Journal of Nepal Geological Society, 1998, Vol. 18, pp. 59-69

Use of LANDSAT-TM data in mapping of the Siwalik deposits, Nepal

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ABSTRACT

Satellite data are exploited to study the Butwal, Hetauda, Bagmati River and Trijuga sections of the Siwaliks and the results of the investigations are discussed. Remote Sensing data deliver information on lithological units, orientation of the strata (bedding as iron plates, strike directions) and tectonic structures (strong lines and other features) of the region.

The data supplemented by multicolour satellite images are valuable assets in deciphering the geology of an area. The satellite LANDSAT-TM data of two false colour composites of the Bagmati and Trijuga River area of the Sub-Himalayan (Siwalik) region show interesting tonal and morphological (topographical and textural) differences. Such variations can be attributed to lithological discrepancies among the geological formations of the area.

At least three different lithological units of the Siwaliks are recognised. They are fine, medium and coarse grained clastic deposits corresponding to the three fold divisions (Lower, Middle and Upper) of the Sub-Himalaya. The three lithological units are morphologically related to the smooth, rugged and dissected terrains. Shifting up of the Siwalik range near about 12 km northeast of Lahan, active fault alignment along with MBT (north of Gaighat), Bhabar Zone (southern part of the foothills of the Siwaliks), Dun Valley (Hetauda) are prominent features observed in the TM-scenes.

Rivers originating in the middle mountains of Lesser Himalaya like Trijuga, Bagmati, Rapti, Tinau and Banganga drain through the Siwaliks crossing the major structure MBT suggesting an antecedent river type. Other streams originating in the Siwaliks and flowing southward are obsequent and subsequent.

INTRODUCTION

The Himalaya is divided into five longitudinal geologcial and the geographical regions. The pattern of the regional geographical subdivisions of the Himalaya shows a close relationship to the geological subdivisions. The longitudinal geological subdivisions of the Himalaya from the south to the north are: northern part of the Indo-Gangetic Plain (Terai), Sub-Himalaya (Siwaliks), Lower (Lesser) Himalaya, Higher Himalaya and Tibetan/Tethys Himalaya. The present paper deals with the Siwaliks of Nepal Himalaya with the site examples of Butwal, Hetauda, Bagmati River and Udayapur (Fig. 1) in understanding the applicability of LANDSAT-TM data in geological mapping.

The Siwalik hills are the first mountain range (foothills) to the north of the Terai without well defined boundary between them but at some places they do thrust southward over the Terai along the Main Frontal Thrust (MFT). Siwalik sediments are mainly the erosional detritus consisting of thick piles of fresh water molasse type sediments derived from the rising Himalayas and deposited in a basin during Middle Miocene to Lower Pleistocene time (West et al., 1978) tilting the strata to the north.

Use of LANDSAT-TM scenes at 1:125,000 scale taken by Thematic Mapper (TM) Sensor System taken between 12th October 1988 to 17th November 1992 in the different false colour composites having three spectral bands of TM helped in getting the

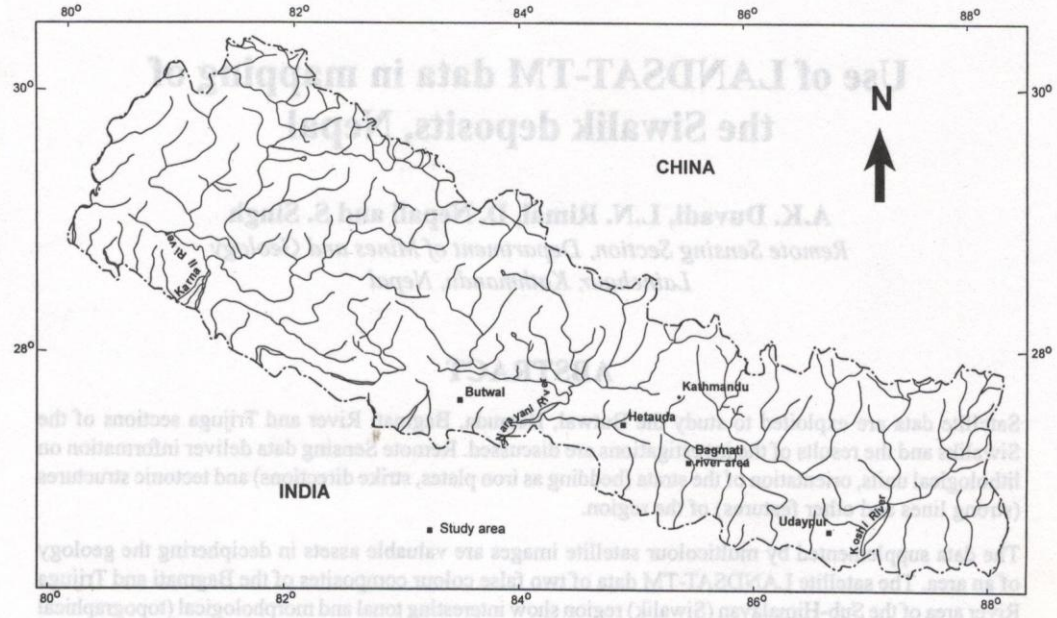

Fig. 1: Location Map.

regional structural, geomorphological, sometimes lithological as well as vegetative cover, shadows and possible landuse patterns. During the course of interpretation, LANDSAT-TM scenes were first visually inspected involving the colour tone as well as morphological differences, flat irons and strong linear lines. Later the various features observed on the TM-scenes were verified in the field. The GIS (Geographical Information System) technique with ARC\INFO software was used in digitising the drainage, geological, geomorphological as well as structural and topographical information separately.

GEOLOGICAL SETTINGS OF THE SIWALIKS

The Siwaliks occur within the limits of the Main Boundary Thrust (MBT) in the north and the MFT in the south consisting mainly of the sedimentary rock sequences like well-bedded sandstone (calcareous graywacke), shale, mudstone, siltstone, conglomerate and some limy beds (argillaceous limestone). Minor marly shales and mudstones are also present. Meta-sedimentary rock sequences of the Lesser Himalayan belt are noticed to the north of the MBT.

Several rivers either originating in the Lesser Himalayas or within watersheds of the Siwalik Range made their way flowing down south crossing the major structure (MBT) and entire foothills towards the Terai Plain following the lineament structures as depicted from the satellite images suggest an antecedent and the subsequent type respectively. The streams in the southern foothill slope of the Siwalik Range are obsequent as they are flowing against the dip direction of the rock units, (Fig. 2, 3, 4 and 5). Trijuga, Bagmati, Rapti, Tinau and Banganga rivers are taken as examples for antecedent type as they drain through Siwaliks crossing the MBT.

Interbeds of sandstone, mudstone, shale and siltstone occur repeatedly and are common throughout the Siwaliks of western, central and eastern Nepal. The rocks of the Siwaliks in these areas are divisible into the three subdivisions based on their lithology, grain size, textural and morphological patterns as well. They are Lower, Middle and Upper Siwaliks in an ascending order from the south to the north. At some places, based on the lithological characteristics, the Upper Siwalik is again subdivided into two subdivisions in an ascending order as Lower Upper and Upper Upper

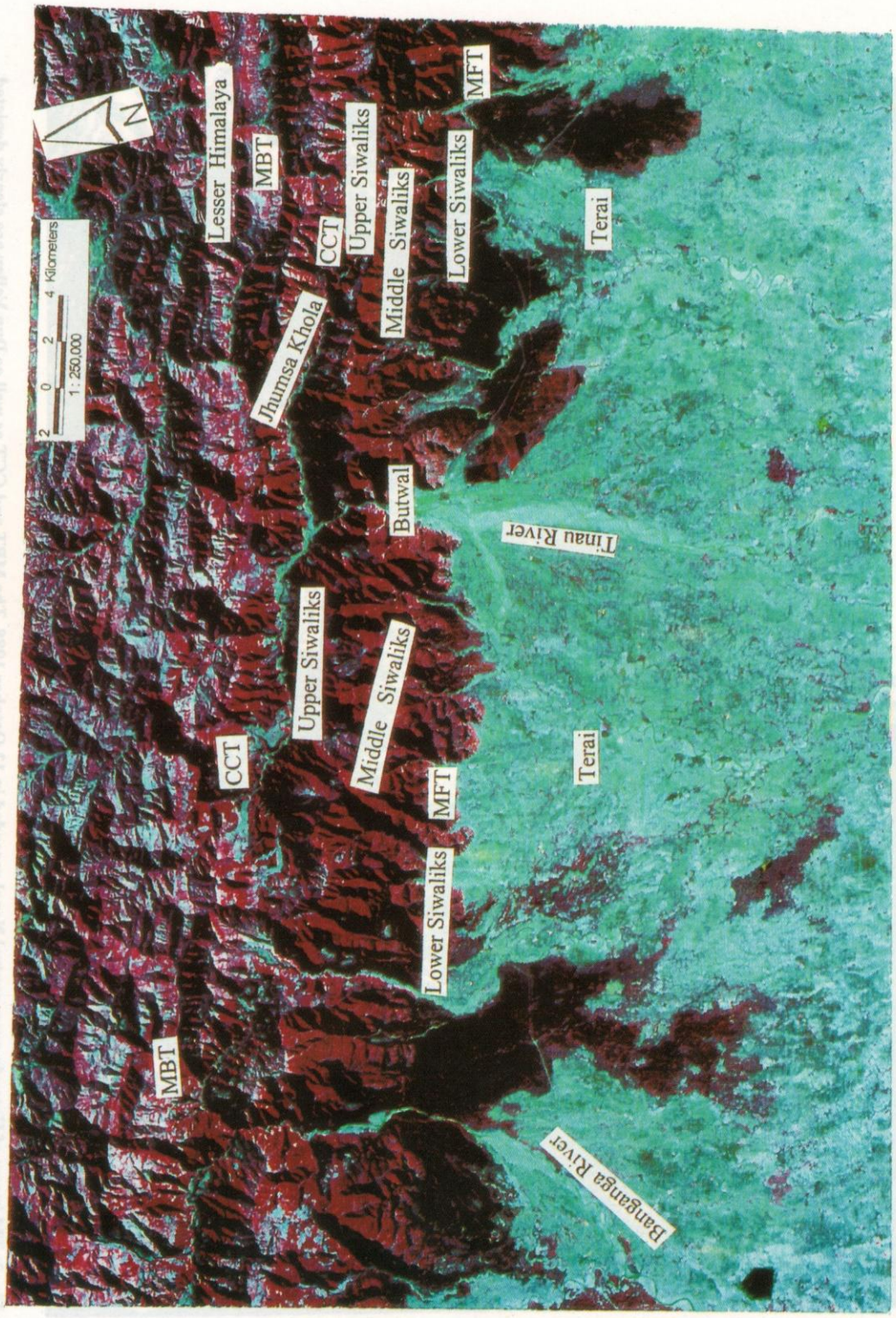

Fig. 2: Image of LANDSAT 5 Thematic Mapper (TM) of Butwal area, western Nepal recorded in 26 November 1990. The MBT and CCT follow the E-W valleys. Three major rock units of Siwaliks (Lower, Middle and Upper) are seen from S to N, respectively.

Fig. 3: TM image of Hetauda area, central Nepal recorded in 12 October 1988. The MBT and CCT as well as Dun Valley are clearly depicted.

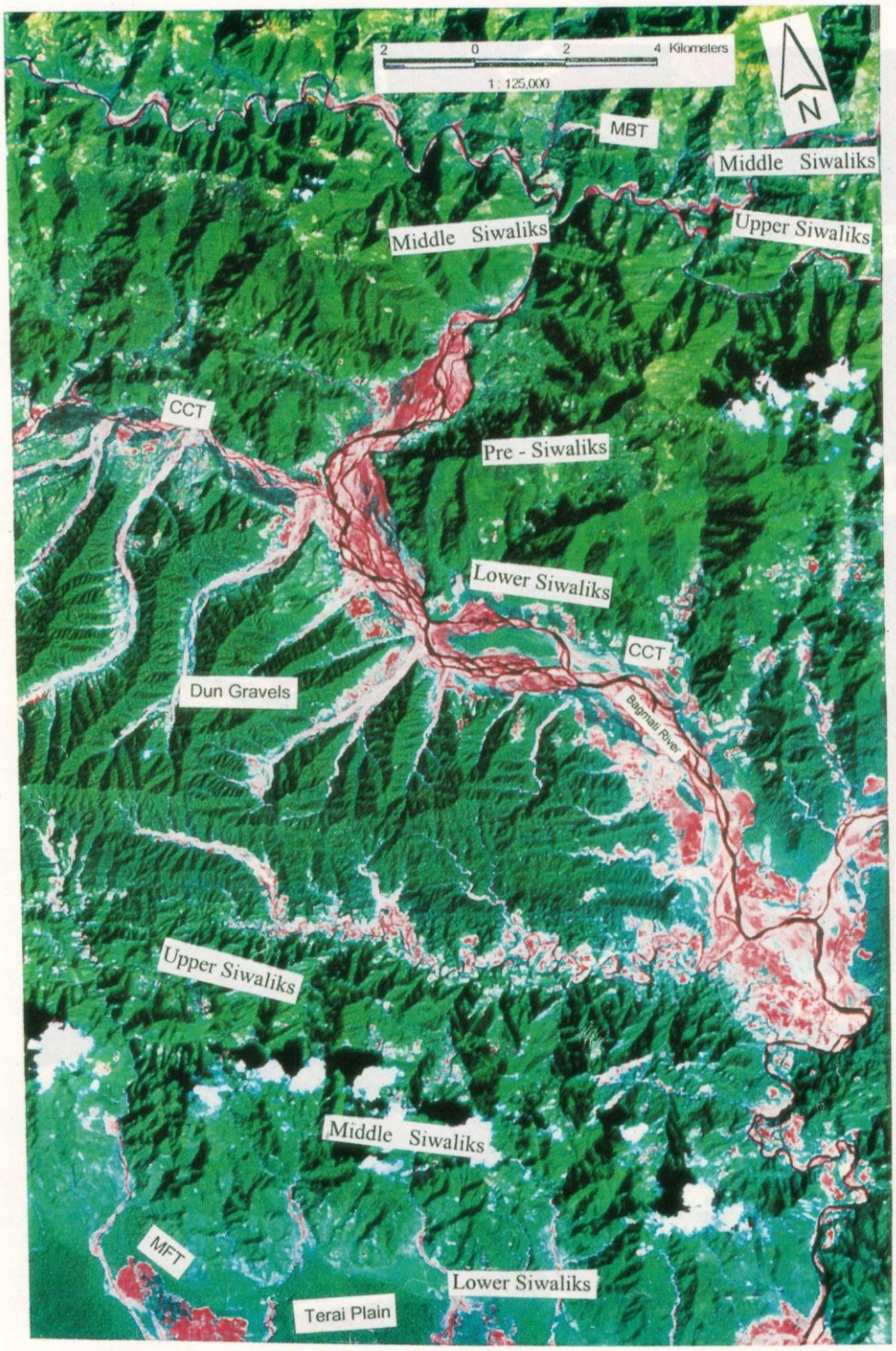

Fig. 4: TM image of Bagmati area, central Nepal recorded in 12 October 1988. Morphological differences of Siwalik rock units and Pre-Siwaliks as well as major structural features are well marked.

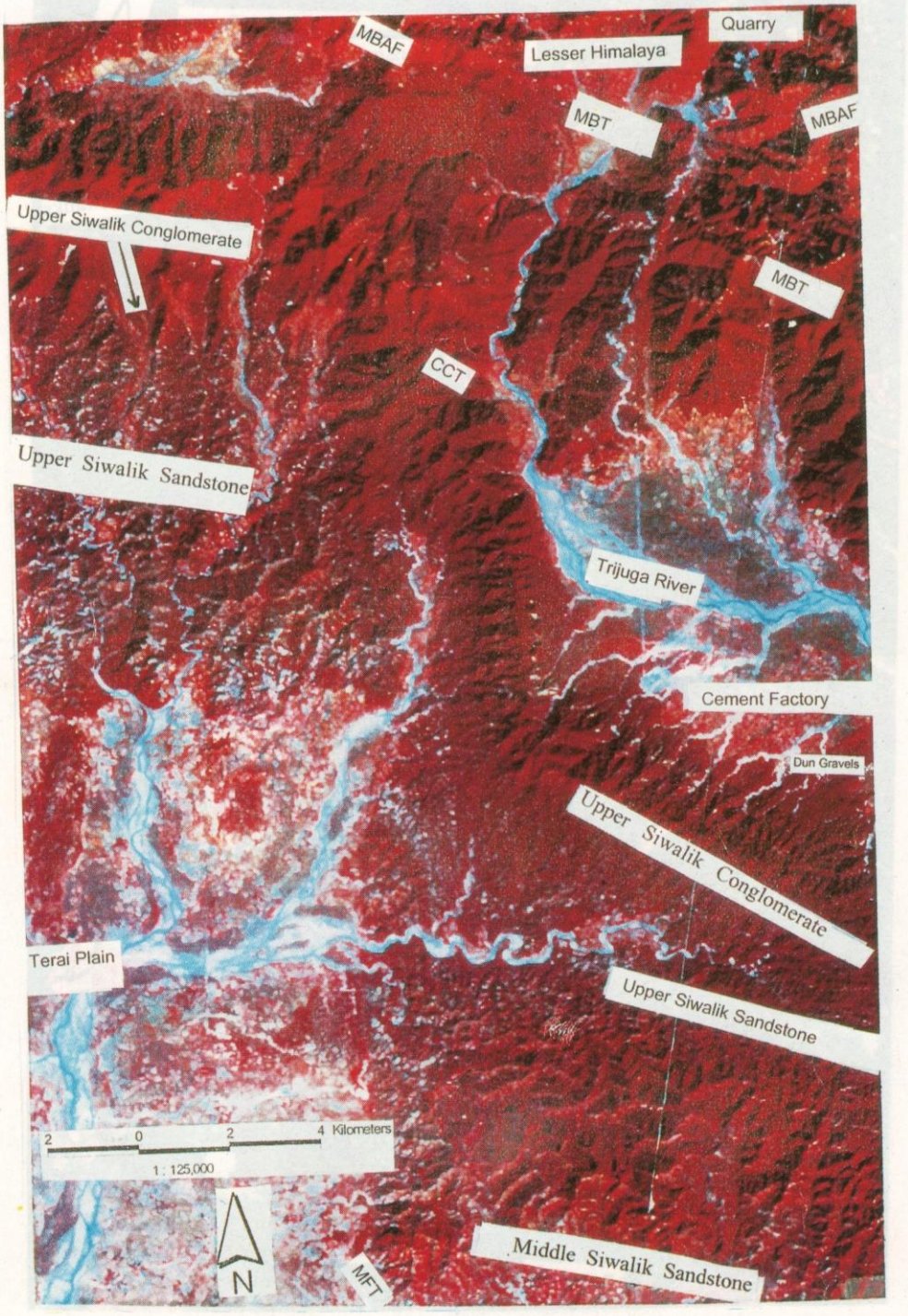

Fig. 5: TM image of Trijuga River (Udayapur) area, eastern Nepal recorded in 17 November 1992 showing the large displacement of the Siwaliks on a N-S directed fault zone.

Siwaliks giving rise to the fourfold subdivisions of the Siwaliks. The Siwalik rock sequence is normally distributed in the North and South belts which are separated to each other by the Central Churia Thrust (CCT) passing almost through the central part of the Siwalik Range nearly in an east-west direction.

The Lower Siwaliks show the smooth topography and is characterised by the fine grained alternating beds of hard, grey sandstone, colourful mudstones, siltstone and varicoloured shales. Shale and mudstones sometimes contain plant fossils (Sah et al., 1994). Cyclic sedimentation with fining upward sequence from sandstone to siltstone followed by mudstone and occasionally to shale beds of varying thickness in each cycle with the repetition of the same cycle are often noticed. In the lower part of the Lower Siwaliks, the mudstone is always found to be predominating over the sandstone. And the gradational increase of the sandstone is marked upwards finally changing into the Middle Siwaliks (Adhikari and Rimal, 1996; Gautam and Appel,1994). In the LANDSAT-TM scene, the Lower Siwaliks show the light colour tone with fine, even, smooth texture and moderate height of the hills. Dense forest cover with lack of traceable bedding as well as the coarse dendritic drainage patterns together with the rare landuse situation are other characteristics often seen in the images.

The Middle Siwaliks on the other hand reflect a nearly WNW-ESE trending ridges immediately to the north of the Lower Siwalik with cuesta-like topography consisting in general of the alternations of sandstones and varicoloured mudstones. Sandstones are medium to coarse grained often showing the pepper and salt textural pattern. Sandstone and mudstones are often found to be distributed in equal proportion at the lower part while in the upper part the sandstone is predominating over the mudstones. Here again the cyclic sedimentation of fining upward sequence from sandstone to mudstone, siltstone and up to shale (with mega plant fossil) and the sedimentary structures like cross-bedding, sole markings are also marked together with the pebbles of quartzites and mudstones containing in them. Sandy concretions (sand balls) and calcareous concretions (nodules) are normally present. Bluish grey, grey or yellowish grey mudstones are found to be spheroidically weathered, cushion structured and lenticular in shape. Sandstones in the upper part of the Middle Siwaliks slowly become massive, very coarse grained (changing from medium to coarse grained in the lower part) and contain the carbonised (petrified) wood pieces changing gradually into the Upper Siwalik (Duvadi, 1997). In the LANDSAT-TM scene, the Middle Siwaliks show the variable colour tone with fine to medium coarse, smooth to rough and even to uneven texture as well as maturely dissected ridges (water divides) containing the resistant rocks showing the flat irons. Well and thick bedding, clear dip slopes, moderate spaced faults and joints (lineaments), sub-dendritic drainage patterns with v-shaped narrow cross profile together with dense forest cover as well as common landuse situation are the other image characteristics of the Middle Siwaliks.

The Upper Siwaliks occurs with small cone-like hillocks and badland topographical features immediately to the north of the Middle Siwaliks stretching nearly in the NW-SE direction. The Upper Siwaliks represented by well to poorly bedded rocks of the massive, coarse grained pepper and salt type pebbly sandstone with minor lenticular colourful mudstones (Rimal and Duvadi, 1992). Mudstone tends to be more dominant than sandstone in the lower part with less commonly preserved gastropods and plant leaf fossils. In the upper part, the Upper Siwaliks are represented mainly by conglomerate bed. They are made up of quartzite pebble to boulder size clasts alternating with the very coarse, loose, brown sandstone and grey or yellowish brown mudstone beds (Duvadi and Pradhan, 1994). At places, the clasts of granites, quartzites, schists and gneisses of the Higher Himalaya as well as limestones, slates, phyllites and sandstones of the Lesser Himalaya are present in the conglomerates. These clasts are often found to be embedded in silty and calcareous sand matrix. In the LANDSAT-TM scene, the Upper Siwaliks show the dark to medium and occasionally light colour tones with coarse, rough, banded, uneven to granular texture. Low to moderate hills with flat irons and poorly bedded rocks having narrow but sometimes U-shaped cross profile, moderately densed forest cover and rare or no landuse pattern are the other image characteristics of the Upper Siwaliks.

In addition, the Quaternary deposits are delineated which represent the Sub-Recent to Recent sediments deposited by the fluvial action. Two types of Quartenary deposits - alluvial and flood plain deposits are marked. Alluvial Deposits are distributed on both sides of the rivers and streams as well as immediately at the extreme southern foot slope (northern part of the Terai close to the first foothill). They are characterised by the river terrace deposits and of unsorted, rounded to subrounded pebbly and gravely materials mixed together with fine sand, silt as well as clay giving rise to the development of the fertile top fine soil usable for the cultivation. In the LANDSAT-TM scene, alluvial deposits often show the light color tone with fine, even, smooth texture as well as flat table land, terrace having good landuse and very low resistant materials consisting shallow, none to dendritic drainage patterns. Flood plain deposits occur right in the present existing river channel itself occupying the area covered by the flood and left barren during the dry season after depositing the various materials carried at the flood time. Flood plain deposits lying below the high floods level consist of loose boulders, cobbles, pebbles, coarse sand and gravels sometimes even derived from the Lesser Himalaya. The aggregates thus derived and deposited often provide an excellent source of building and construction materials. In the LANDSAT- TM scene, flood plain deposits show the very light colour tone with fine, even, smooth texture as well as very low resistant materials having no landuse and consisting shallow, non to braided drainage patterns.

The Sub-Himalaya (Siwaliks) have been presented with three-fold subdivisions since the earliest geological description as the Lower, Middle and Upper Siwaliks. Later in the late eighties as the Middle member is further subdivided into the Lower, Middle and Upper Middle Siwaliks, a fourfold subdivision came into use. In the present study, still a four-fold subdivision is accepted with the change like only one Middle and two Upper Siwaliks instead of one, i.e. Lower Upper and Upper Upper Siwaliks. It is based on the comparative studies of the paleaeontology and magnetostratigraphy that the upper part of the Middle Siwaliks is considered to be equivalent to lower part of the Upper Siwaliks. Table 1 gives an idea of the works of various authors in India/Pakistan, midwest and western Nepal Siwaliks.

The Siwalik rocks are deposited during Mid-Miocene to Lower Pleistocene age as a result of the final collision of the northward moving Indian Plate at the rate of maximum 10 cm/yr with the rigid Asian Plate (Duvadi, 1984) in late Cretaceous in the course of Himalayan orogeny. The rate then slowed down to about 5 cm/yr which is still maintained (Molnar and Taponnier, 1975). The sedimentation environment in the Siwalik depositional basin changed from the brackish (initially) to shallow fresh water followed by the torrential fluviatile as well as to the continental (at the final stage) giving rise to the coarsening upward sequence for the Siwaliks suggesting the tectonic rise of the Himalaya and the simultaneous deposition of the sediments in the foredeep. The general trend of the rock sequences in the Siwaliks show a northerly dipping orientation at the moderate angles. Some localized N-S and E-W trending anticlinal and synclinal folds are noticed. Alternation of wide synclines with steep narrow anticlines are commonly observed in the Siwaliks with their axial planes dipping to the north. LANDSAT-TM scene interpretation work has marked a network of the lineaments having WNW-ESE, N-S, NW-SE, NE-SW trends. Lineaments are interpreted as the possible upward continuation of the structural planes of the weakness in the bedrock below. Lineaments with WNW-ESE trend correspond to the longitudinal thrusting and reverse faulting, while the others are related to the transverse faults that sometimes even crossed the Sub-Himalayan Range (Siwaliks) and are found to be followed by the drainages in the Siwaliks. The E-W trending linear structures that are parallel to the mountain front are considered as indicative of the buried Siwalik ridges and some are probably hidden thrust faults in the foreland basin. Three major thrust systems (MBT, CCT and MFT from north to the south) are normally prominently found in the Siwaliks suggesting the migration of the tectonic front towards south with a series of listric faults that cut across the Siwalik sediments the repetition of the sequence sometimes even inverting the folded strata. MBT runs nearly in an E-W direction as a dividing line between the Lesser Himalaya in the north and the Sub-Himalaya (Siwaliks) in the south and thereby bringing into juxtaposition the rocks of

the Lesser Himalaya with the Siwaliks. Thus the MBT, a basement detachment thrust system brought the rocks of the Lesser Himalaya over the Sub-Himalaya and has caused the intense shearing of Siwaliks sediments further south into broad open anticlines and synclines. Steepening of the beds along the MBT is quite common and at the same time this is displaced by N-S, NE-SW and NW-SE oriented transverse faults. The Main Boundary Thrust is following the sharp east-west valley close to the northern end of the image, between the forest covered Siwalik rocks in the south and the agricultural land on the metamorphic groups in the north (Fig. 4). In the LANDSAT-TM scene, a linear depression, topographic break on the ridge and a linear alignment of the saddles on the morphology of the terrain are the prominent characteristics to be taken into account in marking the MBT. The CCT is generally running parallel to the MBT dividing the Siwaliks into the Northern and Southern Belts. Shearing of the rocks are also seen along the CCT with common distribution of landslides and steepening of the beds in them. In the LANDSAT-TM scene, a linear arrangement of discontinuous steep slopes, wide longitudinal valley (along the rivers) and a contrast in resistance between the Lower and Upper Siwaliks are the main characteristics of the CCT. The MFT does not show its continued exposure and is not prominent like the MBT and CCT. However, it is running nearly parallel to the CCT at the places of its exposures in the hillfront as a divide between the Lower Siwaliks and the Terai Plain. In the LANDSAT-TM scene, the southern part of the Siwalik foothills is found to have sharp, strong, linear depression giving the impression of the lineament that is considered to be the characteristics of the MFT.

RESULTS

LANDSAT-TM scenes of two different false colour composites provide the good informations in delineating the morphological and structural patterns in the Siwalik deposits:

Table 1: Correlation table.

Age (Myr)	Authors / Working area	Johnson et al. (1982) India/Pakistan	Corvinus (1993) Surai Khola (Midwest Nepal)	Tokuoka et al. (1986) Arung Khola (West Nepal)	West et al. (1983) Tinau Khola (West Nepal)	Present study Tinau Khola Jhumsa-Binai Khola, west Nepal
1.8	Upper Siwaliks	Boulder conglomerate	Dhan Khola Formation	Deorali and Chitwan Formation		Conglomerates Upper Upper Siwaliks
2.5	Middle Siwaliks	Pinjor Formation	Dobato Formation	Binai Khola Formation Upper Member	Middle Siwaliks with *Ramapithecus*	Lower Upper Siwaliks
5.1		Tatrot Formation	Surai Khola Formation	Binai Khola Formation Middle member		
7.9		Dhokpathan Formation		Binai Khola Formation Lower member		Middle Siwaliks
10.1	Lower Siwaliks	Nagri Formation	Chor Khola Formation	Arung Khola Formation Upper member		
13.1		Chinji Formation	Bankas Formation with *Gamphotherium* sp.	Arung Khola Middle and Lower Members	Lower Siwaliks	Lower Siwaliks
17.0		Kamlial Formation				

Myr : Million year (Age : not in scale)

Colour Composites:

I. Red = single spectral band number 4 (near infrared);

Green = single spectral band number 3 (visible red);

Blue = single spectral band number 1 (visible blue).

Description:

Red = vegetation

Blue = water body, river

Yellowish, greenish, bluish, greyish with differentiated morphological features = different rock types with accompanied soils and cultivation

White, whitish = clouds, sands, gravels

Black = shadows

II. Red = single spectral band number 7 (short wave infrared);

Green = single spectral band number 4 (near infrared);

Blue = single spectral band number 1 (visible blue)

Description:

Dark blue = river

Black = shadows

White = clouds, sand, gravels

Pink, Red = cultivated land

Green = vegetation

Yellow, grayish with differentiated morphological features = different rock types.

After the interpretation of the information from LANDSAT-TM scenes, the three different units reflected by lithology of the Siwaliks as smooth, rugged and dissected terrains are recognised. These three successive units suggest the fine, medium and coarse grained clastic deposits of the Sub-Himalaya corresponding to the three fold subdivisions (Lower, Middle and Upper) of the Siwaliks confirmed by the field checking (Table 2).

Table 2: Intrepretation of information from LANDSAT-TM since and field data.

Morphological features (TM-scene interpretation)	Sedimentological characteristics (TM-Scene interpretation and field truthing)	Stratigraphic position (Field data interpretation)
Dissected	Coarse	Upper Siwaliks
Rugged	Medium	Middle Siwaliks
Smooth	Fine	Lower Siwaliks

ACKNOWLEDGEMENTS

The authors extend their sincere thanks to Mr. N.B. Kayastha, then Director General and the management of the Department of Mines and Geology (DMG) for the permission to publish this paper. Financial support of the German Geological Advisory Group (GGAG) at DMG for the publication of this paper is highly acknowledged. The authors are highly encouraged by the keen interest shown by Dr. K. Busch (Team Leader of GGAG). Dr. P. Hoppe of BGR, Hannover, Germany provided valuable suggestions for which the authors are indebted. Suggestions, co-operations, constructive criticism and other helps put up by the colleagues from DMG, Petroleum Exploration Promotion Project (PEPP) of DMG are encouraging and beneficial.

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