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Structural pattern of Sub-Himalaya in Dang and Deukhari valleys of western Nepal

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ABSTRACT

Detailed geological mapping was carried out in the Siwaliks of western Nepal surrounding the Dang and Deukhari valleys. The investigation of lithostratigraphy and geological structures revealed several thrusts and folds within this Sub-Himalayan belt. The main thrusts are the Bheri Thrust, Babai Backthrust, Tui Khola Backthrust, and Rapti Backthrust from north to south, respectively. Similarly, the main folds are the Malai Khola Anticline, Masot Khola Syncline, Satbariya Syncline, Agaiya Syncline, Baijapur Anticline, Bhainsai Khola Anticline, and Khairi Khola Anticline. Also, the study shows that most of the Siwalik rocks are overturned. The geological map of the area illustrates that one of the limbs of most folds has been truncated by a thrust. This situation clearly demonstrates that the rocks were subjected to intense deformation, and the folds were formed earlier than the thrusts.

Keywords: Sub-Himalaya, Siwaliks, structure, backthrust, thin-skinned tectonics, overturned folds

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INTRODUCTION

The study area consists of two valleys, one is the Dang Valley and the other is the Deukhari Valley (Fig. 1). The important settlement areas in the study area are Tui Khola, Bakhere, Malai, Satbariya, Amiliya, Agaiya, and Gabar.

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 Deukhari Valley is surrounded by the Siwalik Hills from all sides, whereas the Dang Valley is surrounded by the Siwalik Hills from the southern, eastern and western sides, and is bordered by the Lesser Himalaya in the northern side. The altitudes of the Dang and Deukhari valley floors are about 700 and 300 m above sea level, respectively.

The Dang Valley lies about 10 km north of the Deukhari Valley and closes about 30 km west of the latter. It is about 50 km long, 17 km wide, and is filled up with the Quaternary fluvial sediments of the rivers flowing from north to south. On the other hand, the Deukhari Valley is about 50 km long, 12 km wide and is an elongated trough, filled up with the Quaternary deposits of the Rapti River. Most of the mountain ridges in the study area extend in the east–west direction, parallel to the main geological structures. The Dang and Deukhuri valleys are drained by the Babai and the Rapti rivers, respectively.

LITHOSTRATIGRAPHY

The distribution of different rock units are shown in Fig. 2, and the lithostratigraphy of the study area is given in Fig. 3. The formation nomenclature used in this study follows that of Dhital et al. (1995) from the Surai Khola–Bardanda area.

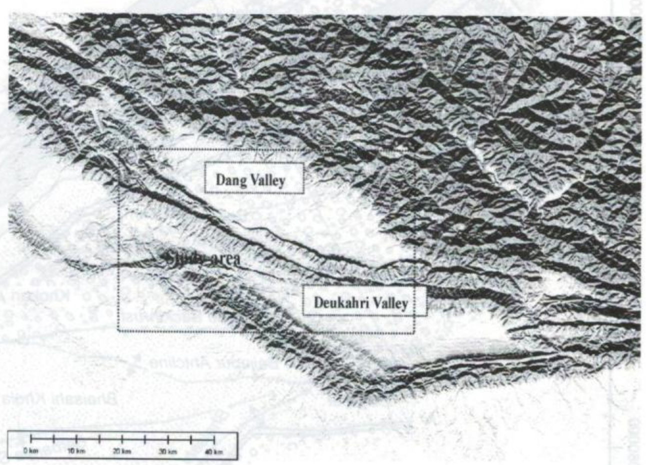

Fig. 1: Physiographic setting of Dang and Deukhari valleys and the position of the study area

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 an ascending order (Figs. 2 and 3). A short description of lithostratigraphy of all the formations is presented below.

Bankas Formation

The Bankas Formation is exposed in many parts of the study area (Fig. 2). 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 Rolpalitara. 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.

The Bankas Formation comprises an interbedding of fine- to very fine-grained, grey-green sandstone and red-purple, yellow-brown, and dark brown mudstone. Predominating colour of the mudstone is red-purple. Palaeosols and calcretes are frequent, and plant fossils occur in the mudstones of its upper part.

The sandstones of the Bankas Formation are of fine- to medium-grained with subrounded and moderately spherical grains. The sandstones contain quartz, feldspar, muscovite, and certain opaque minerals. The grain contacts are sutured to tangential. The micas in the sandstones of the Bankas Formation are rich in muscovite, whereas biotite is absent. Most of the sandstone samples of the Bankas Formation belong to the litharenite and subordinately to the feldspathic litharenite. Frequently, the mica grains present in the sandstone are deformed (Fig. 4).

Chor Khola Formation

The Chor Khola Formation is exposed in many parts of the study area (Fig. 2). It crops out along the Tui Khola, in the Masot Khola, Malai Khola, Kalitara, and around Haure and Bakhere.

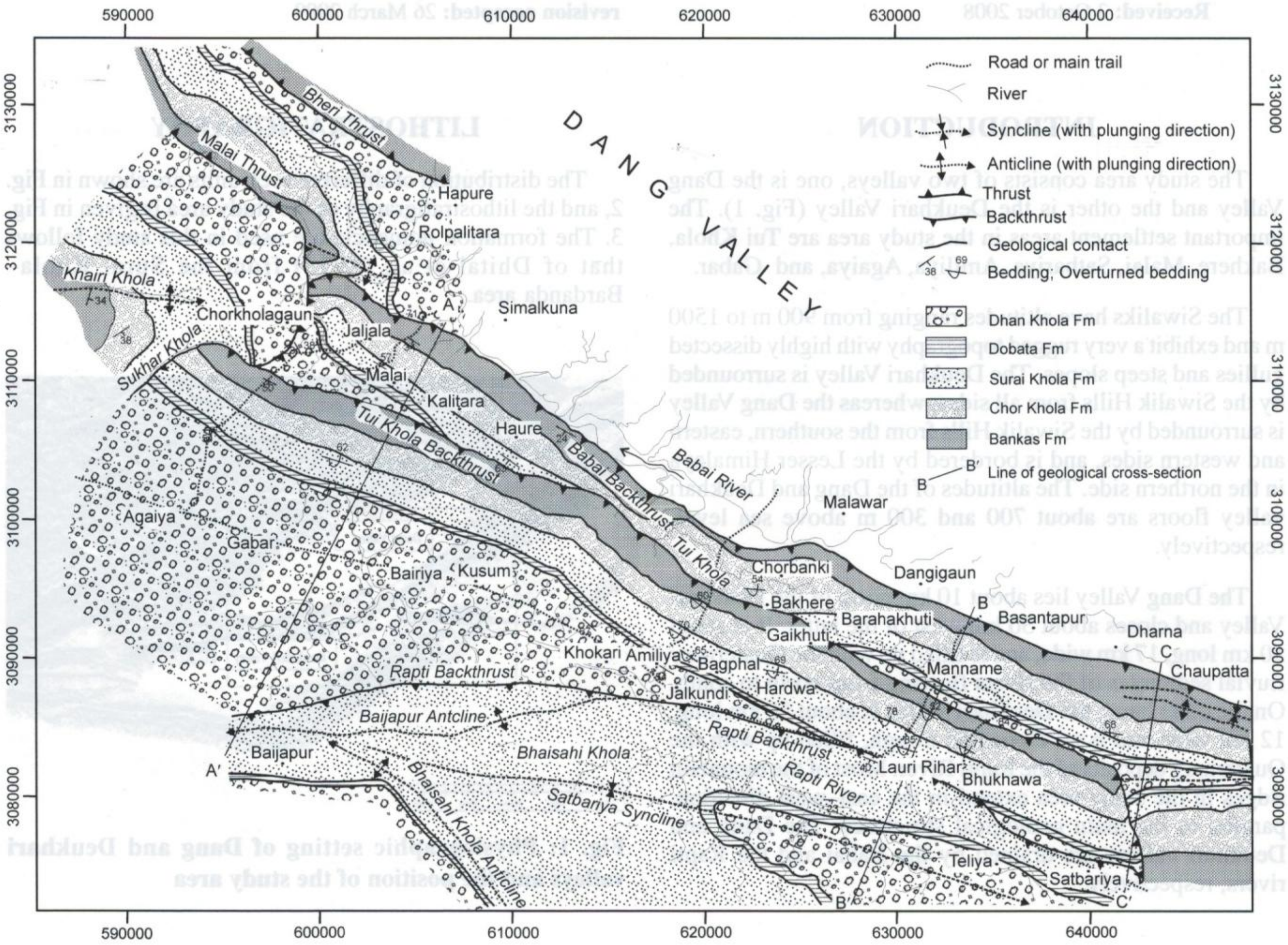

Fig. 2: Geological map of the study area

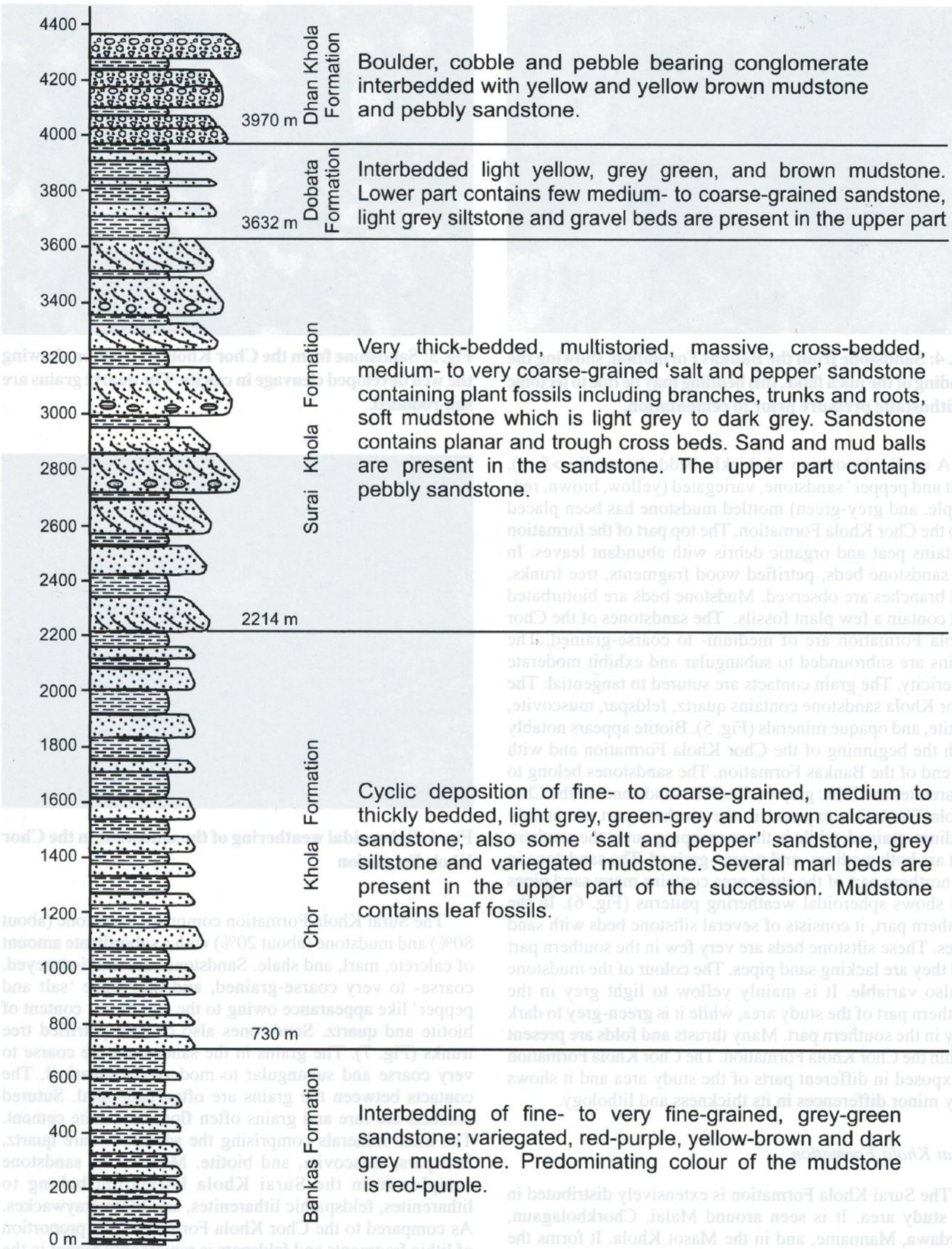

Fig. 3: Generalised lithostratigraphic column of the Siwaliks in the Tulsipur–Amiliya road section

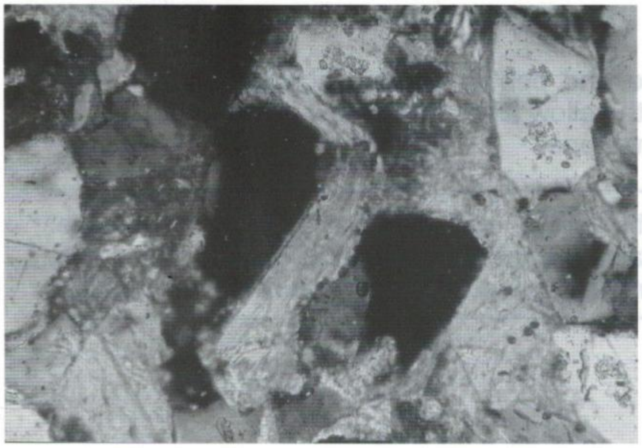

Fig. 4: Sandstone from the Bankas Formation, showing the bending of the mica flake, this bending may be due to tectonic or lithostatic pressure prior to cementation.

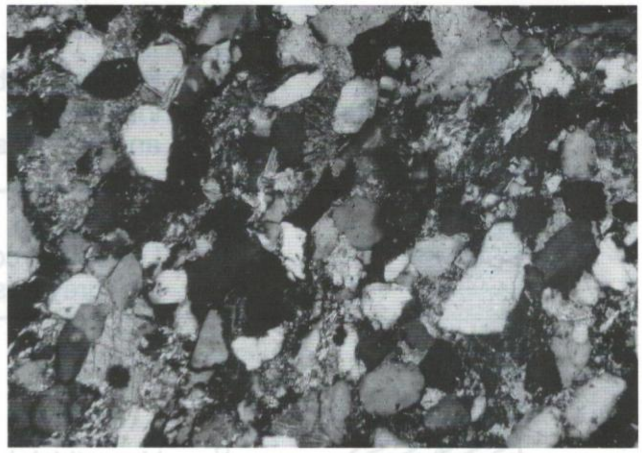

Fig. 5: Sandstone from the Chor Khola Formation showing the well developed cleavage in calcite. The quartz grains are sub-rounded.

A cyclic deposition of thickly bedded (usually >5 m), 'salt and pepper' sandstone, variegated (yellow, brown, red-purple, and grey-green) mottled mudstone has been placed into the Chor Khola Formation. The top part of the formation contains peat and organic debris with abundant leaves. In the sandstone beds, petrified wood fragments, tree trunks, and branches are observed. Mudstone beds are bioturbated and contain a few plant fossils. The sandstones of the Chor Khola Formation are of medium- to coarse-grained. The grains are subrounded to subangular and exhibit moderate sphericity. The grain contacts are sutured to tangential. The Chor Khola sandstone contains quartz, feldspar, muscovite, biotite, and opaque minerals (Fig. 5). Biotite appears notably with the beginning of the Chor Khola Formation and with the end of the Bankas Formation. The sandstones belong to litharenites and lithic greywackes. The sandstones of the Chor Khola Formation exposed in the northern part are mainly medium-grained, while in those cropping out in the southern part are both medium- and coarse-grained. The sandstone in the northern part of the study area contains many sand pipes and shows spheroidal weathering patterns (Fig. 6). In the northern part, it consists of several siltstone beds with sand pipes. These siltstone beds are very few in the southern part and they are lacking sand pipes. The colour of the mudstone is also variable. It is mainly yellow to light grey in the northern part of the study area, while it is green-grey to dark grey in the southern part. Many thrusts and folds are present within the Chor Khola Formation. The Chor Khola Formation is exposed in different parts of the study area and it shows only minor differences in its thickness and lithology.

Fig. 6: Spheroidal weathering of the sandstone in the Chor Khola Formation

Surai Khola Formation

The Surai Khola Formation is extensively distributed in the study area. It is seen around Malai, Chorkholagaun, Hardawa, Manname, and in the Masot Khola. It forms the core of the Baijapur Anticline, Bhaisi Khola Anticline, and Masot Khola Syncline (Fig. 2).

The Surai Khola Formation comprises sandstone (about 80%) and mudstone (about 20%) with a subordinate amount of calcrete, marl, and shale. Sandstones are multi-storeyed, coarse- to very coarse-grained, and they have 'salt and pepper' like appearance owing to the significant content of biotite and quartz. Sandstones also contain petrified tree trunks (Fig. 7). The grains in the sandstones are coarse to very coarse and subangular to moderately spherical. The contacts between the grains are often tangential. Sutured contacts are rare and grains often float on calcite cement. The main minerals comprising the sandstones are quartz, feldspars, muscovite, and biotite. Most of the sandstone samples from the Surai Khola Formation belong to litharenites, feldspathic litharenites, and lithic graywackes. As compared to the Chor Khola Formation, the proportion of lithic fragments and feldspars is remarkably higher in the sandstones of the Surai Khola Formation.

Fig. 7: Sandstone containing petrified tree trunks from the left bank of the Jalkundi Khola, belonging to the Surai Khola Formation

The Surai Khola Formation varies in thickness at different parts of the study area due to the lateral variation during deposition as well as subsequent intense deformation resulting into the formation of a great number of geological structures. The thickness of individual beds also changes from the southern (containing thicker beds) to the northern (with thinner beds) part of the study area. Petrified tree branches, trunks, and stems which are frequently present in the southern part of the study area, are sporadic in the northern part. However, the overall lithology of the Surai Khola Formation in different parts of the study area is almost similar.

Dobata Formation

The Dobata Formation is exposed in five separate belts of the study area (Fig. 2). It overlies the Surai Khola Formation with a transitional contact. The Dobata Formation is exposed in the Masot Khola, at the Haure village of Dang, to the south of Hardawa, to the north of Gabar, at Amiliya, and in Chorkholagaun.

The main lithology of the Dobata Formation is light to dark grey, light yellow and brown mudstone (70%), medium- to coarse-grained, grey sandstone (20%), light grey siltstone and conglomerate (10%). The sandstones in the Dobata Formation are relatively finer-grained than those in the Surai Khola Formation.

The main difference in the Dobata Formation from the northern and the southern parts of the study area is in the structure and texture of mudstones. The thickness of the mudstones in the northern part is less than that in the southern part. However, the mudstones from both the northern and southern parts of the study area are rich in organic matter. In some places, the formation has been cut out by a backthrust creating a ramp–flat geometry. This mainly occurs around Lauri Rihar and in the Kalan Khola (Fig. 2). However, the overall lithology of the Dobata Formation is almost the same with a minor difference in the thickness and in the proportion of mudstone and sandstone.

Dhan Khola Formation

The Dhan Khola Formation consists of conglomerate (70%), mudstone (27%), and sandstone (3%). It forms the core of the Satbariya Syncline, Agaiya Syncline, and the Masot Syncline. It has also created the closure of an anticline in Rolpalitara and in Chorkholagaun. The thickness of this formation is variable from place to place. Both the thickness of the formation and the thickness of individual beds in the southern part of the study area are less than those of the northern part. The Dhan Khola Formation from the northern part consists essentially of boulder conglomerates with a lesser amount of mudstone as compared to the southern part. Similarly, the Dhan Khola Formation in the southern part is dominated by an interbedding of pebble-cobble conglomerate and mudstone. The Dhan Khola Formation exhibits similar lithology and thickness throughout the study area. But, the texture and distribution of pebbles, cobbles, and boulders in conglomerates of this formation vary significantly from place to place.

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 centimetres to many kilometres. 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 backthrusts from all directions. There are three regional-scale backthrusts, 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 north and are trending east–west. 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-skinned 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 steep, 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 favourable 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 footwall 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 (Elliott and Johnson 1980).

If a new thrust develops in the hanging wall of an older thrust, an overstep or overlap sequence results (Elliott 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).

Thrust faults are seldom solitary. Instead, the thrusts, and the horses of rock evolved by thrusts that branch and merge around them, overlap "like roof tiles, all dipping in the same general direction" (Baily 1938).

Structures found in the study area

A short description of structures found in the study area is presented below. It is remarkable that most of the faults inter into the folds, thus cutting one of the fold limbs. This situation is evident particularly in the Masot Khola and around Khokari.

Bheri Thrust

The name of the thrust is derived from the Bheri River in western Nepal (Kayastha 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. 2). In the footwall of the thrust, the younger rocks (i.e., the Dhan Khola Formation) are observed, while in the hanging wall, older rocks (i.e., the Bankas Formation) are found.

Malai Thrust

This north-dipping thrust is named after the Malai River of Dang. 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. 2). From the east of the confluence, it takes the course of the Malai Khola and terminates at the Babai Backthrust forming a branch line. In the hanging wall of the thrust, older rocks of the Bankas Formation are present, 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 Backthrust

This backthrust is named after the Babai River, a trunkline river that flows from the southern part of the Dang Valley. In the study area, the thrust passes through the entire length of the Babai River (from east to west), while it turns to the south after the termination of the Dang Valley in the west (Fig. 2). It is a northeast–southwest trending backthrust, that dips due south. To the north of the Babai Backthrust, the Quaternary deposits of the Dang Valley are observed, while to the south of the thrust, the Bankas Formation crops out. The backthrust is essentially parallel to the overlying rocks of the Banks Formation in most places. However, to the western end of the Dang Valley, it obliquely cuts the rocks of the footwall. This mainly happens near Houre and Kalkate, and then the thrust terminates at the Tui Khola Backthrust, which is located to the south of it.

Tui Khola Backthrust

The northeast–southwest trending Tui Khola Backthrust follows the Tui Khola River, flowing in the south of the Dang Valley (Fig. 2). It forms a ramp to the east of Chorkholagaun and then enters the Malai Khola where it forms a hanging-wall flat. The thrust continues further southeast along the Tui Khola up to Manname where it forms a footwall as well as 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 exposed 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. 2) where the rocks of the Surai Khola, Dobata, and Dhan Khola Formations are exposed. The backthrust cuts obliquely the Siwalik rocks in the north of Satbariya at its southeast end where it terminates at the Rapti Backthrust. It also cuts obliquely the beds (forming footwall and hanging wall ramps) around Agaiya at its northwest extremity. Thus, the overturned hanging-wall block of the backthrust is separated from the right-way-up sequences of the footwall block from all sides.

Rapti Backthrust

Kayastha et al. (1999) named this thrust after the Rapti River flowing through the central part of the Deukhari Valley. It is also a southeast–northwest trending backthrust dipping towards the south and it follows the course of the Rapti River. The older rocks of the Surai Khola Formation are observed in the hanging wall of the thrust, while the rocks of the Dhan Khola Formation, Dobata Formation, and Surai Khola Formation comprise its footwall. The thrust is essentiality parallel to the rocks of the hanging wall, while it obliquely cuts the beds constituting the footwall near Lauri Rihar.

Overturned strata

A large region of overturned succession is observed in the study area (Fig. 2). The overturned zone is located to the west of Satbariya, east of the Sukhar Khola near Agaiya, about 1 km north of the East–West highway, and to the south of the Tui Khola, Malai Khola, and the Masot Khola. The rocks constituting the overturned sequence are trending due NE–SE with dip amounts varying from 65° to 88°.

Another overturned sequence is observed in the Ghorahi–Lamahai Road section. The Bankas Formation and the Chor Khola Formation constituting the overturned successions crop out between Chaupatta and the Masot Khola (Fig. 2). 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 the Masot Khola Syncline is derived from the east-flowing Masot Khola, one of the tributaries of the Rapti River. It is an overturned syncline plunging towards SE (Fig. 2). The axial trace of the fold passes through the right bank of the Masot Khola. The fold is an asymmetric one 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 the western part. This is because one of the limbs of the syncline is cut off by the Tui Khola Backthrust. This mainly happens to the east of Manname. There are many small-scale folds in both the limbs of the fold.

Satbariya Syncline

The Satbariya Syncline is named after the village Satbariya. It is as an open fold (Fig. 2), the core of which consists of conglomerates of the Dhan Khola Formation. It is also an asymmetric fold. The northern limb of the fold has a steeper dip angle than the southern limb. It is plunging towards the west. The axis of the fold follows the course of the Rapti River for some distance and then enters the Bhaisahi Khola. The fold is covered by the alluvial deposits of the Rapti River to the east of Teliya.

Rapti Syncline

The name of the Rapti Syncline was derived from the Rapti River (Kayastha et al. 1999). It is an open fold plunging towards the east (Fig. 2). Part of the fold in the vicinity of Khokari is cut off by the Rapti Backthrust. 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 Baijapur Anticline is named after the locality Baijapur. It is an open fold plunging towards NW (Fig. 2). The fold is cut off by the Rapti Backthrust to the south of Khokari. The anticline consists entirely of the rocks of the Surai Khola Formation. The dip amount of its limbs ranges from 20º to 75º.

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 (Fig. 2). Here the prominent lithology constituting the fold is 'salt and pepper' sandstone of the Surai Khola Formation. The dip of its fold limbs varies from 40º to 60º.

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 whose attitude of limbs ranges from 30º to 70º. In the core of this fold, the rocks of the Bankas Formation are exposed. The outer part of one of the limbs of the fold is truncated by the Tui Khola Backthrust. This mainly happens along the Sukhar Khola. The fold is surrounded by the Malai Thrust in the north whereas there is a huge alluvial fan of Holocene deposits to the south of the core of this anticline (Fig. 2).

Malai Khola Anticline

A periclinal closure of an anticline is seen at the confluence of the Babai River and the Malai Khola (Fig. 2). This anticline is separated from the Khairi Khola Anticline by the Tui Khola Backthrust. It is also an open fold with the attitude of limbs ranging from 40º to 80º.

Structures in cross-section A-A'

Cross-section A-A' extends from Babai Backthrust in the north to the Baijapur Anticline in the south (Fig. 8). It depicts the structure of the western part of the study area. From the north to the south, the prominent structures are the Babai Backthrust, Tui Khola Backthrust, Agaiya Syncline, Rapti Backthrust and the Baijapur Anticline. The Babai Backthrust has the lowest angle and the Rapti Backthrust is the steepest of all the three backthrusts. In the cross-section, the branch line between the Babai Backthrust and the Tui Khola Backthrust is seen in the northern extremity. The rocks in the Babai Backthrust and the Tui Khola Backthrust are overturned. In addition, the rocks in the south of the Tui Khola Backthrust are also overturned. The Babai Backthrust is overtaken by the Tui Khola Backthrust. To the south of the Tui Khola Backthrust, the Rapti Backthrust is observed. It is steeper than the Babai Backthrust and the Tui Khola

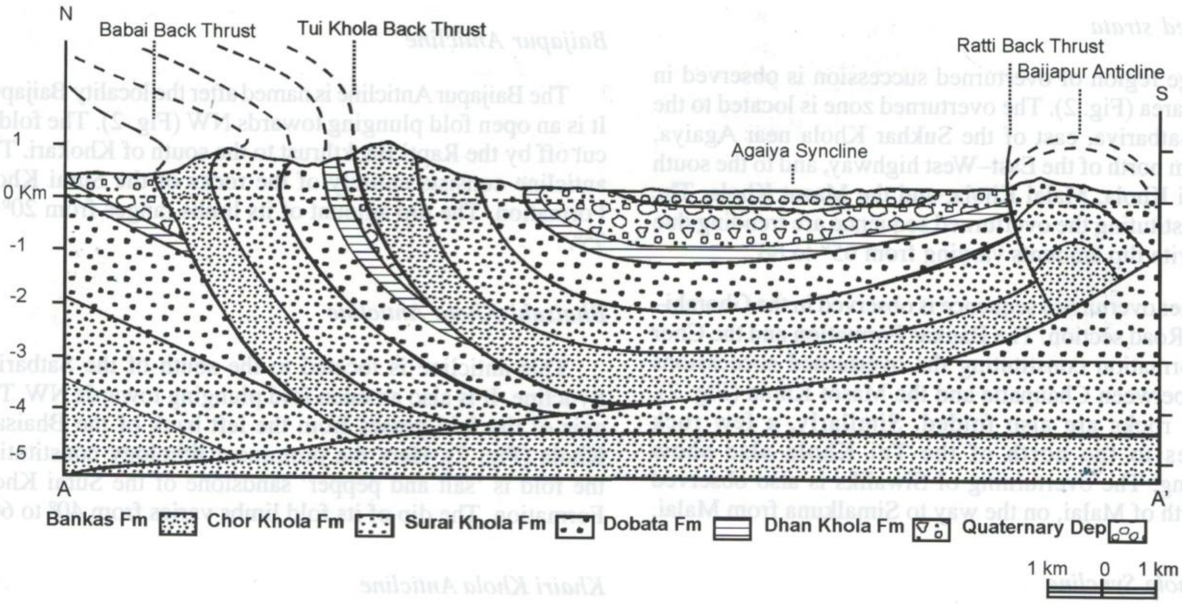

Fig. 8: Cross-section A-A' drawn across the western part of the study area

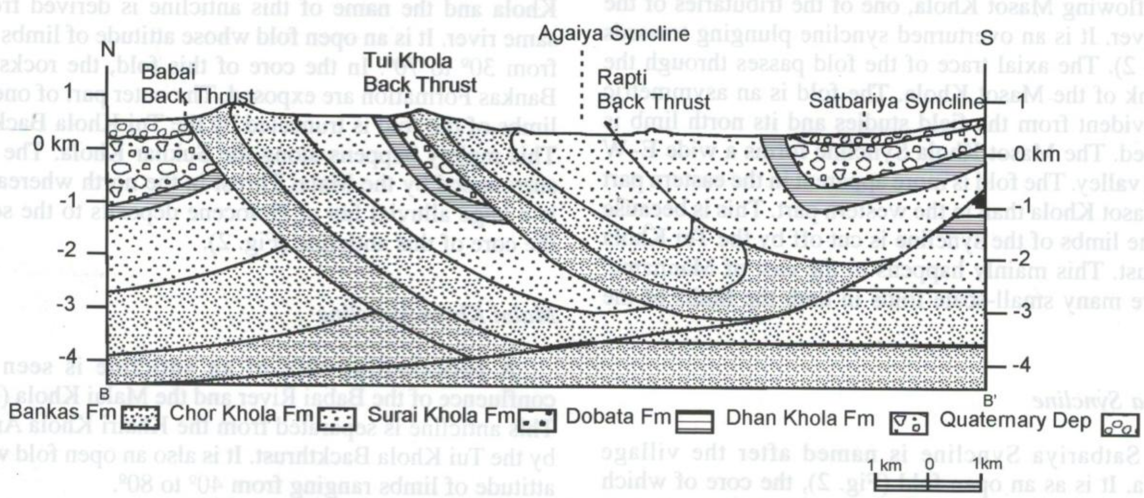

Fig. 9: Cross-section B-B' drawn across the central part of the study area

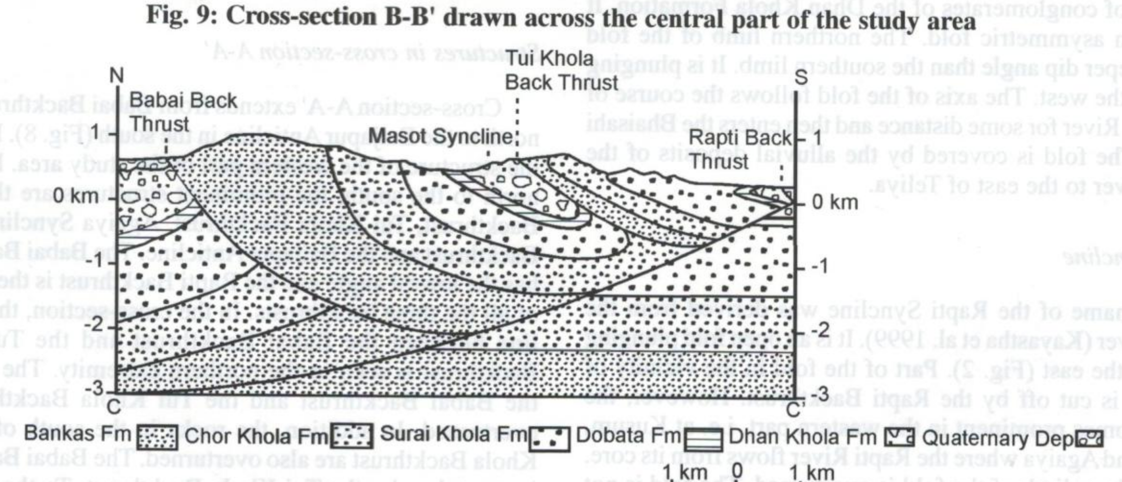

Fig. 10: Cross-section C-C' drawn across the eastern part of the study area

Backthrust. In between the Tui Khola Backthrust and the Rapti Backthrust, the Agaiya Syncline is observed. Its southern limb has been cut out by the Rapti Backthrust. The hinge of the fold is inclined towards N. To the south of the Rapti Backthrust, Baijapur Anticline is observed. The northern limb of the fold is cut out by the Rapti Backthrust. The hinge of the fold is also folded and is inclined towards the south.

Cross-section B-B'

The cross-section B-B' is from the central part of the study area (Fig. 9). From north to the south, three thrust sheets separated by the Babai Backthrust, Tui Khola Backthrust and the Rapti Backthrust occur. The rocks in between the Babai Backthrust and Tui Khola Backthrust and in between the Tui Khola Backthrust and Rapti Backthrust show the overturned successions, while the rocks lying to the south of the Rapti Backthrust form a right-way-up sequence. One of the limbs of the Agaiya Syncline has been truncated by the Rapti Backthrust, while the Satbariya Syncline is fully exposed at the southern end of the cross-section.

Cross-section C-C'

This cross-section is drawn from the eastern part of the study area (Fig. 10). It passes through Dharna in the north and Satbariya in the south. The northern end of the cross-section is demarcated by the Babai Backthrust, while its southern end is bounded by the Rapti Backthrust. The Bankas Formation to the south of the Babai Backthrust is very thick. It consists of both anticlinal and synclinal structures (Fig. 10). While to the south of the Tui Khola Backthrust, its thickness is reduced. This is due basically to thrusting.

In the cross-section, it is also seen that one of the limbs of the Masot Khola Syncline has been truncated by the Tui Khola Backthrust. The northern limb of the fold is distinct, while the southern limb is not seen on the surface. The core of the syncline consists of the rocks of the Dhan Khola Formation. To the south of the Tui Khola Backthrust, the rocks are overturned. In the southern part, the thickness of the Bankas and the Chor Khola formations is diminished, while that of the Surai Khola Formation is increased. The Rapti Backthrust 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 cut across strata boundaries (Boyer and Elliott 1982). The above situation is evident in the study area. They are shown in the geological map of the area (Fig. 2). 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. They are conspicuous especially to the west of Malai, around Bakhere, to the southeast of Manname, and to 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 is terminated at the Babai Backthrust, which is the third splay thrust. There are other two splay thrusts namely the Tui Khola Backthrust and the Rapti Backthrust. All these thrusts were responsible for the shortening of the Siwalik belt in the study area.

As one moves south from the Babai Backthrust towards the Rapti Backthrust, it becomes clear that the thrusts cut off younger rocks from north to south. The backthrusts are migrating from the hinterland towards the foreland, i.e. the younger thrusts were developed in the hanging wall of the older thrust. A 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 a piggy-back model. The study reveals that there is a triangle zone bounded by the Babai Backthrust in the south and the Bheri Thrust in the north.

In the process of detailed geological mapping of the area, it was 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 processes, which have 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 truncated by backthrusts.

Various researchers working in the Siwaliks have suggested different amounts of crustal shortening. According to Adhikari (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 et al. (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%.

CONCLUSIONS

The rocks of the study area are highly deformed. This deformation is expressed in the form of faults and folds, which succeed one another in both space and time. The process of thrust development and folding suggests several deformational phases. A series of faults, which exist from the north to the south, are the Bheri Thrust, Malai Thrust, Babai Backthrust, Tui Khola Backthrust, and Rapti Backthrust. These thrusts show a ramp-flat geometry. The thrusts also have created branch lines and the triangle zone. 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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REFERENCES

Adhikari, S. P., 1993, *Geological study of Bankas Basa-Bardanda area with a special reference to structures.* unpublished M. Sc. thesis of Tribhuvan University, Kirtipur, Kathmandu, Nepal, 89p.

Bailey, E. B., 1938, Eddies in Mountain Structure. Quarterly Jour.Geol. Soc.; 1938; v. 94; issue.1-4, pp. 607–626

Boyer, S. E. and Elliott, D., 1982, Thrust Systems. AAPG Bulletin, v. 66, no. 9, pp. 1196–1230.

Butler, R. W. H., 1982, The terminology of structures in thrust belts, Jour. Struct. Geol., v. 4(3), pp. 239–245.

Dahlstrom, C. D. A., 1970, Structural geology in the eastern margin of the Canadian Rocky Mountains, Bull. Can. Petrol. Geol., v. 18, pp. 332–406.

Dhital, M. R., Gajural, A. P., Pathak, D., Paudel, L. P. and Kizaki, K., 1995, Geology and structure of the Siwaliks and Lesser Himalaya in the Surai Khola-Bardanda area, Mid-Western Nepal. Bull. Dept. Geology, Tribhuvan Univ., Kathmandu. v. 4, Special Issue, pp. 1–70.

Elliott, D. and Johnson, M. R. W., 1980, Structural evolution in the northern part of the Moine Thrust Belt, NW Scotland, Trans. R. Soc. Edinb. Earth Sci., v. 71, pp. 69–96.

Kayastha, N.B., Pardhan, U.M.S., Shrestha, R. B., KC, Shyam, Subedi, D.N. and Sharma, S.R., 1999, Petroleum Exploration Promotion Project, Ministry of Industry 1999.

Mugnier, J. L., Chalaron, E, Mascle, G., Pradier, B., and Herail, G., 1995, Structural and Thermal Evolution of the Siwaliks of Western Nepal. Jour. Nepal Geol. Soc., v.11, pp. 171–178.

Mugnier, J. L., Leturmy, P., Mascle, G., Huyghe, P., Chalaron, E., Vidal, G., Husson, L. and Delcaillau, B., 1999a, The Siwaliks of Western Nepal, I. Geometry and kinematics. Jour. Asian Earth Sci., v.17, pp. 629–642.

Mugnier, J. L., Leturmy, P., Huyghe, P. and Chalaron, E., 1999b, The Siwaliks of Western Nepal, II. Mechanics of thrust wedge. Jour. Asian Earth Sci., v.17, pp. 643–657.