3 The Physiography and Geology of Nepal and Their Bearing on the Landslide Problem

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Nepal can be divided into eight distinct physiographic units: the Terai, the Siwalik (Churia) Range, the Dun Valleys, the Mahabharat Range, the Midlands, the Fore Himalaya, the Higher Himalaya, and the Inner and Trans Himalayan Valleys. Each of these units has distinct altitude, topographical, climatic, and vegetational characteristics.

Geologically, Nepal can be divided into five major tectonic zones: the Terai, the Siwaliks, the Lesser Himalaya, the Higher Himalaya, and the Tibetan-Tethys Himalaya. These zones are separated by major thrusts and faults; two of these, the Main Central Thrust (MCT) and the Main Boundary Thrust (MBT), bring fundamentally different tectonic zones against each other. Each of the tectonic zones is characterised by its rock types, age, metamorphism, structures, and geological history.

The Himalaya is said to be the most active and fragile mountain range in the world: it is a 'live mountain' with active tectonics. The Himalaya is still rising and its rocks are under constant stress as the northward-moving Indian Plate pushes against the more stable Tibetan block. This pressure forces the Himalaya to rise and move horizontally southward along major thrusts. The active nature of the range is also manifested in frequent earthquakes. Moreover, the inherently weak geological characteristics of the rocks make the Himalaya fundamentally very fragile. Triggering factors such as rainfall and earthquakes make the mountains highly vulnerable to landslides and other mass-wasting processes. The combination of weak geology and a monsoonal climate makes each physiographic zone of Nepal unique in its vulnerability to landslides; at present the most active parts of the Himalaya are the Siwalik and the Mahabharat ranges.

A better understanding of the geological nature of the terrain and the interplay of various triggering factors will greatly help in the development of safer infrastructures, mitigation of natural hazards, and control of environmental degradation in the Himalaya.

Introduction

Physiography

Nepal can be divided into eight well-defined physiographic units running roughly east-west (Table 3.1, Figure 3.1). This classification has been adopted from Hagen (1969), with some modifications. It encompasses the important and characteristic physiographic features of Nepal better than does the currently used fivefold classification (Terai, Siwalik (or Churia), Middle Mountain, High Mountain, and High Himalaya).

Terai

The Terai is the northern continuation of the Indo-Gangetic Plain, ranging in elevation from 100 to 200 masl and having a subtropical climate. It extends from the Nepal-India border in the south to the base of the Siwalik Hills in the north. Varying in width between 10 and 50 km, the Terai forms a nearly continuous belt from east to west, exceptions being along the Chitwan and Rapti valleys where the

Table 3.1: **Physiographic units of Nepal**				
Physiographic unit	Width (km)	Altitude range (masl)	Main rock types	Age
1. Terai (northern edge of the Indo-Gangetic Plain)	10-50	100-200	Alluvium: coarse gravels in the north near the foot of the mountains, gradually becoming finer southward; foreland basin deposits	Recent
2. Siwalik (Churia) Range	10-50	200-1300	Mollase deposits of the Himalaya: sandstone, mudstone, shale, and conglomerate	Mid-Miocene to Pleistocene
3. Dun Valleys	5-30	200-300	Valleys within the Siwalik Hills filled up by coarse to fine alluvial sediments	Recent
4. Mahabharat Range	10-35	1000-3000	Schist, phyllite, gneiss, quartzite, granite, and limestone belonging geologically to the Lesser Himalayan Zone	Precambrian and Paleozoic, occasionally also Cenozoic
5. Midlands	40-60	200-2000	Schist, phyllite, gneiss, quartzite, granite, and limestone belonging geologically to the Lesser Himalayan Zone	Precambrian and Paleozoic to Mesozoic
6. Fore Himalaya	20-150	2000-5000	Gneisses, schists, phyllites, and marbles mostly belonging to the northern edge of the Lesser Himalayan Zone	Precambrian
7. Higher Himalaya	10-60	>5000	Gneisses, schists, migmatites, and marbles belonging to the Higher Himalayan Zone	Precambrian
8. Inner and Trans Himalayan Valleys		2500-4300	Gneisses, schists, and marbles of the Higher Himalayan Zone and Tethyan sediments (limestones, shale, sandstone, etc.) belonging to the Tibetan-Tethys Zone	Precambrian and Cambrian to Cretaceous

Nepal-India border coincides with the foot of the Siwalik Range for about 70 km and 80 km respectively. The Terai can be further subdivided into northern (Bhabar), middle, and southern zones.

Siwalik Range (Churia)

The frontal, or southernmost, hill ranges of the Himalaya are generally called the Siwaliks. In Nepal this range is often referred to as the Churia, and in other parts of the Himalaya they are sometimes known as the Outer Himalayan Zone, or Sub-Himalayan Zone. Generally they rise abruptly from the plains of the Terai (Figure 3.2). Running the length of Nepal, the Siwalik hills typically range in elevation from 200 to 1,000m, and rise to 1,300m in many places. They have an arc type face with conspicuously north-dipping beds, forming a steep escarpment towards the Terai. Geomorphologically, the Siwalik hills exhibit a very immature topography with highly rugged terrain dissected by numerous gullies (Figure 3.3). Though most parts of the range are covered by thick forest, it is very dry from December to early June. Due to the fragile character of the rocks, during the monsoon a great amount of sediment is washed from the Siwalik hills into the rivers originating within or to the north of the range. Most of the Siwalik rivers carry water only during the peak monsoon period. These hill ranges fall under the subtropical climatic zone.

Dun Valleys

Where the Siwalik hills bifurcate into two parallel ranges, wide valleys are formed, which are generally called the Dun valleys. The altitude of these valleys varies from 200 to 300m. They are

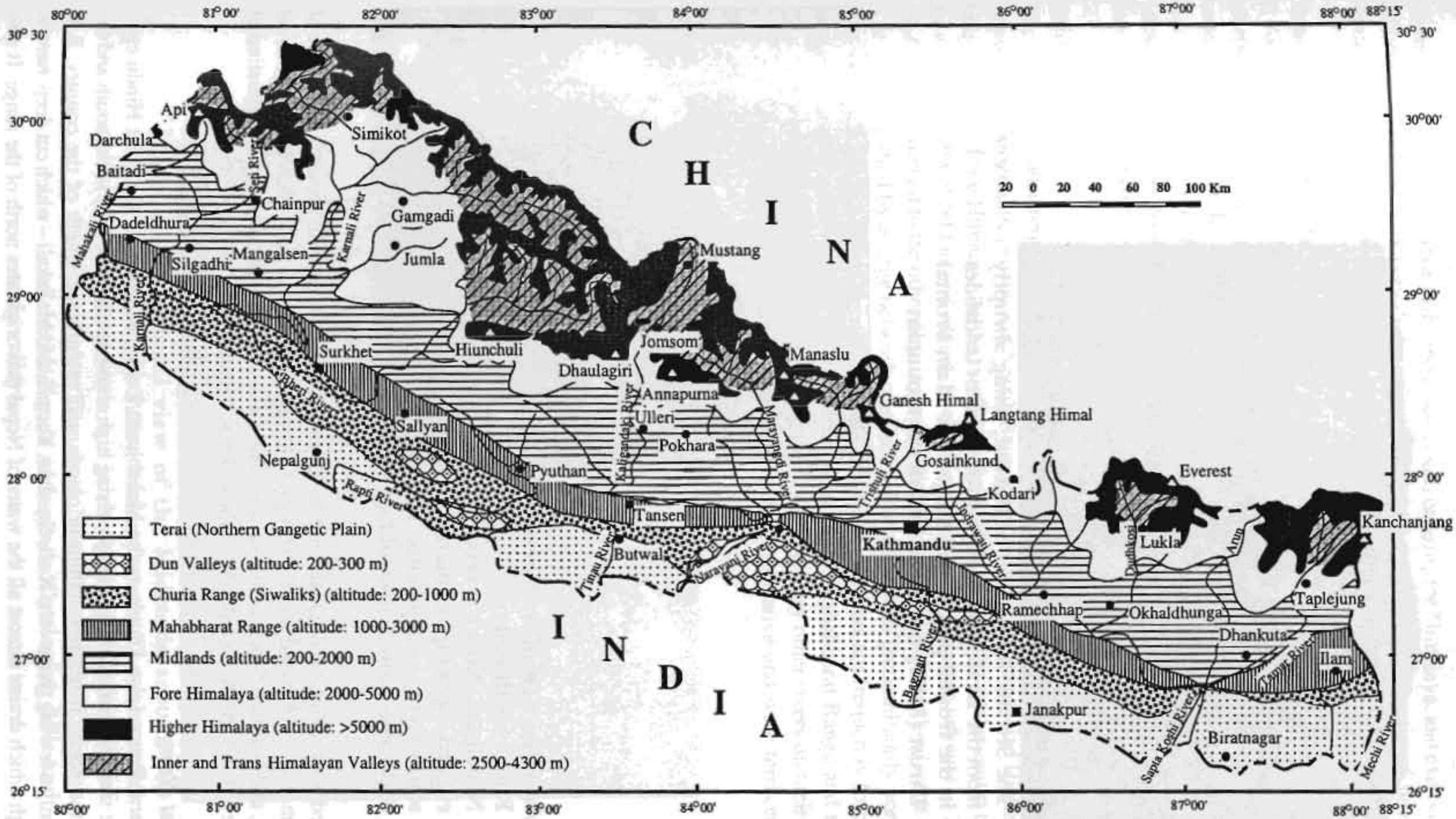

Figure 3.1: Physiographic subdivisions of Nepal (reprinted from Journal of Asian Earth Sciences, Vol 17, Upreti et al., 'An overview of the stratigraphy and tectonics ....., p579 (1999), with permission from Elsevier Science)

Figure 3.2: **The Siwalik Range east of Butwal, rising abruptly from the Terai. Note the evidence of recent landslides in the frontal part of the range. The Main Frontal Thrust (MFT) lies at the foot of the mountain**

Figure 3.3: **An aerial view of the Siwalik Range north-east of Nepalgunj. Note the very rugged topography and the south-facing escarpments. The rocks also show gentle folding**

normally filled with sediments of Quaternary to Recent (1.8 million years to present) age. Some of the larger Dun valleys of Nepal are the Trijuga, Chitwan (east Rapti), Nawalpur, Deokhuri (west Rapti), Dang, and Surkhet. Whereas the Siwalik hills remain sparsely populated, the population of the Dun valleys has increased markedly in the last few decades.

Mahabharat Range

The Mahabharat Range (also known as the Mahabharat Lekh), named after the great Hindu epic, dominates the southern part of the Himalaya, rising high above the Siwalik hills to the south and the Midlands to the north. It reaches 3000m in places, and extends the length of the country. It is breached by only a few big rivers – the Kosi, Gandaki, Karnali, and Mahakali – which cut deep, narrow gorges through which drains almost all the water of Nepal that originates north of the range. It also forms the first effective barrier to the monsoon clouds entering the Himalaya, and exerts considerable influence on the country's rainfall distribution. The Mahabharat Range continues beyond Nepal's western border through the Indian hill ranges of Nainital, Mussouri, Simla, and beyond.

Topographically, the Mahabharat Range is markedly higher than the Siwalik hills and the Midlands. It forms rugged terrain with sharp crests and steep slopes. The southern slopes are generally steeper than the northern ones. In spite of its inhospitable terrain, the range is well populated, especially on its northern slopes. From the crest of the Mahabharat Range one commands a comprehensive view to the north of the low-lying Midland hills and the bright, snow-covered Himalayan ranges beyond; to the south, beyond the Siwalik hills, the vast Gangetic Plain seems to merge with the horizon.

Midlands

The Midlands, consisting of subdued hills, wide river valleys, and tectonic basins, form the most important physiographic province of Nepal. Bounded by the towering snow-clad Higher Himalayan ranges and the Fore Himalaya to the north and the Mahabharat Range to the south, this zone has an average width of 60 km and ranges in elevation from 200m (in river valleys) to 2,000m. The Midlands, in contrast to the other physiographic divisions, exhibit a mature landscape (Figure 3.4). The area is drained by a large network of rivers and streams with predominantly north-south and east-west valleys. The larger, predominantly south-flowing, rivers are frequently forced to deflect at right angles when they reach the northern slopes of the Mahabharat Range and subsequently flow east-west for long distances, collecting the waters of many other rivers on their way (Figure 3.1). Midland rivers have very low gradients and form extensive and wide terraces along their courses.

Figure 3.4: A general view of the Midlands around the Panchkhal Valley, looking north. The mountains with snow cover in the background are part of the Higher Himalaya. Note the gentle topography of the Midlands with gradually sloping hills and wide valleys.

Within the Midlands are the tectonic valleys of Panchkhal, Banepa, and Kathmandu in central Nepal, and Pokhara and Mariphant in western Nepal.

Due to the gentle topography and mild temperate climate, this zone is very densely populated, accounting for nearly 52% of the total population of Nepal. Every possible hill slope has been terraced and cultivated. Deforestation is a serious problem, and as a result this belt of the Nepal Himalaya is also faced with a high rate of soil erosion.

Fore Himalaya

All along the Nepal Himalaya, a transitional zone can be recognised between the Midlands and the Higher Himalaya. Named the Fore Himalaya by Hagen (1969), this zone ranges in altitude from 2,000 to 5,000m. It is best developed in the Chainpur-Humla-Mugu-Jumla area of western Nepal, where it is over 150 km wide, and in the Solu-Khumbu area (north of Okhaldhunga) in the east (Figure 3.1). Elsewhere it occupies a narrower strip, typically 20-30 km wide, lying directly to the south of the Higher Himalayan Ranges. This unit's physiography, climate, and vegetation are distinct from those of the Midlands and the Higher Himalaya. The topography is much more rugged and the slopes steeper than in the Midlands (Figure 3.5); the altitude is higher and temperatures much colder, with snowfall in winter, although summers are quite warm. Surprisingly, in some places, such as Jumla, rice is widely cultivated.

In the Fore Himalaya, the taller plant species are confined below 4,000m; shrubs and algae predominate from that elevation up to the permanent snow-covered area. The lack of good agricultural land and the cold climate have deterred human settlement, with the result that there is a comparatively low population density in this unit.

Higher Himalaya

The hills of the Fore Himalaya give way to the snow-capped peaks of the Higher Himalaya to the north. Nepal not only contains the highest peak of the world (Mt. Everest or Sagarmatha, 8,850m) but also the greatest number of peaks over 8,000m altitude. Unlike other physiographic zones, the Higher Himalaya is not a single range but rather a discontinuous echelon of parallel ranges variously

Figure 3.5: **A general view of the Fore Himalaya in far western Nepal, looking north.**

running east to west, north-west to south-east, and north-east to south-west. A few major rivers originating north of the Higher Himalaya dissect these ranges, forming some of the deepest gorges in the world. These antecedent rivers have been flowing along their courses since long before the rise of these formidable mountains; their continuous downcutting has kept pace with the mountains' rise.

Topographically, this mountain range shows extremely rugged terrain with very steep slopes and deeply cut valleys (Figures 3.6 and 3.7). Generally, all terrain above 5,000m (roughly corresponding to the permanent snow line in Nepal) may be considered the Higher Himalaya. The southern faces of the Higher Himalaya and the Fore Himalaya receive heavy precipitation: 2,000 mm on average, and as much as nearly 5,000 mm south of the Annapurna Range (Chalise et al. 1996; Upreti and Dhital 1996) (Figure 3.8).

Figure 3.6: The Ganesh Himal (seen from the south), illustrating the very rugged topography and steep slopes of the Higher Himalaya

Figure 3.7: The Dudh Khosi north-east of Namche Bazaar in eastern Nepal, which forms a typically deep, steep-sloped valley of the Higher Himalaya. View to the west

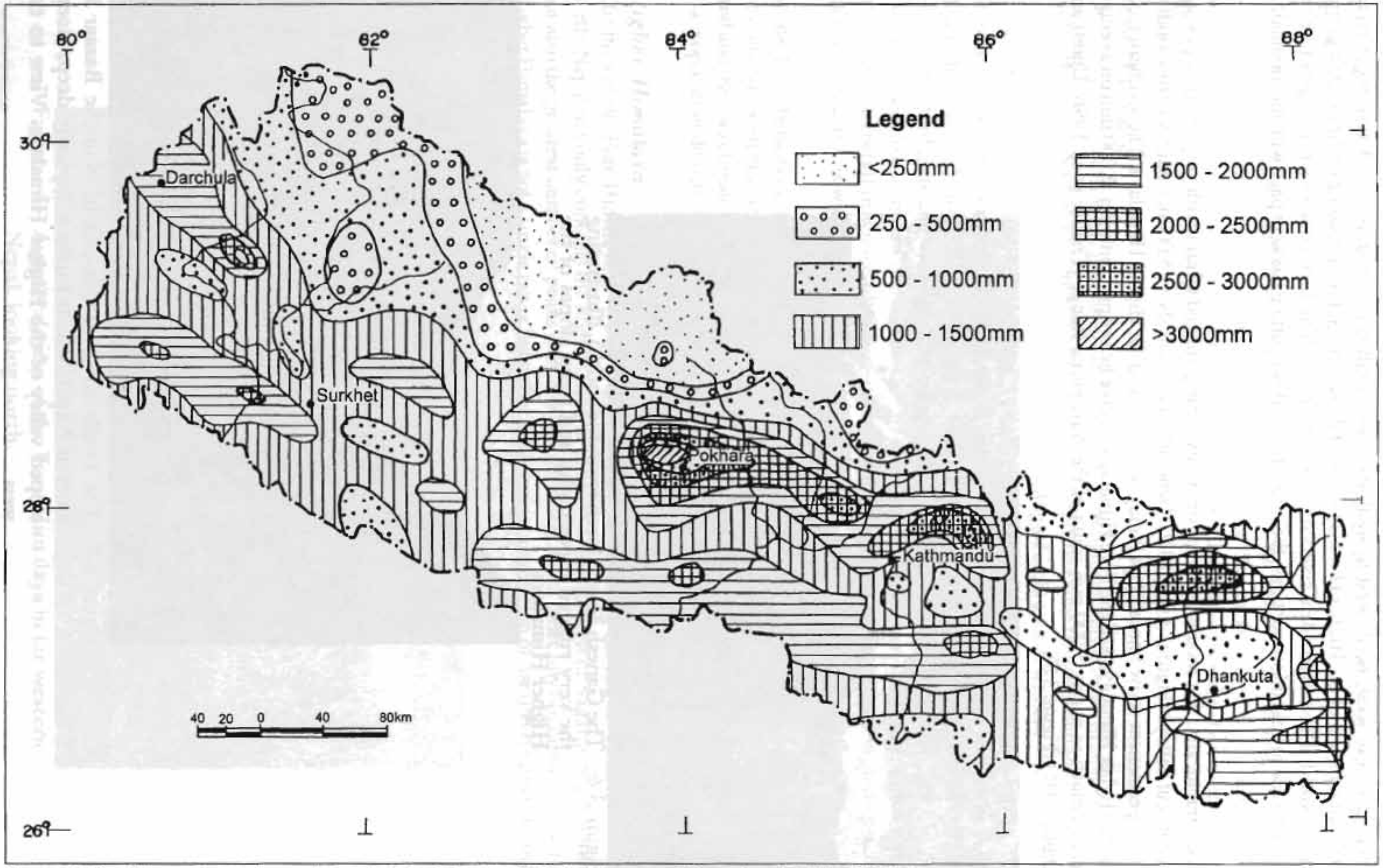

Figure 3.8: **Mean annual precipitation in Nepal 1971-85** (source: Upreti and Dhital 1996)

Inner and Trans Himalayan Valleys

A number of valleys in northern Nepal run north-south and east-west. Some, known as Trans Himalayan Valleys, are situated to the north of the Higher Himalayan ranges; these include Dolpa (north of the Hiunchuli and Dhaulagiri ranges), Mugu (north of the Kanjiroba range), Mustang (also known as the Thak Khola valley, north of Dhaulagiri and Annapurna), and Manang (north of Annapurna). Others, known as Inner Himalayan Valleys, lie south of the highest ranges but still within the Higher Himalaya. These include the Langtang Valley (south of Langtang Himal), Khumbu Valley (south of Everest), and Ghunsa (west of Kangchenjunga). The length and width of these valleys varies.

These Inner and Trans Himalayan Valleys are unique in their climate and vegetation. Lying within the rain shadow zone, they remain very dry throughout the year. However, rain-bearing clouds do reach these valleys through the deep river gorges between the Higher Himalayan ranges, bringing some precipitation (around 250 mm on average) and supporting some vegetation and fairly large populations. In this unit, human settlements can be found up to 4,000m and above (as high as 4,300m at Phopagaon in the Langtang area).

Figure 3.9: **The Thak Khola, a Trans Himalayan valley in western Nepal. Note the absence of vegetation on the hill slopes, indicating a dry climate. Where irrigation facilities are maintained, agriculture creates green oases.**

Major Geologic Zones of Nepal

Nepal can be divided, from south to north into the following five major tectonic zones separated by major thrusts and faults.

Terai Zone
Main Frontal Thrust (MFT) (sometimes called the Himalayan Frontal Thrust (HFT)
Siwalik Zone
(also known as the Churia, Outer Himalayan, or Sub Himalayan Zone)
Main Boundary Thrust (MBT)

Lesser Himalayan Zone
Main Central Thrust (MCT)
Higher Himalayan Zone
South Tibetan Detachment (STD)
Tethys Himalayan Zone
(in Nepal generally called the Tibetan-Tethys Himalayan Zone)

There are a number of other thrusts and faults, such as the Mahabharat Thrust (MT), but none that runs the length of the country.

Each zone is characterised by its own lithology, tectonics, structure, and geologic history. These features are summarised in the form of a generalised geological map in Figure 3.10. many of the names used in the physiographic divisions are also used for the geologic zones. However, the boundaries of the physiographic divisions are based arbitrarily on altitudes, whereas the geologic zones have clear and well-defined boundaries marked by thrusts or normal faults. The correspondence between the physiographic and geologic zones is shown in Table 3.2. Figure 3.5 in the previous paper shows a generalised cross-section through the meridian of Kathmandu showing the major tectonic features of the Himalaya.

Table 3.2: Geologic and physiographic units of Nepal

Geologic unit (south to north)	Physiographic unit (south to north)
Terai	Terai
Siwalik Zone	Siwalik Hill Range and Dun Valleys
Lesser Himalayan Zone	Midlands, Mahabharat Range, parts of Fore Himalaya
Higher Himalayan Zone	Higher Himalaya and parts of Inner Himalayan Valleys
Tibetan-Tethys Himalayan Zone	Some parts of the Higher Himalaya, and Inner and Trans Himalayan Valleys

Terai Zone

The southernmost tectonic division of Nepal, the Terai, represents the northern edge of the Indo-Gangetic alluvial basin. In the north it is bounded by the Main Frontal Thrust (MFT), whose outcrops are exposed at many places along the southern front of the Siwalik Range. The Terai plain is made up of alluvium of Pleistocene to Recent age (1.8 million years to the present) with an average thickness of about 1,500m. These sediments rest on the Siwalik Group (Middle Miocene-Pliocene), which in turn rests on rocks of still older ages belonging to the Indian Peninsular.

The Terai Zone shares a significant proportion of current Himalayan stress accumulation, which is manifested in the development of thrusts and thrust-propagated folds beneath the sediments. The northern part of the zone represents a mountain in the making: the Himalayan mountain front is continuously propagating to the south through this zone.

Siwalik Zone

The Siwalik Zone (in Nepal often called the Churia) consists of fluvial sedimentary rocks of Neogene to Quaternary age (14-1 million years ago). The zone is bounded to the north by the Main Boundary Thrust (MBT) and to the south by the Main Frontal Thrust (MFT). The outcrop of the MBT is very well exposed in the field and can be very well mapped even from aerial photos (Figure 3.11). Lesser Himalayan metasedimentary rocks have been thrust southward over the Siwalik rocks along this

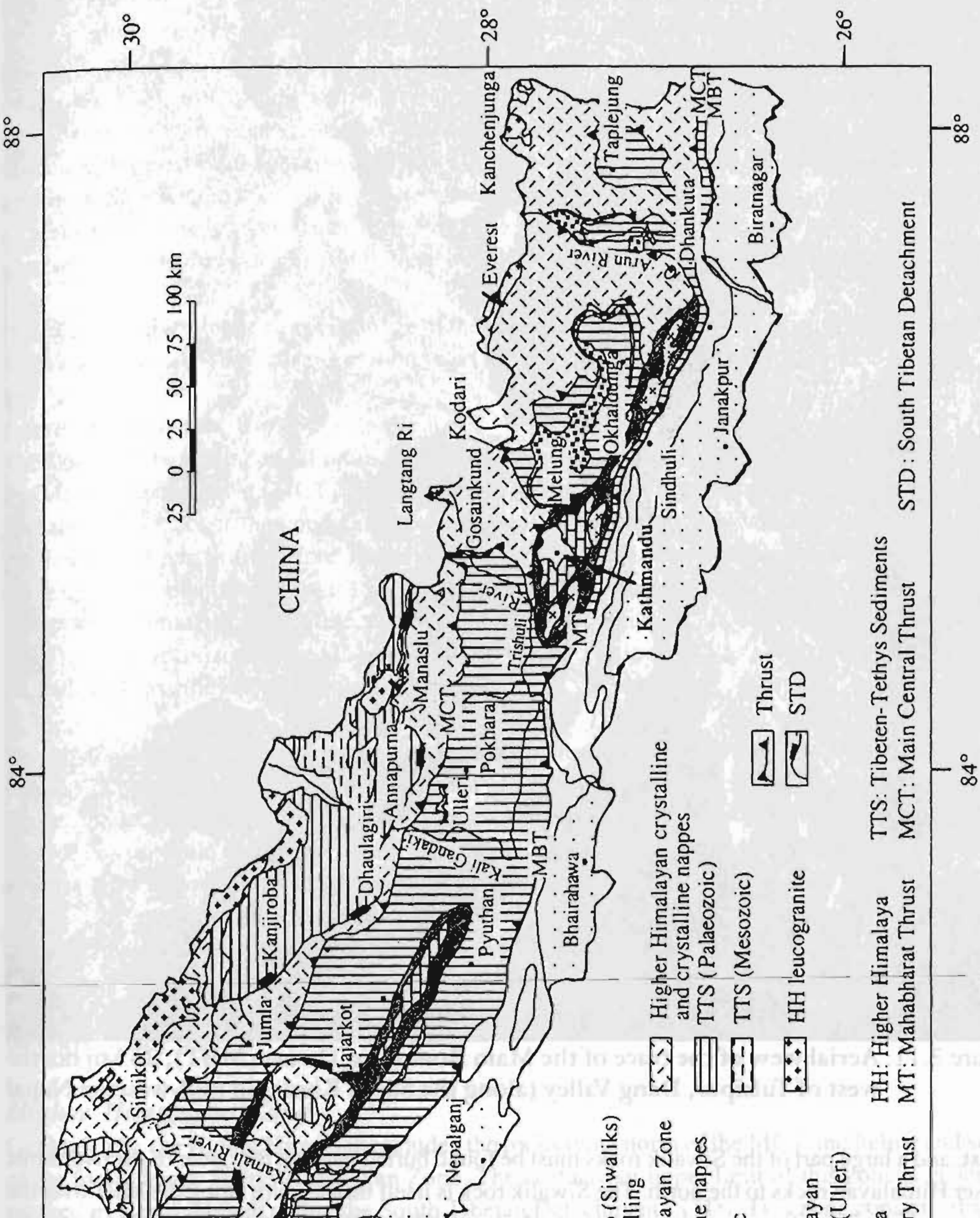

Figure 3.10: Geological map of Nepal (modified from Upreti and Le Fort 1999)

Figure 3.11: **Aerial view of the trace of the Main Boundary Thrust (MBT), 25 km north-west of Tulsipur, Dang Valley (along the Sarda Khola) in mid-western Nepal**

thrust; and a large part of the Siwalik rocks must be found buried beneath the cover of the overthrust Lesser Himalayan rocks to the north. The Siwalik rock is itself thrust south along the MFT over the alluvium of the Terai (in contrast to the area to the south of the MFT where the Terai alluvium rests on top of Siwalik rock).

In general, the rocks of the Siwalik Zone dip northwards at varying angles and the overall strike is east-west. A number of east-west running thrusts are recognised within this zone. All the thrusts originating in the Siwalik are believed to be shallow and to join the basal decollement thrust (Main Himalayan Thrust) beneath the Himalaya.

Rocks of this zone are divided stratigraphically into three parts. The deepest stratum, the Lower Siwalik, is essentially composed of alternations of fine-grained sediments such as various-coloured mudstone, siltstone, and shale with subordinate amounts of fine-grained sandstone. The Middle Siwalik is marked by the first appearance of thick multistoried sandstone beds, measuring several metres to tens of metres in thickness and alternating with subordinate beds of mudstone. Because of the abundance of biotite and the presence of light-coloured quartzes and feldspars, these sandstones have acquired the nickname 'pepper-and-salt sandstones'. Cycles of fining-upward sequences are commonly observed, in which a bed begins with a coarse sandstone, gradually fines upward and ends up in thin clay layers or paleosols. The clay layers normally preserve good fossils of plants and (locally) freshwater molluscs. The Upper Siwalik is characterised by very coarse-grained rocks such as boulder conglomerates with minor proportions of mudstone intercalations.

Based on palaeomagnetic studies, the age of the exposed Siwalik Group in Nepal ranges from around 14 million years ago to less than 2 million years ago (Tokuoka et al. 1986; DeCelles et al. 1998).

Lesser Himalayan Zone

The Lesser Himalayan Zone (Figure 3.10) is bordered to the south by the MBT and to the north by the Main Central Thrust (MCT). The MBT is a low-angle fault that has brought very old Lesser Himalayan rocks over the younger Siwalik Group. Three physiographic units – the Mahabharat, Midlands, and parts of the Fore Himalaya – belong to the Lesser Himalayan Zone. The zone is made up mostly of unfossiliferous sedimentary, and metasedimentary rocks such as shale, sandstone, limestone, dolomite, slate, phyllite, schist, and quartzite, ranging in age from Precambrian (as old as 1, 800 million years) to Eocene (about 40 million years). The rocks in this zone are highly folded and faulted, and have developed complicated structures.

The Lesser Himalaya of Nepal shows much variation in stratigraphy, structures, and magmatism. In the east it is characterised by the development of extensive thrust sheets of crystalline rocks of the Higher Himalaya (gneisses and schists) that have travelled southward from their root zone in the north. Large tectonic windows – notably the Taplejung, Arun, and Chautara-Okhaldhunga – expose low-grade metamorphic rocks of the Lesser Himalaya below the cover of these crystalline thrust sheets. In central Nepal, a large thrust sheet called the Kathmandu Nappe covers a wide area around the Kathmandu region. West of Kathmandu, between the Burhi Gandaki and Bheri Rivers, the crystalline rocks are restricted to the region north of the MCT. Between the Bheri River and the western border of Nepal, crystalline nappes reappear and cover much of the Lesser Himalayan terrain (Figure 3.10).

Higher Himalayan Zone

Geologically, the Higher Himalaya includes the rocks lying north of the MCT and below and south of the fossiliferous Tethys Himalayan Zone. The northern or upper limit of this zone is generally marked by a normal fault called the South Tibetan Detachment (STD). This zone consists of a 10-12 km thick succession of high-grade metamorphic rocks also known as the Tibetan Slab (Le Fort 1975). The crystalline unit of the Higher Himalaya runs the entire length of the country, its width varying from place to place. The high-grade metamorphic rocks such as gneisses, migmatites, schists, quartzites, and marbles of this zone form the basement of the Tethys Himalayan Zone. Some young granites (24-19 million years old, Guillot et al. 1994) occur in the upper part of the unit and also intrude into the rocks of the Tethys Himalayan Zone (Figure 3.10).

Tethys Himalayan Zone

The Tethys Himalayan Zone, also known as the Tibetan-Tethys Himalayan Zone or Tibetan Tethys Zone, adjoins the Higher Himalayan Zone with a normal fault contact (the STD) and extends to the north into Tibet. This zone is composed of sedimentary rocks such as shale, limestones, and sandstones, ranging in age from Cambrian (570 million years ago) to Cretaceous (70 million years ago). In Nepal, the fossiliferous rocks of the Tethys Himalayan Zone are well developed in the Thak Khola (Mustang), Manang, and Dolpa areas. Most of the High Himalayan peaks of Nepal, including Everest, Manaslu, Annapurna, and Dhaulagiri, are made up of these Tethys Himalayan rocks and of young granites intruding into them (Figure 3.10).

The Restless Mountain

The Indian plate is moving northward into the Eurasian plate at an average rate of about 1.5 to 5 cm per year (depending on the location), with nearly half of this horizontal slip being accommodated within the Himalaya (Bilham et al. 1998). This constant compression makes the Himalaya one of the world's most active and fragile mountain ranges. The rocks of the Himalaya are moving upward as well as horizontally southwards along the major thrusts discussed above. The range is presently rising at a rate of about a few millimetres per year depending on the location, reaching nearly one cm in the Fore Himalaya south of the MCT (Jackson and Bilham 1994).

Different parts of the range have moved at different rates in the past. Between approximately 25 and 19 million years ago, the Main Central Thrust (MCT) was very active and the northern part of the Himalaya (areas occupied by the present-day Higher Himalaya) rose very quickly, attaining nearly their present height; deformation and partial melting within the MCT hanging wall occurred around 22 million years ago (Copeland et al. 1991; Hodges et al. 1996). The movement along the MCT caused the Higher Himalayan rocks to move southward, sliding over the Lesser Himalaya, eventually travelling horizontally more than 100 km. Higher Himalayan crystallines must once have covered the Lesser Himalaya like a blanket, but most have by now been eroded away. After a period of inactivity, the MCT was reactivated 6-8 million years ago (Harrison et al. 1997), rejuvenating the Higher Himalaya.

Around 10-11 million years ago, the movement that had been occurring along the MCT shifted to a new location, the Main Boundary Thrust, essentially creating the Mahabharat Range (Meigs et al. 1995). This movement also forced the Lesser Himalayan rocks over the Siwalik rocks; a large contingent of Siwalik rocks is presumably buried under the Lesser Himalaya. The MBT remains very active, with the result that the frontal part of the Lesser Himalaya is rising comparatively fast.

As the MBT gradually became inefficient in accommodating the northward displacement of India, new thrusts formed to the south. They include the Main Frontal Thrust (MFT), along the southern front of the Siwalik Hills, as well as others further south in the plains. The latter are covered by the alluvium of the Ganges and Indus river systems (Figure 3.12) and therefore cannot be seen directly, but thrusting and uplifting can be inferred from folded and tilted river terraces and domal uplifts as much as tens of kilometres south of the mountain front. The still-active MFT continues to press the Siwalik Range higher and its rocks southwards.

All the above-mentioned thrusts run east-west the length of the Himalaya. The compression resulting from the northward movement of the Indian Plate against the rigid Asian landmass has also given rise to many other faults and folds, large and small, active and inactive, and of various orientations. In Nepal there are large east-west-running folds, an anticline (a fold in which layered strata are inclined down and away from the axes) within the northern part of the Lesser Himalaya, and a syncline (a concave upward fold with younger material in its core) in the front occupying the Mahabharat Range. The Himalayan rocks in general are also highly criss-crossed by joints (fractures without discernible displacement) as a result of the tectonic forces prevailing in the Himalaya.

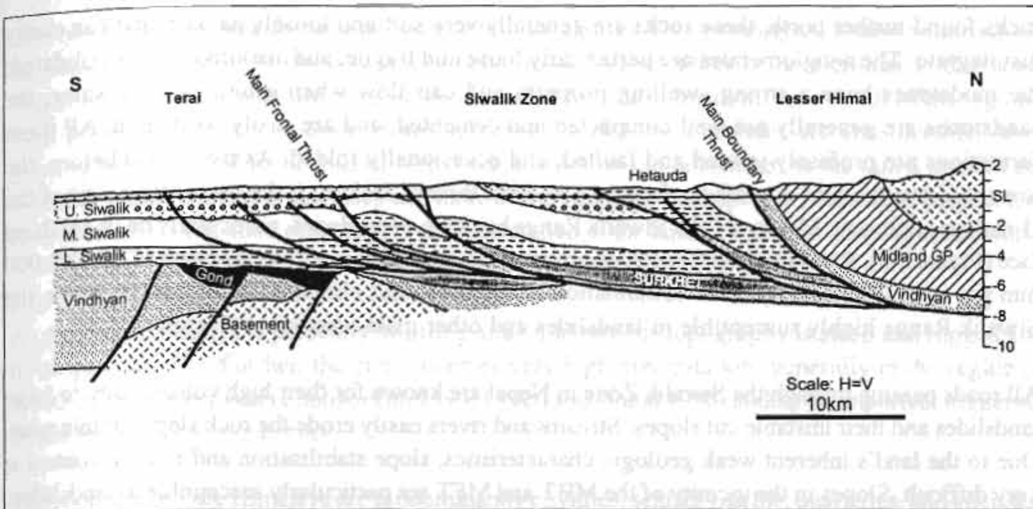

Figure 3.12: **Structural cross-section across the Terai, Siwalik, and Lesser Himalaya** (after Bashyal 1998, with permission from the Nepal on ecological society)

In general, the presence of so many thrusts, faults, folds, and joints makes any rock of the Himalaya physically weak. Rocks adjacent to faults and thrusts, those along the axis of folds, and those that are jointed are particularly weak.

A final factor in the dynamism of the Himalaya is its continual battle between weathering and uplift. Both mechanical and chemical weathering processes are quite intense in the region. The Himalaya, which is generally agreed to have attained nearly its present height by 17 million years ago (France-Lanord et al. 1993), would have been reduced to a plain if it had not constantly offset the weathering and erosion processes by further uplift. An area with a high uplift rate will maintain steep slopes and rugged features as it outpaces weathering and erosion; a slowly rising or stable area will over time become more smooth and rounded and will have thick soil development. Thus the parts of the Himalaya that are rising faster – the Higher Himalaya, Mahabharat, and Siwalik Ranges – are steeper and more rugged than the Lesser Himalaya. The latter has remained comparatively stable for a long time, geologically speaking, and therefore the effects of weathering and erosion can be seen in its rounded hills, less steep slopes, lower heights, and thick soil layers. This has resulted in the development of a more hospitable region for human settlement in an otherwise inhospitable Himalayan terrain.

Landslide Problems in Nepal

The predisposing factors for landslide occurrence and other slope instabilities are the inherent geological condition and the high angle of slope of the terrain. Factors such as raised groundwater level, undercutting by rivers, and loss of vegetation, may facilitate landslide occurrence. The actual triggering agents can be any of a variety of factors such as excessive rainfall, earthquakes or artificial vibrations, and various anthropogenic activities. Conditions predisposing to the occurrence of landslides on a wide scale are found in all the geomorphic and geological zones of the Himalaya.

Siwalik Range

As discussed above, the Siwalik Range is made up of geologically very young sedimentary rocks such as mudstones, shale, sandstones, siltstones, and conglomerates. Unlike the metamorphic rocks found further north, these rocks are generally very soft and loosely packed, and can easily disintegrate. The conglomerates are particularly loose and fragile, and are almost unconsolidated; the mudstones have a strong swelling property and can flow when saturated with water; the sandstones are generally not well compacted and cemented, and are easily weathered. All these formations are profusely jointed and faulted, and occasionally folded. As mentioned before, the Siwalik Zone contains a number of major east-west thrusts, making it the most active part of the Himalaya at present. Moreover, the Siwalik Range has very steep slopes, particularly on its southern face (Figure 3.3). Rainfall in the Nepalese portion of this zone is normally in the range of 1,500-2,000 mm per year (Figure 3.8). This combination of geologic and climatic conditions has made the Siwalik Range highly susceptible to landslides and other mass-wasting processes.

All roads passing through the Siwalik Zone in Nepal are known for their high vulnerability to large landslides and their unstable cut slopes. Streams and rivers easily erode the rock slopes of this zone. Due to the land's inherent weak geologic characteristics, slope stabilisation and erosion control is very difficult. Slopes in the vicinity of the MBT and MFT are particularly susceptible to landslides.

Mahabharat Range

As the first effective mountain barrier to the monsoon clouds, the Mahabharat Range greatly influences the distribution of rainfall in Nepal. In some places, such as the Dhankuta-Okhaldhunga area, it even forms a kind of rain shadow to its north (Figure 3. 8) (Chalise et al. 1996). Where the range is relatively higher – as in (from east to west) Ilam, Ramechap-Udaipur Garhi, the southern and south-eastern rim of the Kathmandu Valley, Tansen, and Dadeldhura – rainfall amounts also tend to be higher (Chalise et al. 1996; Upreti and Dhital 1996). The frequency of high-intensity rainfall (cloudbursts) is also high in these areas (Upreti and Dhital 1996).

The climatic factors in combination with the very steep slopes and inherently weak geologic conditions, make the Mahabharat Range highly susceptible to landslides. The presence of phyllites, slates, and thinly bedded interlayered sequences of phyllites and quartzites add to the instability; intense weathering makes the rocks still weaker. Only where the Mahabharat Range is made up of rocks such as limestone, dolomite, marble, and granite are the slopes more stable. The region is dotted with prominent landslide paths: Ramechap, the east-flowing sector of the Sun Khosi River, and the Salyan-Pyuthan area are well known for their landslide activity. Roads passing through or crossing the Mahabharat Range are highly hazardous: the Dang-Salyan road, the Kanti Highway (Tikabhairab-Hetauda road), the newly constructed Katari-Okhaldhunga road, and the Dharan-Dhankuta road illustrate how hazardous and difficult it is to build – and maintain – roads in such terrain.

Better monitoring of rainfall data and the installation of more meteorological stations might help to give advance warning of disasters, floods and debris flows as well as landslides) and help save lives and property in the region.

Midlands

The Midlands have a more subdued topography than the other zones. However, the rocks in the Midlands are deeply weathered, and thick soil formations are found on most hill slopes; these soils are generally prone to landslides, especially in areas of intense deforestation. Most parts of the Midlands receive an annual rainfall of between 1,000 and 2,000 mm, with some exceptionally high precipitation pockets This rainfall intensity is enough to trigger widespread landslides in the Midlands. The bottoms of major valleys are particularly prone to landslides as a result of undercutting by rivers.

The Midlands are home to most of Nepal's hill population. This physiographic unit is intensively cultivated, with even the steepest slopes being used. Deforestation is most critical in this zone. Wherever possible, slopes are terraced and irrigated for rice cultivation. As a result of the region's high population density, anthropogenic influences in causing landslides are considerable. Most good agricultural land in the hills of Nepal actually lies on old landslides, as the failed mass of the landslide makes the terrain less steep and more moist. In such areas improper methods of irrigation or road or canal construction often trigger the reactivation of the landslide, threatening the entire slope.

Fore Himalaya

As the Fore Himalaya is presently uplifting at a rapid rate, its topography is steep and rugged and its slopes unstable. Further, the zone receives very high precipitation, generally in the region of 2,000-3,000 mm per year (Chalise et al. 1996; Upreti and Dhital 1996) adding an important triggering factor for landslide occurrence.

The rocks of the Fore Himalaya are predominantly phyllites, schists, marble, quartzites, and gneisses. The slopes are commonly covered with thick, bouldery soils, generally known as colluvium, that are prone to large and unmanageable landslides. A number of such landslides can be found along the Arniko Highway (Kathmandu-Kodari Highway), at Charnabati near Charikot, and north of Dolakha. Similar soils and associated landslides can be found along most of the major north-south flowing rivers of Nepal. In some narrow valleys, large parts of the hills have collapsed towards the centre of the valley, producing larger-scale landslides. These features can be seen along the Kodari Highway opposite Sakhua, north of Barhabise.

Higher Himalaya

The Higher Himalaya is the most rugged of Nepal's physiographic units. The gneisses, migmatites, schists, marbles, and quartzites of this zone have undergone metamorphism at very high temperatures and pressures, and so are comparatively strong and can support very steep slopes. Near-vertical pitches of 3,000m or more are not uncommon. The southern slopes of the Higher Himalaya generally receive high precipitation. Physical weathering is dramatic in this unit, but very little soil cover can remain on its very steep slopes.

Despite their geologic strength, the rocks of the Higher Himalaya are subject to landslides of various sizes. Most are rockslides, but exceptionally large landslides have also been reported: the Tsergo Ri mega-landslide in the Langtang Valley had a displaced volume of rock estimated at 10 cu. km (Weidinger and Schramm 1995). As the Higher Himalaya is practically unpopulated (except in some valley bottoms), these landslides generally have little socio-economic impact. However, construction of roads and other infrastructure in this zone is a formidable task.

Inner and Trans Himalayan Valleys

Lying in the rain shadow of the Himalaya, with an average annual rainfall of less than 250 mm, these valleys experience less frequent landslides than other areas. The most common cause of landslides here is the failure of colluvial and moranic materials on steep valley slopes.

Conclusion

Landslide occurrence in Nepal is a function of the inherently weak geology and physiography of slopes, combined with triggering factors such as heavy monsoon rainfall, cloudbursts, and earthquakes. These factors vary in different physiographic, geologic, and climatic zones. It is likely to be inappropriate to use a uniform approach to the study and mitigation of landslide hazards in every zone of the Himalaya: the landslide problem in the Siwalik hills is unique and entirely different from that of the Higher Himalaya and vice versa. A better understanding of the geologic, physiographic, and climatic zones and their combined overall effects on the terrain is a prerequisite for any successful project of landslide study and mitigation in Nepal. Obtaining more reliable data through a better network of meteorological stations will greatly help correct assessment of the extent of rainfall and its role in landslide occurrence.

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