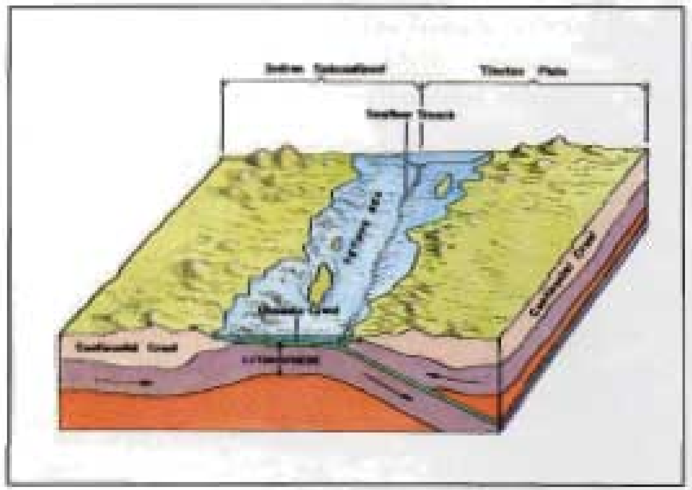
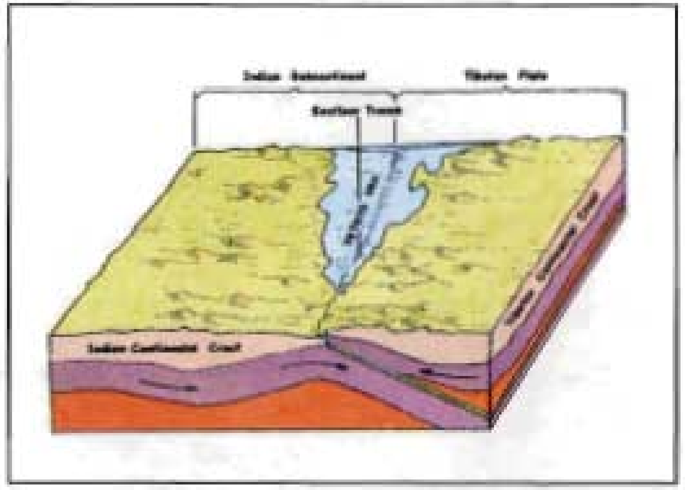
1. GEOLOGY

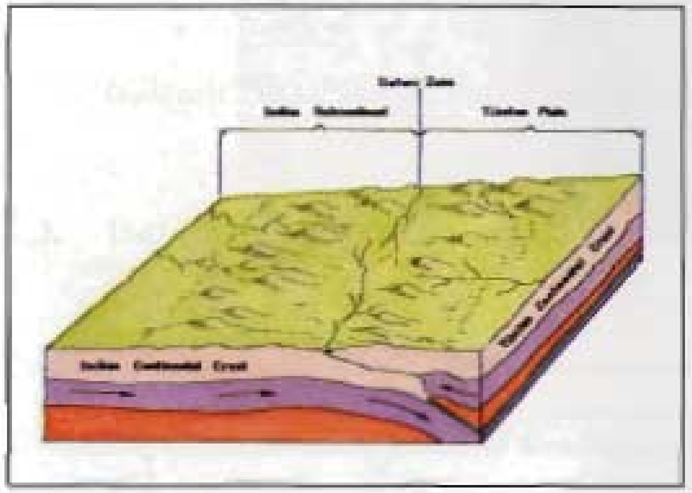
1.1 Origin of the Himalaya



Prior to forty million years ago, there was a sea (called the Tethys) between the Indian Subcontinent and the Tibetan Plate. The Indian Subcontinent was moving gradually towards the Tibetan Plate.

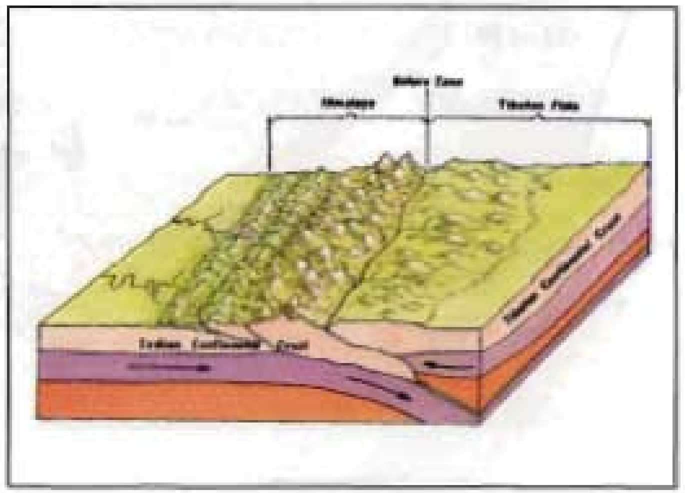
About 40 million years ago, the Indian Subcontinent came into contact with the Tibetan Plate and the Tethys Sea retreated gradually.

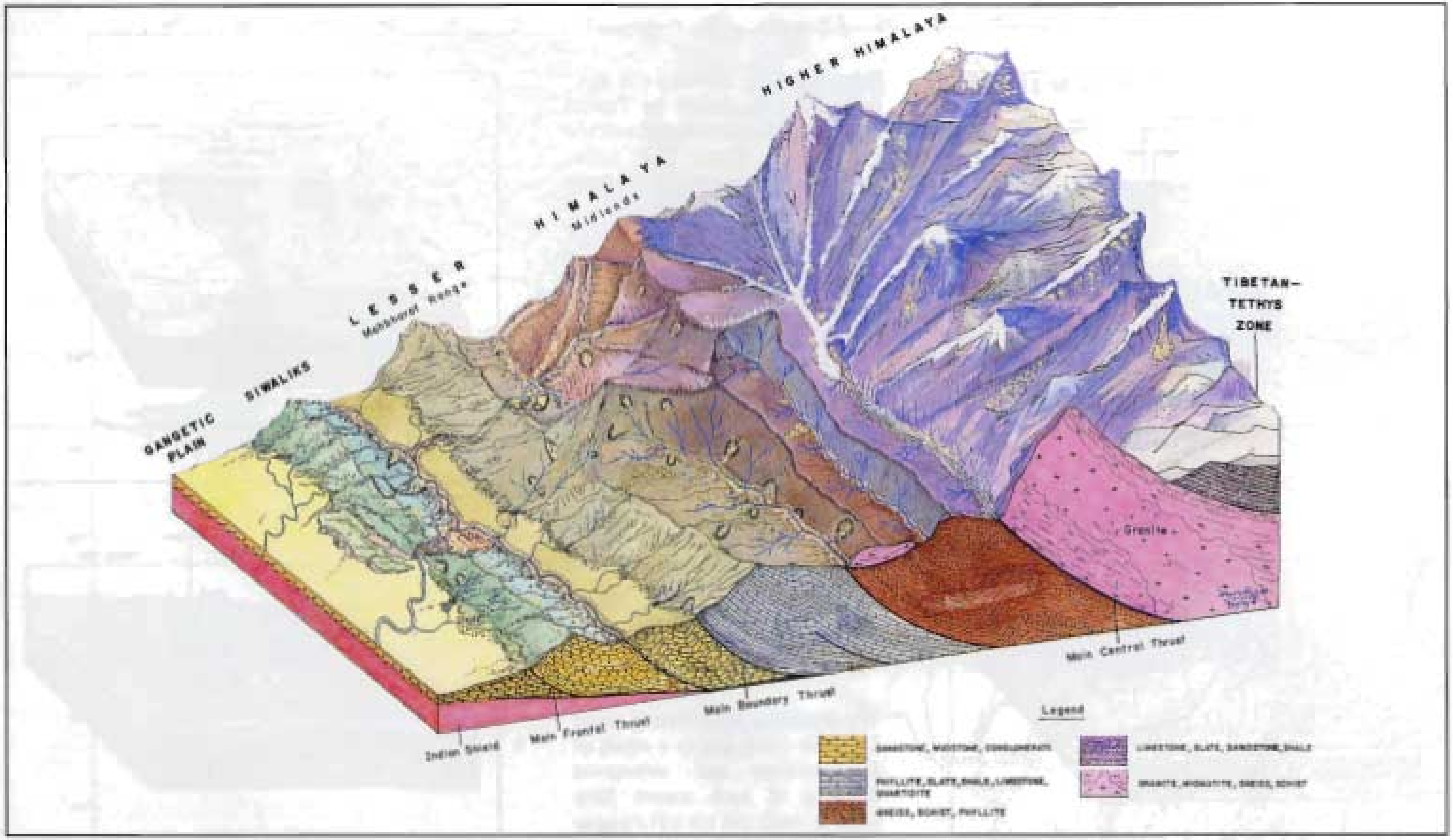




The Indian Continental Crust, being lighter than the Tibetan Oceanic Crust, could not sink into the mantle and remained beneath the Tibetan Continental Crust. Twenty million years ago, there was no Himalayan Chain nor was there a Tibetan Plateau.

The *Himalaya* were formed about 2 million years ago as a result of the collision and subsequent thrusting of rock masses from north to south and are still rising at a rate of 2-5 mm per year.





Block diagram of the *Himalaya*

1.2 Geological Subdivisions of the Himalaya

The process of collision of the Indian Subcontinent with the Tibetan Plate and the subsequent folding, faulting, and upheaval of rock masses led to the formation of the world's highest and one of its most active mountain ranges - the *Himalaya*. The Himalayan Range can be subdivided into the following zones from south to north, respectively:

1. The Gangetic Plain, formed on the Indian Shield as a result of the accumulation of sediments transported by rivers and streams from the Himalaya, is followed northwards by the Sub *Himalaya* or the Siwalik Foothills. The boundary between the Gangetic Plain and the Siwaliks is occasionally a fault called the Main Frontal thrust (MFT).

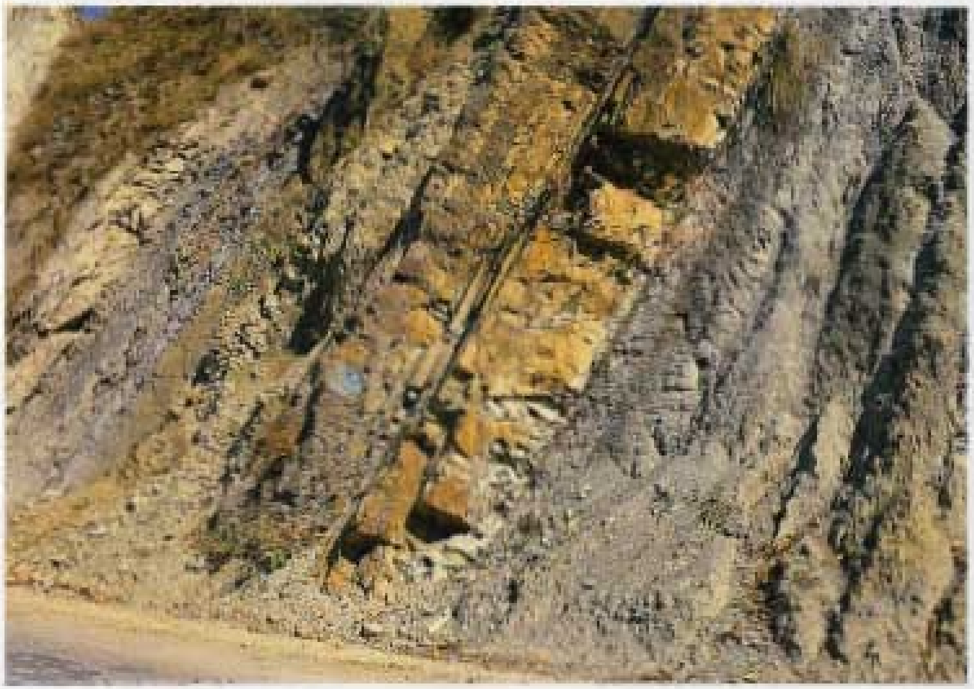
2. To the north of the Sub *Himalaya* lie the Lesser *Himalaya* which are separated from the former by the Main Boundary Thrust (MBT). The Lesser Himalaya can be further divided into the southern mountain belt, called the Mahabharat Range, and the inner zone of the Midlands.

3. The Lesser Himalaya are followed further northwards by the Higher *Himalaya*, and the boundary between the two zones is the Main Central Thrust (MCT).

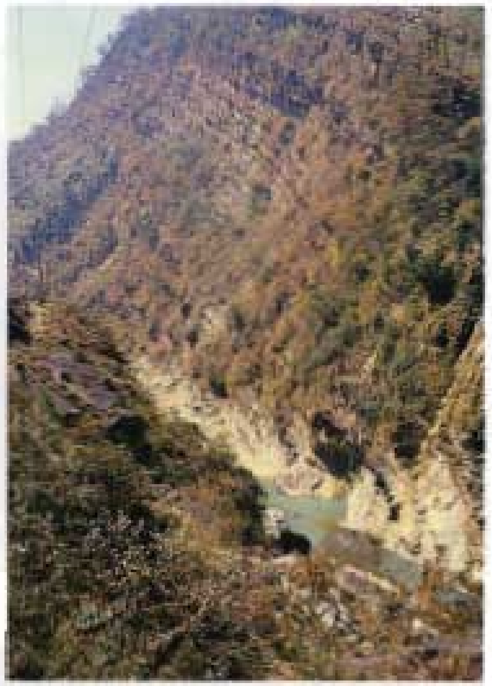
4. The Higher *Himalaya* gradually pass into the sedimentary belt of the Tibetan - Tethys Zone.

1.2.1 Sub *Himalaya* or Siwaliks

The Siwaliks are the youngest rocks in the *Himalaya*. They are from 40 to 2 million years old (Neogene Period) and are made up of mudstone, sandstone, and conglomerate. They are further classified into the Lower, Middle, and Upper Siwaliks.

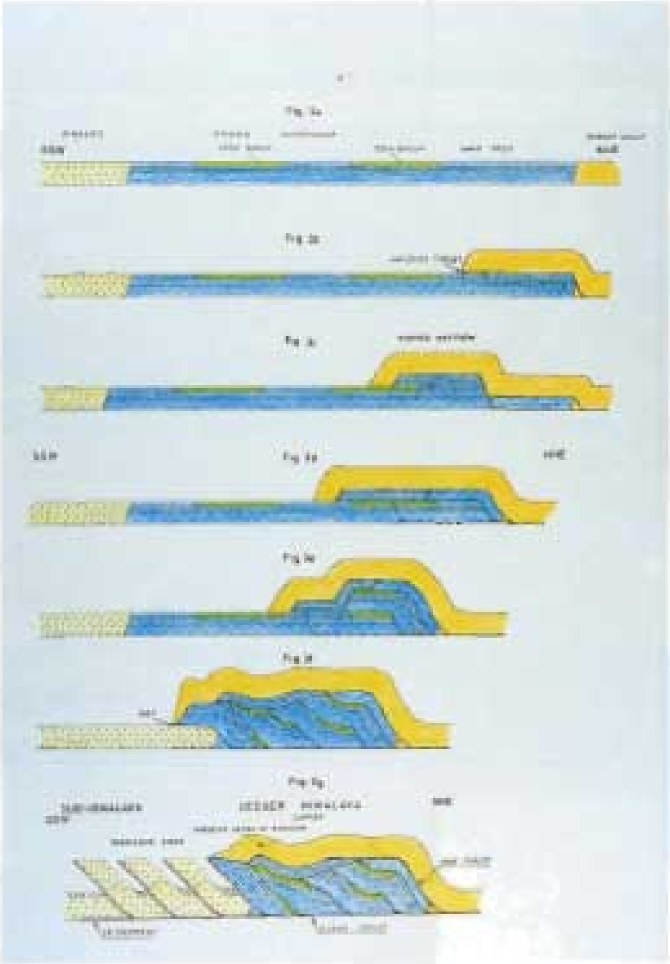


The lower Siwaliks are represented by interbedded soft mudstone and sandstone. They are occasionally faulted and override the younger Middle and Upper Siwaliks.



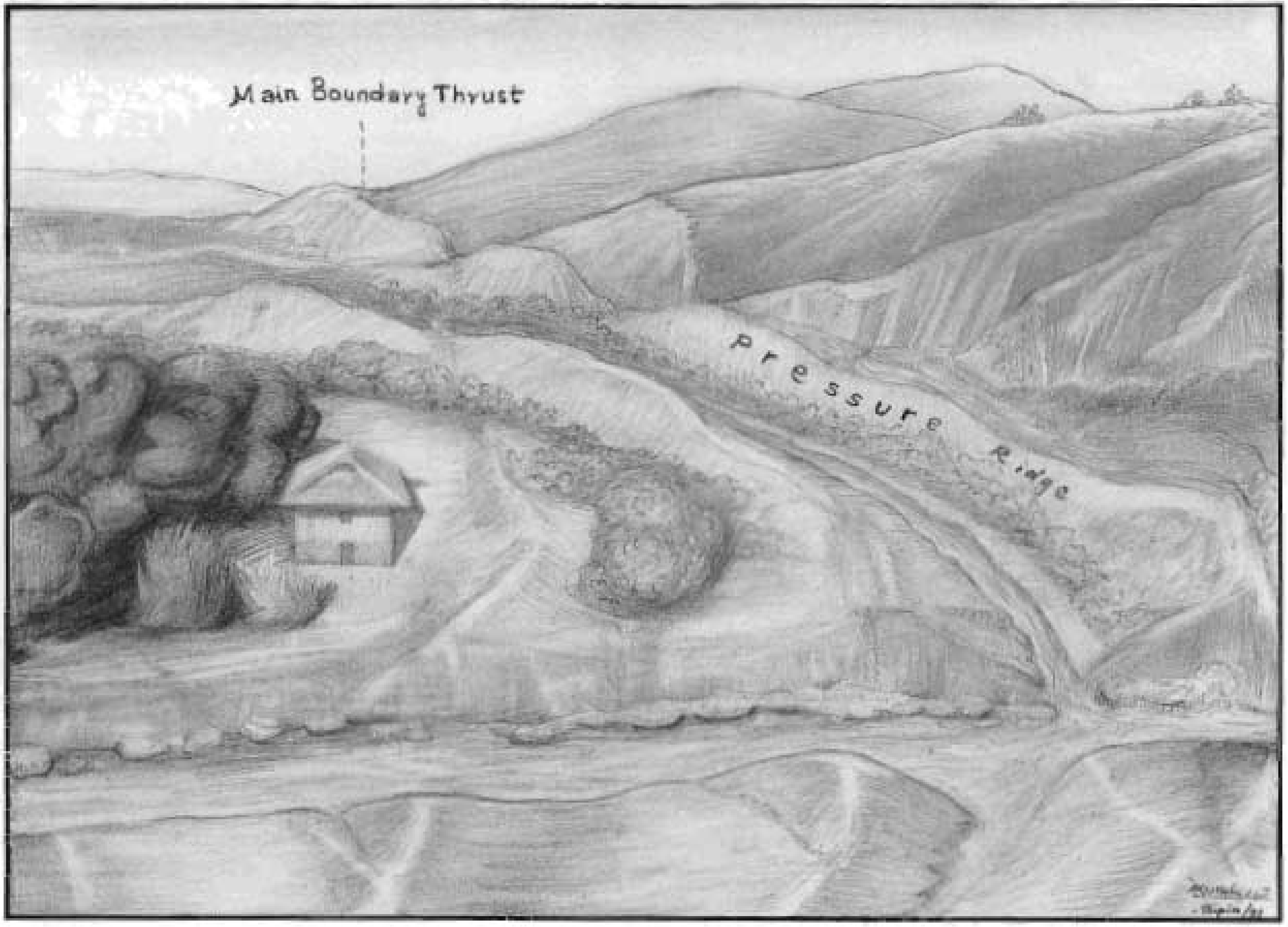
The Middle Siwaliks, comprised of thick-bedded sandstone and mudstones, are generally soft, but may constitute steep river gorges such as the Tinau Khola of West Nepal.

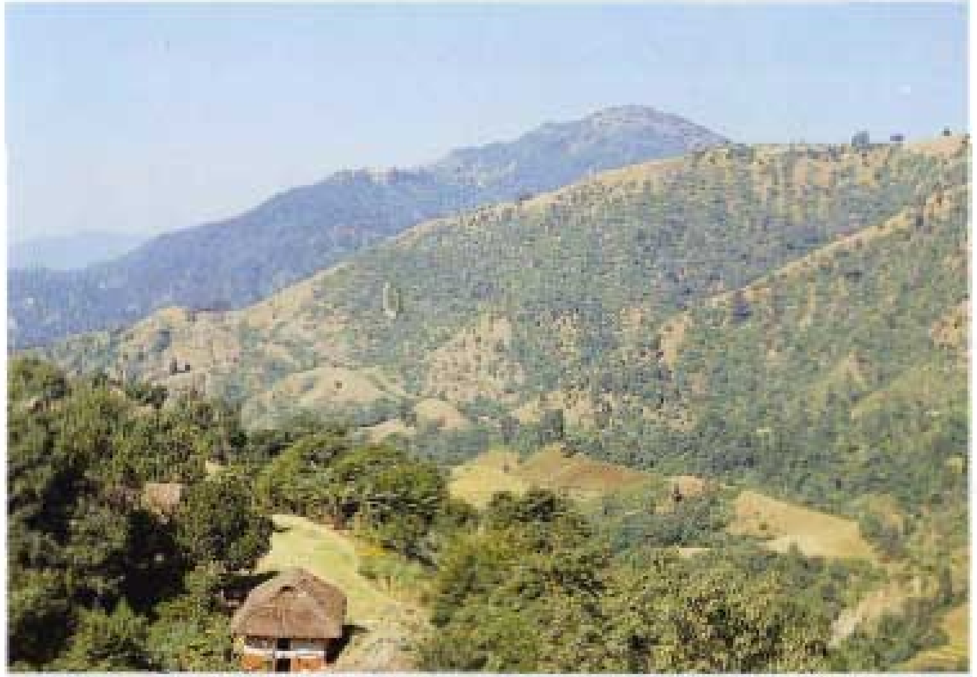
Gravels and conglomerates of the Upper Siwaliks have also experienced tectonic movement, and, therefore, the beds are tilted. Most of the pebbles and boulders seen on the river bed are derived from Upper Siwalik conglomerate.



The Siwalik rocks are gently folded and often dislocated by steep faults which become gentler below the surface and join with each other. They are called imbricate faults. The process of imbricate faulting still continues, and therefore it is seismically the most active region of the *Himalaya*.

The Main Boundary Thrust as seen in the Dang Valley, West Nepal

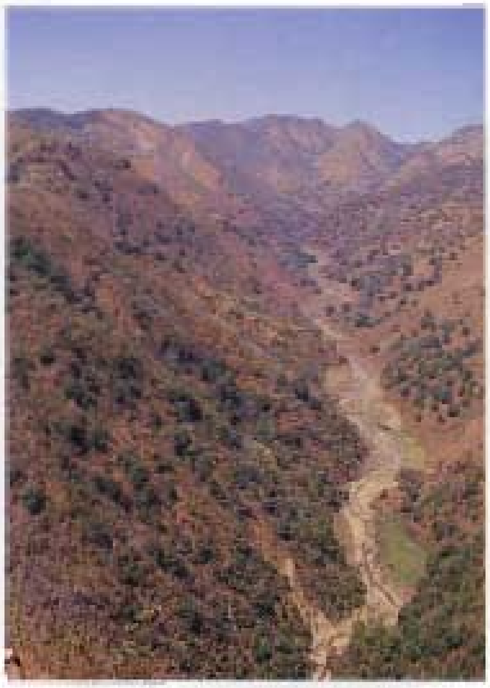




1.2.2 The Lesser *Himalaya*

◂ The Siwaliks are delimited from the north by the Main Boundary Thrust, one of the active faults of the *Himalaya*. Rocks are generally crushed near the fault and the effect dies out gradually away from the fault.

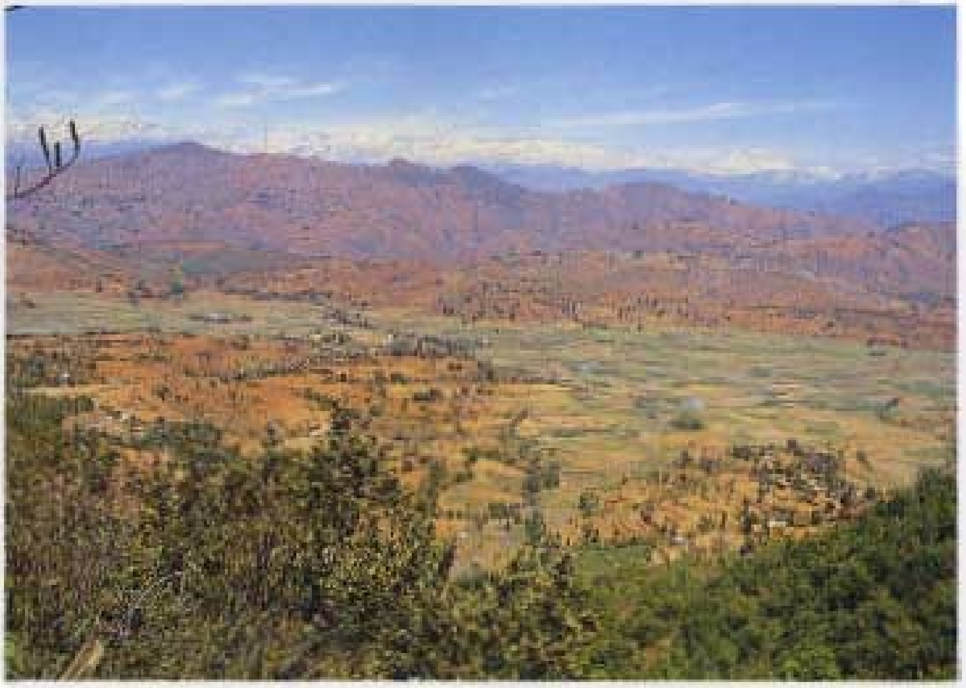
The Mahabharat Range, The outer Lesser *Himalaya* exhibits a young topography with active gullies, steep slopes, and many imbricate faults.



In Pakistan, to the north of the Siwaliks are found soft, red coloured mudstone and sandstone of the Murree Zone.

◂ The steep, dolomite gorge of the Tinau Khola, with vertical beds, is characteristic for the active Mahabharat Range. It depicts the faster rate of upheaval in comparison to the rate of erosion.

The inner Lesser *Himalaya*, called the Midlands, are characterized by the mature topography and wide development of red soil in slate, phyllite, and schist.



1.2.3 The Higher *Himalaya*

The Higher *Himalaya*, lying north of the Main Central Thrust,are represented by high-grade metamorphic rocks which gradually become less metamorphosed northwards and pass into the Tibetan-Tethys Zone.

The Tibetan-Tethys Zone is made up of sedimentary rocks ranging in age from Paleozoic to Neogene and are delimited from the north by the Incus-Tsangpo Suture Zone - the boundary of collision of the Indian Subcontinent and the Tibetan Plate.

1.3 Endogenous Geological Processes

Owing to the stresses related to the convergence of the Indian Subcontinent, th sedimentary and metamorphic rocks of the *Himalaya* have undergone intens deformation. The deformation is expressed in the form of folds, faults, joint foliation, and shearing.

◂ This is an example of concentrically folded limestone from the West Nepal Lesser *Himalaya*.

Some of the rock masses have moved hundreds of kilometres from north to south along such faults as the Main Central Thrust and the Main Boundary Thrust. In the process of movement, the rocks adjacent to the fault experienced crushing, shearing, and milling.

The example shown here is a thrust fault with a crushed zone below it which underwent subsequent sliding and gully erosion.

The rocks surrounded by two imbricate faults experienced intense deformation, and in the process of the movement of the thrusts, they were also disrupted.

Thinly interbedded limestone and claystone have open joints and small-scale folds are developed in the process of shearing.

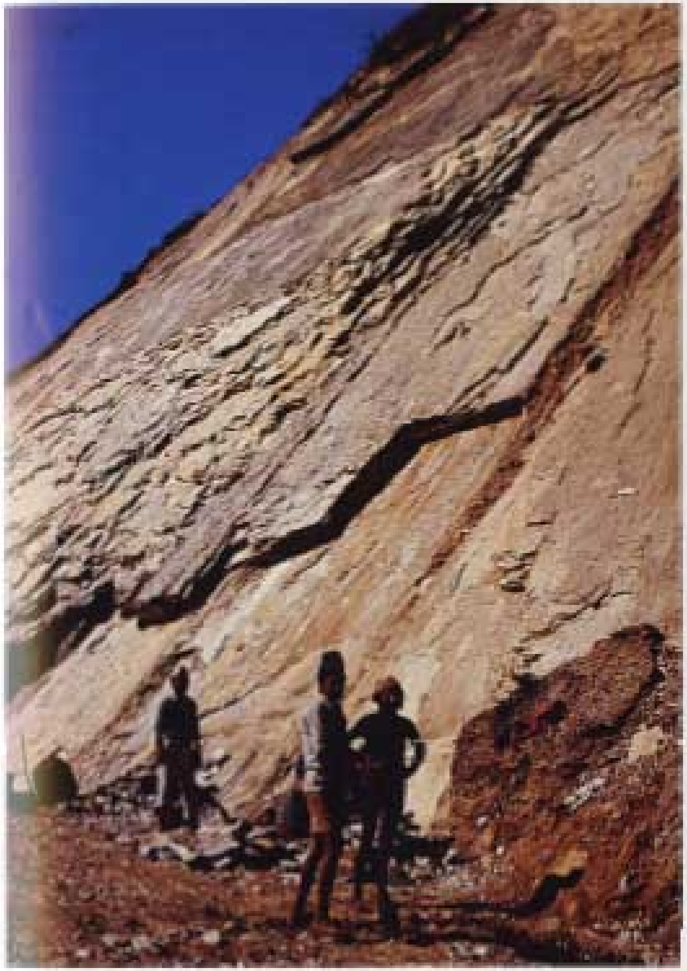
An example of very cleaved and folded slate with more than three sets of joints. The rock is unstable and talus slopes occasionally develop.

The high rate of uplift in the *Himalaya* does not permit lateral shifting of the rivers, and the rivers continually cut into the mountains forming steep gorges. The highly foliated and jointed phyllite and schist create talus cones which can slide into the river and create landslide-dams and subsequent outbursts which further steepen the river.

1.4 *Exogenous Geological Processes and Mass Movement*

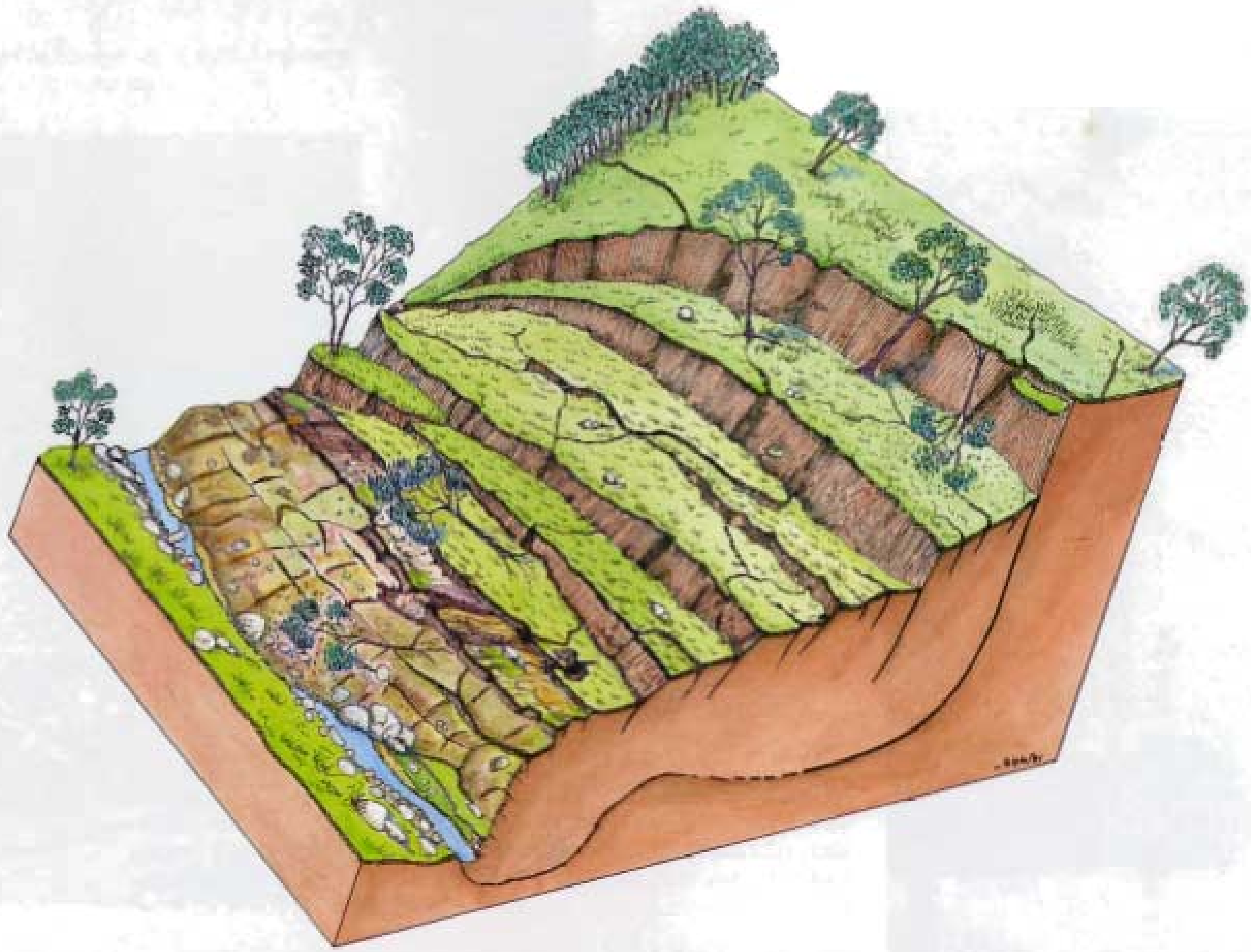
1.4.1 Plane and Wedge Rock Failures

Plane rock failure parallel to the foliation and joints

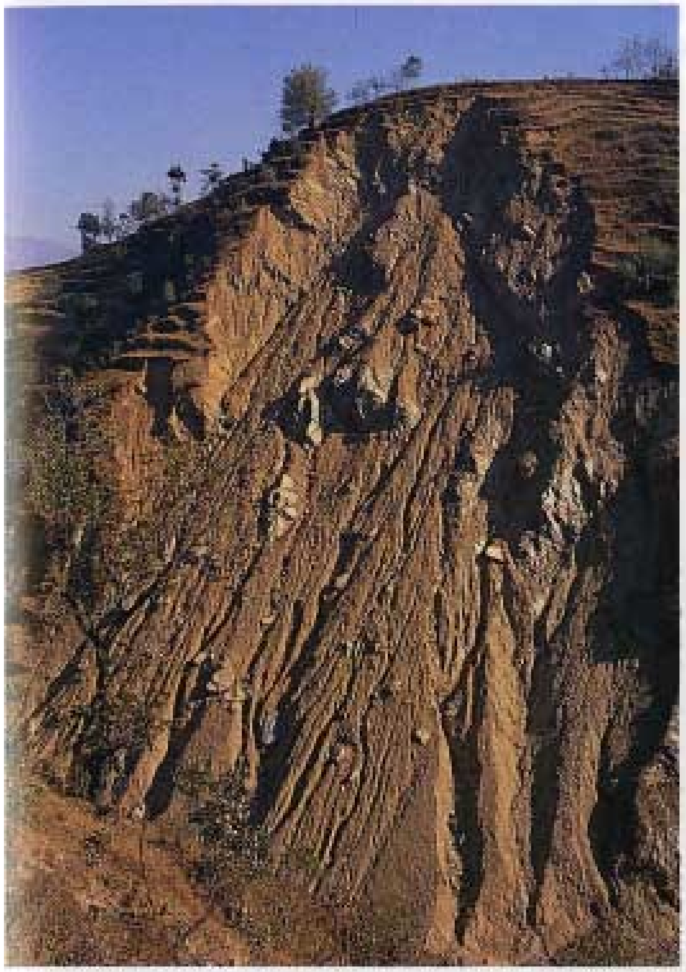


A wedge failure in the weathered rock. Three sets of joints are visible.

A sketch of a rotational slide damming a river



1.4.2 Translational and Rotational Slides

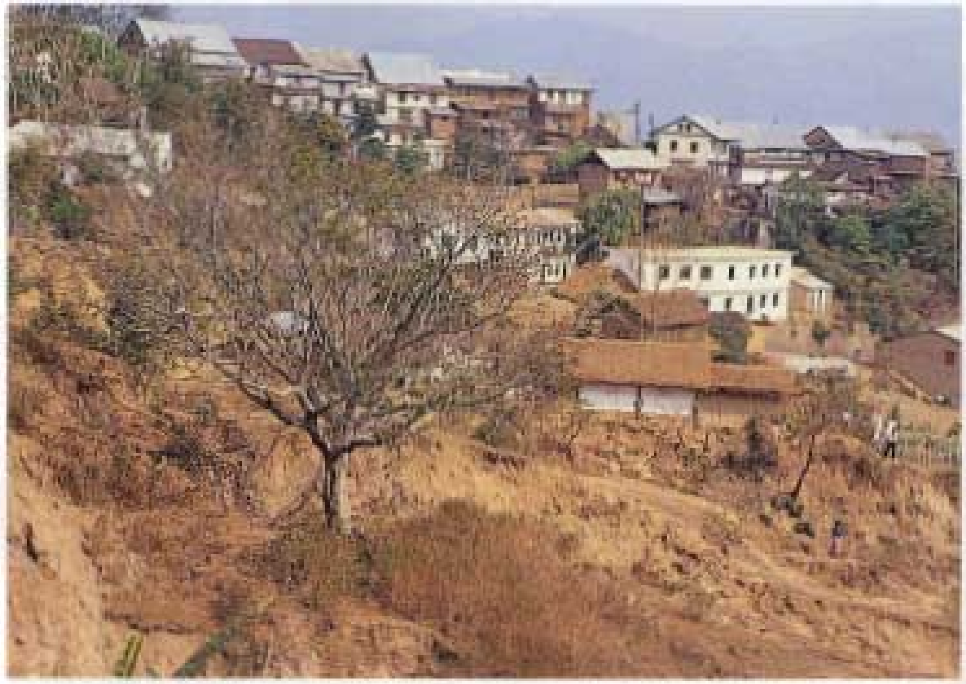


The deeply weathered phyllite underwent sliding and rill erosion.

The deeply weathered area disturbed by faulting in the Siwalik rocks underwent rotational sliding and completely destroyed the bridge near the temple in 1978.

Deep soil cover may be saturated with groundwater and, if stream undercutting takes place, a deep rotational slide may occur.

◄ An old landslide can be inferred from the scar on the upper surface of the green cultivated land.



Rotational slides are also common on slopes covered with residual soil developed from the weathering of rocks. Notice that the tree is taken downslope almost in an intact position, Dhankuta, East Nepal.

1.4.3 Debris Slide and Rill Erosion

◄ Debris slides are common in coarse-grained soil made up of debris from glaciers (i.e. glacier till), or from colluvium resulting from the disintegration of rocks *in situ*, or from soil deposited from past debris flows. Notice the angular fragments.

Rill erosion is common on bare slopes composed of soft rock, soil, or weathered rock. The rill erosion can trigger larger slides.
▼

1.4.4 Debris Flows

◄ The night of the 30[th] June, 1987, witnessed a cloudburst in the upper catchment of the Sunkosi River, East Nepal. It triggered a huge debris flow which dammed the Bhote Kosi (to the right) and damaged roads and other infrastructures downstream.

A debris flow in China.

A closer view of a small debris fan. The material was brought from the severely fractured slate upstream.

An effect of debris flow triggered by a cloud burst over the Charnawati stream catchment area, East Nepal. Notice the excessive soil thickness (more than 50 m).

The Kalimati Gully, a tributary to the Charnawati Stream, also experienced very high concentration of storm runoff which resulted in deep gullying. More than 17 houses were destroyed overnight.

1.4.5 River Undercutting

◂ Occasionally, landslides are caused by river undercutting in rocks (left) and in soil (right). Notice that these slides are difficult to stabilize unless expensive mitigatory measures are undertaken. ▸

1.4.7 Badland Formation

Excessive deforestation may lead to badland formation, rill erosion, and gullies and, hence, the environmental degradation.