Chapter 5*

TECTONIC SETTING OF THE HIMALAYA

Most of the Asiatic mountain belts begin from the Pamir Plateau which acts as a knot. The Kun-Lun and Tien-Shan belts divert to E and NE from the Pamir Knot, respectively. While the Karakoram Range runs to SE from the Pamirs, the Hindu Kush Range continues up to SW of the Pamirs. The Himalayan Arc extends to SE of the Pamir Knot and lies between the Tibetan Plateau and the Indian Shield. The Himalayan arc is about 2,400 km long and convex towards the Indian Shield. After two conspicuous syntaxial bends, at Kashmir and Assam, the Himalayan Range is followed by the Baluchistan Arc in the west and the Arakan Yoma Arc in the east (Fig. 5.1)

The Himalayan Range with its NW-SE general trend was formed by the collision of the Indian Plate with Eurasian Plate. This collision, which began with first contact about 40 million years ago, caused the sediments of the intervening Tethys Sea and the Indian Shield to be folded and faulted into the lofty peaks and odd outliers visible in the *Lesser Himalaya*. From south to north, the Himalayan Mountains can be divided into the following major tectonic zones, which trend northwest to southeast perpendicular to the direction of plate collision (Fig 5.2).

5.1 GANGETIC PLAIN

The Gangetic Plain lies south of the Himalayan Range and is covered by alluvium several hundred metres thick eroded from the *Himalaya*.

5.2 MAIN FRONTAL THRUST (MFT)

This more or less conspicuous fault surface separates the Siwalik Hills from the Gangetic Plain, which it overrides.

5.3 SIWALIKS

The Siwalik rocks are exposed to the north of the Main Frontal Thrust (MFT) and constitute the southern foothills of the *Himalaya*. Their height rarely exceeds 1,000m. They are generally covered with thick forests and comprise the youngest rocks in the range. The soft, loose, and easily erodible rocks are represented by sandstone, siltstone, mudstone, and conglomerate.

Common types of mass movement in the Siwaliks are gully erosion, mudflow, slumping, toppling, and rockfall. The frequency of sliding increases considerably in the rainy season, as the soft rock saturated with rainwater acts like semi-fluid. The water penetrates into colluvium and into the rock along the fractures and joints. It exerts enormous pressure causing huge slumps and mudflows.

* Figures and Tables without credit lines in this Chapter are compiled by the author.

Steep river banks with the exposed Siwalik rocks should be avoided if possible, as in this region the side-cutting action of rivers is very fast. Better alignment could be the upper river terraces, occasionally found on the river banks, the ridge, spur, shoulder, or saddle. If the road runs along the river valley, it should be aligned at least 50m up the river bed and the material from side cutting should not be disposed of along the natural slope into the river.

Generally, the Siwaliks have inverse relief. It means that the synclines are found along the ridges and the anticlines in the valleys. The synclines are often open and the anticlines are tight to close. Steep faults may run along the foothills of the Siwaliks.

The conglomerate beds of the Upper Siwaliks are fairly stable if they are not alternating with thin claystone and sandstone beds. The interbedded mudstone and sandstone rocks of the Middle Siwaliks are rather unstable, and the Lower Siwaliks, which are composed predominantly of green-grey sandstone with a minor amount of claystone, are moderately stable. However, the above-mentioned factors are largely modified by such local conditions as rainfall, land use, vegetation, groundwater, and seismicity.

5.4 MAIN BOUNDARY THRUST (MBT)

The Main Boundary Thrust is one of the most conspicuous faults in the *Himalaya*. It marks the boundary between the Siwaliks and valley deposits to the south and the older rocks of the *Lesser Himalaya* to the north. The MBT is an active fault.

5.5 THE *LESSER HIMALAYA*

The *Lesser Himalaya* is a rugged and highly dissected mountain region reaching altitudes of 4,000 m. Morphologically it can be divided into the southernmost part called the Mahabharat Range and the more depressed Midland Zone further North. Both zones consist of a thick sequence of unmetamorphosed or weakly metamorphosed rocks on top of which can be seen the high grade metamorphics called 'Lesser Himalayan Crystallines'. The *Lesser Himalaya* is also intricately folded and faulted. From the engineering as well as from the geological point of view, the *Lesser Himalaya* can be divided into the sedimentary belt and the metamorphic belt.

5.5.1 *The Sedimentary Belt*

The vast territory immediately north of MBT in Central and West Nepal and Kumaon is covered by sedimentary rocks with a few klippen of metamorphics resting on them. In the inner part of the *Lesser Himalaya* the sedimentary rocks are found in the windows in East and Far West Nepal, Darjeeling, and elsewhere.

The MBT Zone is tectonically one of the most active regions of the *Himalaya*. In this zone many imbricate faults, tight folds, and various systems of joints are occasionally encountered.

The rocks range from weak slate to massive and thick-bedded dolomite. The most common types of mass movement are wedge failure, rockslide, rockfall, rock toppling, debris avalanche, deep gully erosion, debris flow, debris and alluvial fans, and slump.

To highlight the engineering-geological problems related to the various rock types, the following rock types are treated separately.

a. *Very Fractured and Crumbly Slate*

These types of rocks cover a large territory in the inner part of the Nepal *Lesser Himalaya* and they are also found immediately north of the MBT. Their typical property is that they easily break into long, pencil-shaped, or small polygonal, flat chips which cleave off the bed even in dry season. There is a high risk of gully erosions, debris fans and debris flows, toppling, wedge failures, and the occurrence of huge talus cones and slumps. A possible way of controlling this mode of mass wasting is not to disturb the natural slope and to balance the cut and fill. It is recommended that the vegetation cover should not be destroyed and the cut slope should be made as close to the natural slope as possible. It is suggested that the alignment along the ridge be followed, rather than the valley with bare rock. The road alignment must maintain the vegetation cover up as well as down slope.

b. *Interbedded Quartzite and Shale*

These types of rocks are found near the MBT as well as in the inner part of the *Lesser Himalaya*. The anisotropy inherent to the interbedding of resistant quartzite or sandstone with weak shale or mudstone may contribute significantly to mass movement. In this situation, even the slightest disturbance of natural slope may lead to huge rockslides parallel to the bedding plane. If the quartzite is very thickbedded and heavily jointed, there is always a strong possibility of wedge failure. On the other hand, if the shale or mudstone predominates, slumping may be expected.

c. *Medium to Thick-bedded Dolomite or Calcareous Quartzite with Thin Beds or Partings of Claystone or Slate*

The most common types of mass movement in this kind of rock are rockslides parallel to the bedding plane and wedge failure. Thick beds of dolomite fail along the thin clay partings if the natural slope (which is in most cases the dip of the bedding plane) is disturbed by the steeper cut slope of the road. Steep gullies cut through and a lot of debris is unloaded on the road. The side-casting further worsens the situation and triggers off the rocksliding and wedge failure down the road. Preventive measures against the loss of vegetation cover and the penetration of rainwater must be taken. It is better to avoid the wet areas and the areas with paddy grounds.

d. *Massive and Cliff-forming Dolomite, Limestone, and Quartzite*

In normal conditions, these rocks are fairly stable and generally do not create any problems. When they are joined, wedge failure can be expected.

e. *Deeply-weathered Soil, Colluvium, and Loose Mass*

After weathering and disintegration of rocks, various kinds of soil and colluvium of varying thicknesses are seen in the *Lesser Himalaya*. Rotational slides (slumps) are common in this soil. If the slope is not very steep (less than 25°) it may be fairly stable. But steep, natural slopes combined with rainwater or irrigation water may create catastrophic conditions.

Apart from this, a special kind of 'soil' which is nothing but fault breccia, fault gouge, or crushed zone, developed by the thrusts and faults, is also encountered. Generally, the fault zone stretches from a few metres to 50 metres wide. It may happen that two imbricate faults run close to each other, and the zone may be wider, up to 100m and more. In such 'soil', occasionally, big exotic boulders of limestone, dolomite, quartzite, fragments of slate, phyllite, and gneiss are encountered. The 'soil' is unstable on the steep slopes, and the situation is further aggravated if the road runs along the river valley, as the rivers are prone to follow the path of least resistance which is nothing but the fault itself. It is recommended that such areas be avoided if possible.

5.5.2 *The Metamorphic Belt*

The metamorphic belt of the *Lesser Himalaya* is mainly represented by low-grade metamorphic rocks with some high-grade metamorphics such as gneisses.

The metamorphic rocks constitute klippen resting on the sedimentary rocks and these are also present in the inner part of the *Lesser Himalaya*. They are represented by phyllite, marble, quartzite, schist, and gneiss.

a. *Phyllite and Quartzite Alternation*

Generally, it is a monotonous very thick succession. There may be major anticlines and synclines with numerous small-scale folds. Generally the terrain is less rugged than the Mahabharat Range. Numerous rivers flowing from north to south with river terraces of various levels are encountered. Alluvial deposition and lateral shift of the rivers are common. Occasionally they have a braided course. Most of the tributaries make torrent fans with terrace cultivation. But some are very active, especially where their drainage basins are being deforested and opened to cultivation.

Major mass wasting processes are debris slides, debris flows, and slumping. There may be some large-scale slides present and the area may be further aggravated by cultivation, irrigation, deforestation, and the toe-cutting action of older slides by rivers. In rainy season, deep slumps may occur in weathered phyllite or soil. If the slump occurs in very wet material, it may grade downslope into debris flow. The size of the slumps ranges from hundreds of metres in width and length and tens of metres in depth. Sometimes very thick colluvium, or tillitic material with huge slides, is encountered along the river banks.

b. *Thick-bedded Quartzite, Marble, or Limestone*

Generally these are found in the form of a narrow band of about 500m in thickness, together in a vast territory covered with phyllites. In the quartzites, the rivers become narrower and have steeper gradients. The rock is quite stable and could provide good sites for bridge construction. If fractured, there is a possibility of wedge failures.

5.6 MAIN CENTRAL THRUST (MCT)

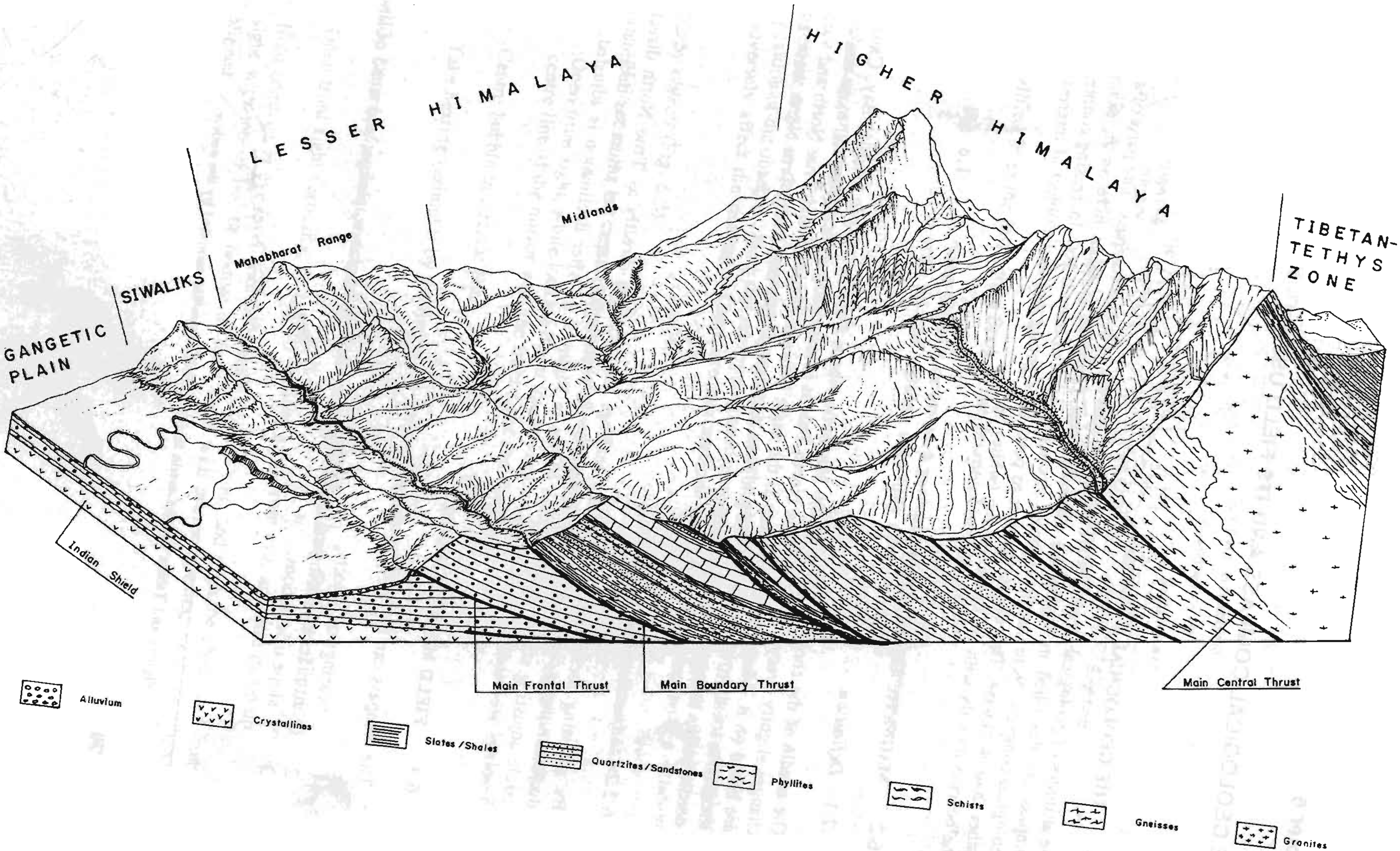
This tectonic boundary separates the *Lesser Himalaya* from the *Higher Himalaya* to the north.

5.7 THE *HIGHER HIMALAYA*

North of the MCT, high-grade metamorphic rocks such as gneisses, migmatites, schists, and marbles are prevalent. They are competent and massive. They produce very rugged and high mountain terrain. Altitude increases steadily northwards ranging up to 8,000m and more. Due to the high rugged terrain there is little human activity. The rocks can be divided into two major units: (a) **The Central Crystallines**, comprised of high grade metamorphics such as gneisses, migmatites, and granite rocks, and (b) The **Tibetan-Tethys Zone** which is made up of fossiliferous, sedimentary rocks. With increasing relief, rock and debris falls become dominant and coarse and mixed colluvium, talus cones, and mantles of waste are encountered on the lower slopes. At higher altitudes, gentle slopes contain mantles of colluvium and/or glacial till which are acted upon by solifluction and gelifluction processes. This material is prone to gullying and sliding adjacent to torrents. The steep upper slopes are dominated by more rapid forms of alpine denudation, especially avalanches and rock and debris falls. Most of these upper slopes contain structural scarps and cliffs. Extensive glacial deposits and cirques, outside the area now undergoing glaciation, give evidence of former more extensive glaciers than at present. On the other hand, the glacier lakes found in this region create a high hazard for the areas below the region, as sudden glacier lake outbursts are not uncommon in this region.

The Tibetan or Tethys Zone is composed of incompetent rocks such as shale, sandstone, siltstone, and conglomerate with competent limestone and quartzite interbeds. There are also many river terraces. Occasionally, the rocks are intensely folded and faulted. The river channels, during the periods of high flood, erode adjacent terrace scarps and torrent fans entering the floodplain, subsequently causing slumps and slides along the floodplain margins. Several slump areas are found associated with poorly consolidated, alluvial and lacustrine deposits. Where cliffs and structural scarps occur, rapid mass wasting occurs and downslope piles of colluvium are typical. At higher altitudes, both glaciation and periglaciation are intense. In them ice and rock avalanches are common. Similarly, rockfalls and debris slides are also common on the steeper slopes.

Fig 5.1 Sketch map of Asiatic mountain ranges


LESSER HIMALAYA
HIGHER HIMALAYA
TIBETAN-TETHYS ZONE
GANGETIC PLAIN
SIWALIKS
Mahabharat Range
Midlands
Indian Shield
Main Frontal Thrust
Main Boundary Thrust
Main Central Thrust
Alluvium
Crystallines
Slates / Shales
Quartzites / Sandstones
Phyllites
Schists
Gneisses
Granites