrust is derived from the Tui Khola River, located in the south of the Dang Valley (Fig. 3). It is also a northeast-southwest trending back thrust, dipping towards the south. The back thrust forms a ramp in the vicinity of the Sukhar Khola in the western extremity of the study area, and then it enters the Malai Khola where it forms a hanging wall flat. The thrust continues further southeast along the Tui Khola up to Gaikhuti where it forms a footwall and a hanging wall ramp. In the hanging wall of the thrust, the older rocks of the Bankas Formation are observed, while in its footwall, the younger Chor Khola Formation is observed in the middle reaches of the Tui Khola. There are two synclines developed at its two ends, i.e. around the Malai Khola in the west and the Masot Khola in the east (Fig. 3) where the rocks of the Surai Khola, Dobata, and Dhan Khola formations are exposed. The back thrust cuts obliquely the Siwaliks in the north of Satbariya at its southeast end where it terminates at the Rapti Back thrust. It also cuts obliquely the Siwaliks (forming footwall and hanging wall ramps) around Agaiya at its northwest extremity. Thus, the overturned hanging wall block of the back thrust is separated from the right-way-up sequences of the footwall block from all sides.

## Rapti Back Thrust

The name of the thrust is derived from the Rapti River flowing through the central part of the Deukhari Valley (Kyastha et al., 1999). It is also a southeast-northwest trending back thrust dipping towards the south, and it follows the course of the Rapti River. The Mahendra Highway (Fig. 3) runs on the back thrust between Jalkundi and Lauri Rihar. The older rocks of the Surai Khola Formation are observed in the hanging wall of the thrust, while the rocks of the Dhan Khola, Dobata, and Surai Khola formations are observed in the footwall of the thrust. The thrust is essentially parallel to the rocks of the hanging wall, while it obliquely cuts the rocks of the footwall near Lauri Rihar.

## Overturning of the Siwaliks in different parts

A large block of overturned Siwalik succession is observed in the study area (Fig. 3). The overturned block is located to the north west of Satbariya, east of the Sukhar Khola in Agaiya, 1 km north of the Mahendra Highway, and to the south of the Tui Khola, Malai Khola, and the Masot Khola. The rock constituting the overturned sequence is trending due NE-SE and the dip varies from 65° to 88°.

The Bankas and Chor Khola formations constituting the overturned succession crop out between Chaupatta and the Masot Khola (Fig. 3). Here the rocks are also folded. Similarly, a few rock exposures to the north of the Tui Khola also show overturning. The overturning of Siwaliks is also observed to the north of Malai, on the way to Simalkuna from Malai.

## Masot Khola Syncline

The name of this fold is derived from the Masot Khola, flowing from west to east, one of the tributaries of the Rapti River. It is an overturned syncline plunging towards SE (Fig. 3). The axis of the fold passes through the right bank of the Masot Khola. The fold is asymmetric as evident from the field studies and its north limb is overturned. The Masot Khola Syncline forms a wide E-W trending valley. The fold is more apparent in the eastern part of the Masot Khola than in its western part. The reason is that because one of the limbs of the syncline is cut off by the Tui Khola Back Thrust. This mainly happens to the west of Ghumne. There are many small scale folds in both the limbs of the fold.

## Satbariya Syncline

The name of this fold is derived from the village of Satbariya. It is as an open fold (Fig. 3), the core of which consists of conglomerates of the Dhan Khola Formation. It is also an asymmetric fold. The north limb of the fold has a steeper dip angle than the south limb. It is plunging towards the west. The axis of the fold passes through the Bhaisahi Khola. The fold is covered by the alluvial deposits of the Rapti River to the east of Teliya.

## Agaiya Syncline

The name of this fold is derived from the name of the village Agaiya. It is an open fold plunging towards the east (Fig. 3). Part of the fold in the vicinity of Khokari is cut off by the Rapti Back Thrust. However, the fold becomes prominent in the western part, i.e. at Kusum, Gabar, and Agaiya where the Rapti River flows from its core. The northern limb of the fold is overturned. The fold is not seen to the west of Agaiya, as it is covered by the alluvial deposits of the Rapti River.

## Baijapur Anticline

The name of this fold is derived from the name of Baijapur. It is an open fold plunging towards NW. The fold is cut off by the Rapti Back Thrust to the south of Khokari, i.e. it is not seen to the north of Khokari. The anticline is consisting entirely of the rocks of the Surai Khola Formation. The dip amount of the limbs ranges from 20° to 75°.

## Bhaisahi Khola Anticline

This anticline is located to the south of the Satbariya Syncline. It is also an open fold plunging towards NW. The axis of the fold passes from the left bank of the Bhaisahi Khola. Here the prominent lithology constituting the fold is salt and pepper sandstone of the Surai Khola Formation. The dip of the fold limbs ranges from 40° to 60°.

## Khairi Khola Anticline

The core of an anticline is observed along the Khairi Khola and the name of this anticline is derived from the same river. It is an open fold. The attitude of the limbs ranges from 30° to 70°. At the core of this fold, the rocks Bankas Formation are exposed. The outer part of one of the limb of the fold is cut-off by the Tui Khola Back Thrust. This mainly happens along the Sukhar Khola. The periphery of this fold is marked by the Malai Khola Thrust and to the south of the core of this anticline, huge alluvial fan of recent deposit is observed.

## Mali Khola Anticline

A periclinal closure of an anticline in seen at the confluence of the Babai River and the Malai Khola, thus the name of this fold is taken from the name of Malai River. This anticline is separated from the Khairi Khola Anticline by the Tui Khola Back Thrust, i.e. to the south of the Tui Khola Back Thrust along the confluence of the Babai and the Malai River, Khairi Khola Anticline is observed and to its north, Malai Khola Anticline is observed. It is also an open fold. The attitude of the fold limbs ranges from 40° to 80°.

## Structures in cross-section

## Structure in Cross-section A-A'

Cross-section A-A' extends from Babai Back Thrust in the north to the Baijapur Anticline in the south (Fig. 26). It is from the western part of the study area. From the north to the south the prominent structure are the Babai Back Thrust, Tui Khola Back Thrust, Agaiya Syncline, Rapti Back Thrust and the Baijapur Anticline. The Babai Back Thrust has the lowest angle and the Rapti Back Thrust is the steepest of all the three back thrusts. In the cross-section, the branch line between the Babai Back Thrust and the Tui Khola Back Thrust is seen in the northern extremity. The rocks in the Babi Back Thrust and the Tui Khola Back thrust are seen to be overturned. In addition, certain rocks in the south of the Tui Khola Back Thrust are overturned. The Babai Back Thrust is overtaken by the Tui Khola Back Thrust. To the south of the Tui Khola Back Thrust, the Rapti Back Thrust is observed. It is steeper than the Babai Back Thrust and the Tui Khola Back Thrust. In between the Tui Khola Back Thrust and the Rapti Back Thrust, Agaiya Syncline is observed. Its southern limb has been cut off by the Rapti Back Thrust. The hinge of the fold is inclined towards N. To

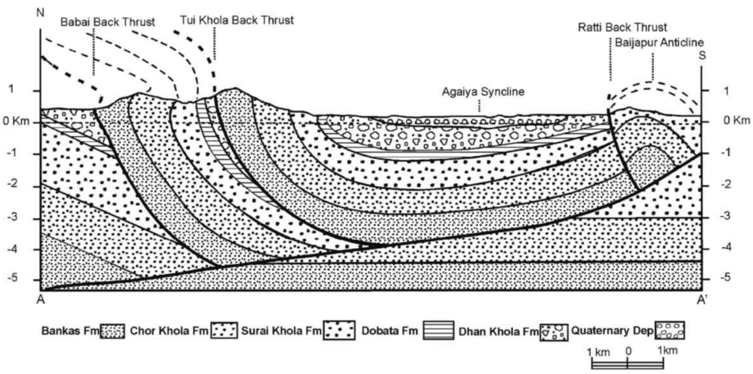


Fig. 26 : Cross-section 1, along the western part of the study area.

the south of the Rapti Back Thrust, Baijapur Anticline is observed. The northern limb of the fold is cut off by the Rapti Back Thrust. The hinge of the fold is also folded and is inclined towards S.

## Cross-section B-B'

The cross-section B-B' is from the central part of the study area (Fig. 27). From north to the south, three thrustsheets separated by the Babai Back Thrust, Tui Khola Back Thrust and the Rapti Back Thrust occur. The rocks in between the Babai Back Thrust and Tui Khola Back Thrust and in between Tui Khola Back Thrust and Rapti Back Thrust show the overturning sequences, while the rocks lying to the south of the Rapti Back Thrust shows the normal sequence. One of the limbs of the Agaiya Syncline has been truncated by the Rapti Back Thrust, while the Satbariya Syncline is fully exposed in the southern extremity of the cross-section.

## Cross-section C-C'

This cross-section is drawn from the eastern part of the study area (Fig. 27). It is drawn between Dharna in the north and Satbariya in the south. The northern extremity of the cross-section is demarcated by the Babai Back Thrust, while its southern end is bounded by the Rapti Back Thrust. The Bankas Formation to the south of the Babai Back Thrust is very thick. It consists of both anticlinial and synclinal structures. While to the south of the Tui Khola Back Thrust, its thickness is lower. This is due to the thrusting.

In the cross-section, it is also seen that one of the limb of the Masot Khola Syncline has been truncated by the Tui Khola Back Thrust. The northern limb of the fold is distinct, while the southern limb is not seen on the surface. The core of the Syncline is consisting of the rocks of the Dhan Khola Formation. To the south of the Tui Khola Back Thrust, the rocks are overturned. The thickness of the Bankas and the Chor Khola Formation is lower, while the thickness of the Surai Khola Formation is

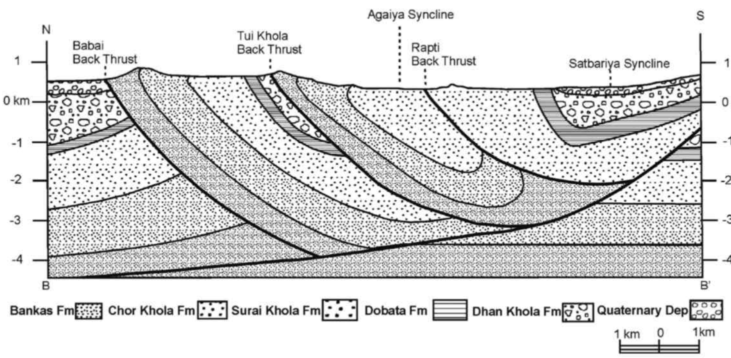


Fig. 27 : Cross-section 2, along the central part of the study area.

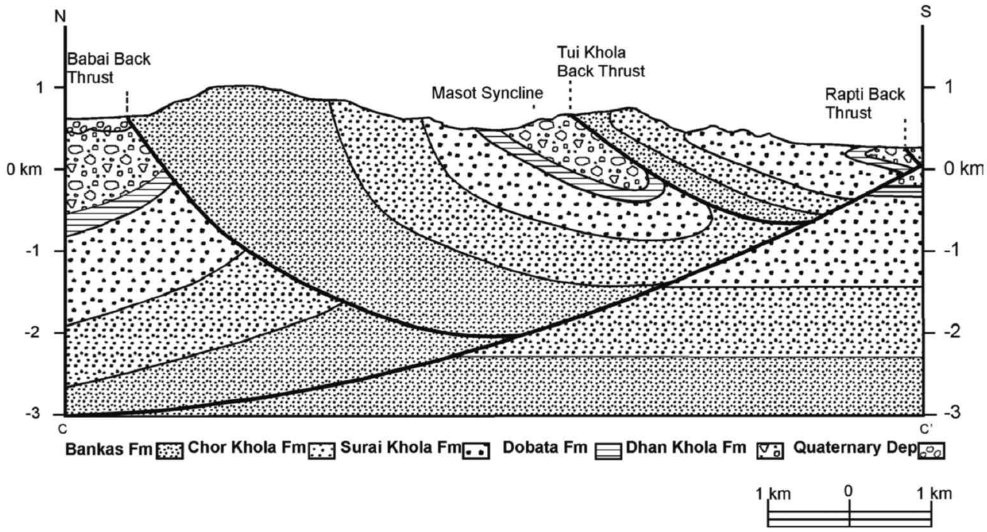


Fig. 28 : Cross-section 3, along the eastern part of the study area.

greater than that of the northern part. The Rapti Back Thrust is seen to be overturned.

## Regional Structural Interpretation

In order to establish that a thrust belt is a thin skinned, it is necessary to demonstrate that thrust fault surfaces possess irregular 'staircase' trajectories, with long 'flat' sections, parallel to bedding, separated by short 'ramps', which cuts across strata boundaries (Boyler and Elliot, 1982). The above situation (i.e. : flat and ramp) is evident in the study area. They are shown in the geological map of the area (Fig. 3). The rocks in the study area show smooth flats, parallel to the bedding plane and steep ramps cutting through the bedding. Both the hanging-wall as well as footwall ramps are observed in the study area. This situation occurs in the west of Malai, around Bakhariya, in the south east of Manname and in the north of Satbariya.

In the study area altogether five splay thrusts are observed. To the northern extremity, the first splay thrust is represented by the Bheri Thrust. It is a north-dipping thrust with the Bankas Formation in the hanging wall and the Dhan Khola Formation in its footwall. The second splay thrust is represented by the Malai Thrust. It is also a north-dipping thrust. It gets terminated at the Babai Back Thrust, which is the third splay thrust. There are other two splay thrust namely the Tui Khola Back Thrust and the Rapti Back Thrust.All these thrusts were responsible for the shortening of the Siwalik belt in the study area.

As one moves south from the Babai Back Thrust towards the Rapti Back Thrust, it becomes clear that the thrusts cut off younger rocks from north to south. The back thrusts are migrating from the hinterland towards the foreland, i.e. the younger thrusts were developed in the hanging wall of the older thrust. Piggy-back propagation pattern (Dahlstrom, 1970) originates if a younger thrust develops on the footwall of an older thrust and if the thrusts migrate sequentially from the hinterland towards the foreland. Thus, from the definition of the piggy-back thrusting, it is clear that the pattern of thrusting in the study area is like piggy-back. The study reveals that the Dang Valley is located in a triangle zone bounded by the Babai Back Thrust in the south and the Bheri Thrust in the north.

In the process of detailed geological mapping of the area, it has been observed that the thickness of the Siwaliks is not constant throughout the area. In some places it is very thick, while in some other places it is less. This is mainly due to the tectonic process, which has resulted in the formation of several faults, thrusts, and folds. Also, the study shows that the Siwaliks were subjected to more than one deformational phases. This is clear from the fact that one of the limbs of most of the folds has been traccuted by back thrusts.

Studies by various researchers in the Siwaliks suggested different amounts of crustal shortening. According to Adhakari (1993), about 28 km of crustal shortening had occurred in the Siwaliks of the Surai Khola area i.e. almost about 40% of the total width of the Siwalik basin. Similarly according to Mugnier (1995), the western part of the study area suffered a crustal shortening of greater than 40%. From this it can be said that the present study area also exhibits crustal shortening of an order of 40%.

## Conclusion

Based on the detail mapping in the southern part of the Dang Valley as well as the study of cross-sections, route maps, geological columns, rock outcrops, hand specimens, and thin sections, the following conclusions are drawn.

From the detailed lithostratigraphic studies in the Amiliya-Tulsipur road section, the rocks of the study area could be correlated with the already established stratigraphy of the Surai Khola-Bardanda area of Mid-Western Nepal. The rocks of the study area can be classified into the Bankas, Chor Khoal, Surai Khola, Dobata, and Dhan Khola formations, respectively in an ascending order. The Bankas Formation is represented by an interbedding of red-purple mudstone, shale, and fine-to very fine-grained sandstones. The Chor Khola Formation shows a gradual increase of sandstone grain size as well as thickness of beds. The sandstones are calcareous and rich in plant fossils. The mudstones are variegated in the lower part and gray-green in the upper part. The Surai Khola Formation is mainly represented by multi-storied, coarse-to very coarse-grained 'salt and pepper' sandstones. The beds yield a great amount of petrified wood in the form of steam, branches, and roots. The Dobata Formation is predominated by mudstones with a minor amount of sandstones and conglomerates. The Dhan Khola Formation comprises compact and hard boulder-and pebble-bearing conglomerates, with yellow mudstones in the lower part and loose conglomerates with yellow mudstones in the upper part.

The Siwalik sandstones as a whole show a coarsening-upwards sequence with the fine-to very fine-grained sandstones in the lower part and cobble-boulder conglomerates in the upper part, but in an individual depositional cycle, the sediments show fining -upwards sequence. The fining-upwards sequence is developed because the Sub-Himalaya is the product of the fluvial deposition, while the coarsening-upwards sequence of the entire Sub-Himalaya is due to the tectonic processes, which resulted in a series of uplifting events. The sandstones of the of the study area mostly belong to the litharenites, feldspathic litharenites, and lithic graywakes of the sandstone classification proposed by Folk (1974). The sandstones of the present study area are almost similar to those of the Surai Khola section. However, the differences occur in the calcite content. Here, the rocks contain a high amount of calcite as the cementing material.

The rocks of the study area are highly deformed. The persistence of shortening between India and Asia involves their deformation. This deformation is expressed in the form of faults and folds which succeed one another in both space and time. The study area is subjected to more than one phase of deformational process. The study area comprises a series of faults such as the Bheri Thrust, Mali Khola Thrust, Babai Back Thrust, Tui Khola Back Thrust, and Rapti Back Thrust. These thrusts show a ramp-flat geometry. The thrusts also have created branch lines and triangle zone. The Dang Valley is situated in the triangle zone formed by the thrusts. Thus it can be said that the formation of other Dun Valleys are linked with the pattern of the thrusts in that area. There are also a number of folds such the Baijapur Anticline, Bhaisahi Anticline, Khairi Khola Anticline, and Malai Khola Anticline, Agaiya Syncline, Satbariya Syncline, and Masot Khola Syncline.

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