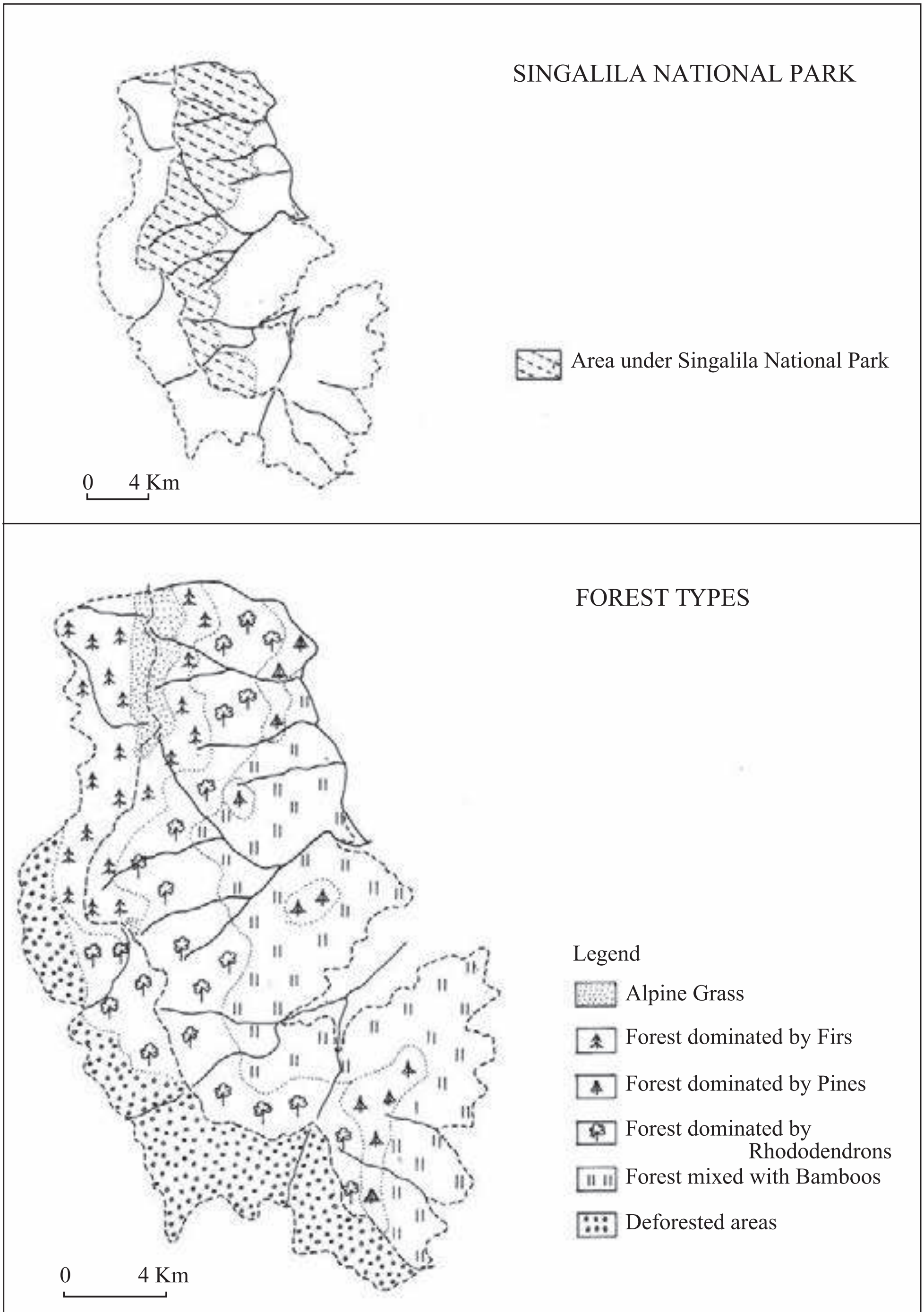
Range. The forests of this zone, experiencing somewhat tundra-type environment, are almost open with some mere undergrowths of hydrangea and cyperacea. In between Sandakphu and Phalut the crest-line is, however, covered with dense shrubs of stunted rhododendrons. Aconites are well spread over Sandakphu, while the top of Phalut is singly haired with alpine grasses (genus Poa). Seidge and juniper (genus Juniperus, sukpadhup in Nepali, chukboo in Lepcha) are well abundant from Sandakphu to Sabarkum area. They form patches on the periglacial swamps of the upper Rato Khola and Siri khola basins.

Since the year of Hooker's journey the distribution of flora has changed enormously especially due to human activities. Some species such as fir have been transplanted well below 3000m. While many alien plants have set up their colonies in the lower belt of vegetation. Japanese fir (Cryptomeria japonica) is the best example of the latter type which now dominates the tree-line along the valley of the river Chhota Rangit.

Habitats of some well abundant plants are enumerated in the following table:

Name of the plant	Altitude (m)	Growing area
Fir	3200-3650	Sandakphu, Thakum,Sabarkum
Pine	2200-2800	Gurdum, Rammam,Gorkhey
Alder	2500-3000	Rammam,Gorkhey
Oak	1800-2600	All ridge-slopes
Larch	2000-2500	Lamedhura, Daragaon, Rammam
Hemlock	2800-2900	Gurdum, Rammam
Rhododendron(tree)	2300-3200	All ridges
Rhododendron(shrub)	3200-3600	Sandakphu, Thakum, Sabarkum, Tumling
Magnolia	2300-3000	Kaiyakatta, Rimbick
Champ	200-2500	Lamedhura, Rimbick,Gurdum
Mountain fig	1800-2400	All ridge-slopes
Juniper	3300-3600	Sabarkum
Alpine grass	3500-3600	Phalut
Maling bamboo	2800-3100	All ridges
Pareng bamboo	2200-2500	All ridge-slopes
Tree fern	1800-2000	All ridge-slopes

Forest Cover: Southern Singalila Range



4.3. Faunal Kingdom

As the tract of the Southern Singalila represents the extended part of the East Himalayan Bio-diversity Hotspot so its forests are well populated by different types of animal ranging from insects to mammals – the classical scenario of a colossal pyramid for ecological sustainability. At the apex of that pyramid dominate obviously the carnivorous birds and mammals who can live only on their preys. Amongst such birds the Eagle family including Hawk eagle (Soizaetus nioalensis, kanzha chil in Nepali, Kanda panthiong in Lepcha) and Himalayan eagle (Lophotriorchis k. Kieneri) ranks atop, though the number of these two species is decreasing rapidly. Among the preying mammals Clouded leopard (Neofelis nebulosa, lamchituwa in Nepali, satchuk in Lepcha, kung in Tibetan) and Snow leopard (Panthera uncia, heiun chituwa in Nepali, phaley in Lepcha, shen or sachak in Tibetan) are the most noteworthy: the former showing some definite lairs in the region whereas the latter is found rarely near Phalut - occasionally coming from northlying mountains for hunting their preys. Both of them avoid Homo sapiens and are, therefore, harmless to trekkers. There are some common Leopards (Panthera pardus, chituwa in Nepali, syiyak in Lepcha) making their lair in the deep gorges near Rammam which are to be avoided by humans. The Himalayan civet (Peguma larvata, suilyu in Lepcha) and Leopard cat (Prionilurus bengalensis) are other two carnivorous mammals with smaller size. The former is now a highly endangered species, while the latter found frequently which always finds an opportunity to kill domestic pigs and kids.

The Himalayan black bear (Selenarctos thibetanus, bhaloo in Nepali, sona in Lepcha, dom in Tibetan) is omnivorous and is the single dangerous animal residing in the local forests. Red panda (Ailurus fulgens, nigalva ponva in Nepali, sankam in Lepcha, oakdonga in Tibetan), Goral (Nemorhaedus goral, ghoral in Nepali, ra giyu in Tibetan, suh ging in Lepcha), Tahr (Hemitragus jemlahicus, jharal in Nepali), Barking deer (Muntiacus muntjak, ratoya in Nepali, shikku in Lepcha), Wild boar (Sus scrofa, banel in Nepali, mon in Lepcha, nagshep phakpa in Tibetan), Yellow throated marten (Martes flavigula), Squirrel (Callosciurus pygerythrus, lokria/lotherke in Nepali, sayang in Lepcha) and Sikkim vole (Pitymys sikimensis, bu ring in Tibetan) are other members of the mammalia being found here. All of them are herbivorous. Some wild horses (not original but belonged to second or successive generation, probably aroused from domestic, sick and abandoned parents) are also noticed near Phalut peak. Musk deer (Moschus moschiferus, kasturi in Nepali, sayar or savar in Lepcha, glaba in Tibetan), now extinct here, was used to be found abundantly over the summits till mid-19th century. The name of the peak Sabarkum still bears its memory which had been one of its past grazing areas.

Raven (Corvus corax, kag in Nepali, hick in Lepcha, neka wak in Tibetan), Himalayan monal (Lophophorus impejanus, dangan in Nepali, fo dong in Lepcha, bup in Tibetan), Tragopan (Tragopan satyara, munal in Nepali, tarrhyak in Lepcha, omo or chamdong in Tibetan), Black eagle (Ictinaetus malayensis, hugong in Nepali, laknangbang in Lepcha), Golden eagle (Aquila chrisaetos), Blood pheasant (Ithaginis cruentus, chilimili in Nepali, semo in Lepcha, seto in Tibetan), Kalij pheasant (Lophura leucomelanos, kalij/rechabo in Nepali, kar rhyak in Lepcha), are viewed all over the terrain which fly and nest here permanently. Whereas other avian species, around 120 as recorded, are found seasonal. The Rato khola and Siri khola basins are heavens for bird-watchers. Spotted forktail (Enicurus macalatus, khanjan in Nepali, ching pho in Lepcha, chukka leka in Tibetan), Spotted wren-babbler (Spelaeomis formosus, marchek pho in Lepcha), Large Tit (Parus major), Fire tailed Sunbird (Aethopyga ignicauda), Common Hoopoe (Upupa epops) and many other beautiful birds can easily be noticed here. Several types of Pigeon (genus Treron, parewa in Nepali, sang pong and kuhu pho in Lepcha), Thrush (genus Garrulax, pho in Lepcha), Snipe (genus Gallinago, bharka in Nepali), and finch (family Estrildidae) are also met across the whole terrain, especiallyin warmer months with great profusion. Many of them fly upward in summer and go down in autumn. The gathering of them reaches at maxima in the latter and in early spring times because the flocks of inter-continental migratory birds (generally smaller in size) often take rests on the mountain during their voyage.

Reptiles cannot live along the summit section due to low temperatures. Several types of snakes (sub-order Serpentes, sanp in Nepali, bu in Lepcha, sbrul or dhrue in Tibetan) are found below 2000m – most of them being non-poisonous. Some lizards, however, move slightly upward especially in summer months. Though unusual, but some families of amphibians find their habitats upto 2800m. In this class the most important is Salamander (Tylototriton verrucosus), the single species so far recorded in the Eastern Himalaya, living in and around the shallow pools between Manebhanjyang and Lamedhura. Besides the newt (paha in Nepali), several types of frogs (family Ranidae, bhyaguta in Nepali, luk in Lepcha, sbal-pah in Tibetan) inhabit across the hill slopes of which at least five species are consumed by the local tribes. Tree frogs are called simook in Lepcha.

The extents and varieties of the invertebrate fauna found in the region are vast. Large types of moth and butterfly (order Lepidoptera, putalee in Nepali, lip pra in Lepcha) are found here abundantly. They are the most beautiful creatures in the forests as well as are very responsible families for maintaining the ecological bases. Beetles (order Coleoptera, keera in Nepali, sbran in Lepcha, sbur in Tibetan) and spiders (order Araneae, makura in Nepali, satum in Lepcha, sdom in Tibetan) make their home anywhere: from the highest peak to the deepest valley segments. Some families of fleas (order Siphonaptera) and flies (order Diptera) are also found in the bushes and under the mattress of mosses but below the summit section. Crickets (Gryllidae family, jhyaunkiri in Nepali) are confined in some parts of Rammam forest, especially near the confluence point of Pathey khola and the river Rammam. Ants (family Formicidae, kamila in Nepali, grog ma in Lepcha) are rare above 2700m. Aquatic insects of course flourish in each waterbody in warmer months even in the lake water of the Chandupokhri situated at the head of the Siri khola. Earthworms (order Haplotaxida, ganeula in Nepali) are almost absent over the high slopes of the mountain, but several species of leeches (family Haemadipsidae, juka in Nepali) are met frequently in the forests. One of them is black mountain leech (Haemadipsa montana), less than two cm in length, attaining its habitat as high as 3000m. Termites (order Isoptera, dhamira in Nepali), especially of wet-forest types show their buildings along the ubac sides of the Kingsa danda and Sabarkum ridge. They are responsible very much for the formation of a unique type of geomorphological feature – conical shaped mounds (upto 2m in height) being composed of rotten woods and other organic matters produced by these insects. Not only the termites, but all other insects also play important role for modifying the surface landscape either in a little or an immense scale. In most of the cases they work together with dead plants to start the processes of bio-chemical weathering and ultimately create a geomorphological feature having some spectacular characteristics of its own.

Special thanks to Dr. Binod Chandra Sharma, W.B.E.S. for his valuable suggestions regarding the spelling of Nepali term of all plants and animals.

Part II
Geomorphological Study

The same physical processes and Laws that operate today operated throughout geological times, although not necessarily with the same intensity as now.

Sir Charles Lyell, 1837

Chapter 5 | Geomorphic Processes: Differentiation in the Development of Landforms

5.1. Introduction

Geomorphological processes are such operations which act on the earth's surface to produce geomorphic features as well as relief on the earth's surface. Each type of those processes is executed by a particular type of agent, called 'geomorphic agent' and gets energy either from the Sun or from the internal heat of the earth to be operational. Running water, ground water, glacier, wind, oceanic waves and tides are important agents acting on the earth's surface. All these are responsible for denudation of the earth's crust and are dependent on the supply of solar energy. The organisms including man also owe the same energy to be active as geomorphic agents. Obviously all these are categorized as exogenetic; while the diastrophic and volcanic activities are endogenetic because energy used in these activities arise from the internal heat of the earth. Mountains like the Himalaya are uplifted from the sea bed by the forces of latter type. But as soon as they emerge above the sea level and reach in atmospheric layers, they are exposed to the activity of exogenetic forces, modified and shortened in height. Thus different types of landforms are produced each of which show individual shape, slope and other morphometric characteristics.

Like other parts of the Himalaya the Southern Singalila Range shows a wide variation in structural ages as well as stages of development of landform, though all of them are relatively young compared to the old landmasses lying to its both sides – to the north the Tibetan plateau, and to the south the Indian shield. Diastrophic forces originated during Plate movement are the main factors to elevate this Range high above the mean sea level (described in chapter-2). Whereas the exogenetic forces operating on it are varied in types – different types of weathering, mass wasting, erosional work of running water, glacier and wind (in limited extent). Since "each geomorphic process develops its own characteristic assemblage of landforms" (W.D.Thornbury, 1954), several sets of landform have been evolved on the tract depending on the belts or zones of operating processes. Thus, at present climatic condition, extreme north-western part of the Range (the summit section in between Phalut and Sabarkum peaks) exhibits some features produced by combined actions of periglacial process and running water; while rest of the mountain is left for the development of fluvial features (produced primarily by the action of running water). Relics of glacial landforms developed during the Pleistocene glacial ages have almost been obliterated except some portions of glacial terraces along the summit section (above Bikhebhanjyang and below Sabarkum peak).

Relief is a product of multifunctional actions of endogenetic as well as exogenetic forces. Furthermore it itself shows an important control on the activity of geomorphic agents. High relief invites their activities with high intensity as more potential energy is converted to the kinetic energy to be involved in operation. Consequently ruggedness of the terrain increases and other geomorphological characteristics vary at their highest level. Large variation in landform features thus produced through such operation becomes attractive much more to the geomorphologists and the experts of other branches of natural sciences.

5.2. Influence of Climate on Geomorphic Processes

Since the exogenetic processes are propelled by solar energy climate plays a dominant role in their degree of acvitity. Moreover mountains like the Singalila Range show much variation in climatic conditions prevailing over them. This is caused for altitudinal changes from place to place and the nature of slopes exposed to solar radiation. The rate of denudation is high in low altitudinal belts because of the presence of high temperature and moisture. The depths of solum and regolith are also high in these belts. On the other hand, the processes of all types of denudation run at slower rate over the summits and contiguous portions. Low temperature and moisture conditions along this section retard all types of denudation except mechanical weathering. In consequence of such diversified activities of exogenetic forces relative relief, slope and other morphological attributes of the region vary tremendously – from low or moderate on upper zones to very high at lower altitudes.

Among all exogenetic processes weathering and mass wasting are controlled mostly by the variation of temperature prevailing over the tract; while the rate of erosion is little influenced by that because most parts of the Southern Singalila Range have been experiencing humid climate since the retreat of last glacial age. The effects of mechanical weathering are much prominent over the summit section. Cambering due to unloading of upper layer rockmasses and sheeting of top-layer strata following the joints are two conspicuous mechanical processes found along this belt. Rock fracturing by freeze-thaw action during the winter months is also a common phenomenon over the crests. The fluctuation of diurnal and annual temperatures is not so high on this mountain that could be effective to cause fragmentation of granite-gneissic strata which are dominant here. Low temperatures throughout the year also slower the rate of chemical and bio-chemical processes over high altitudinal zones.

Relatively higher temperature in mid-altitudinal zones coupled with higher humidity (local precipitation plus waters flowing down from summit section) invite chemical and bio-chemical weathering. The conditions are very much prerequisite for starting transportation of surface materials as well as lowering of landscape.

Mass wasting of weathered rocks and soils, i.e. the first stage of transportation, depends little on temperature but largely on the presence of moisture in sub-surface layers. Thus different types of mass movement including landslides occur frequently in monsoon season when supply of moisture exceeds the retention capacity of top-soil layer and underlying regolith. When the kinetic energy of a fully discharged stream exceeds enough the inertia of weathered rockmass the solid mass slips downslope and is moved away through the current of that stream. The same effect can also be found for gushing run-off across the steep slope of mountain sides, but the formidable gradient of the slope then plays more important role than the momentum of running water.

Erosion is the second or final stage of transportation. As for mass wasting it also depends primarily by the momentum of stream discharges. The slope of landscape, however, controls the rate of erosion – the higher the gradient of the slope the higher the quantum of erodibility. All types of denudation activities remain ceased during winter months over summit section due to the covering of snows and firns. Effect of climatic conditions on individual processes of exogenetic forces found in the region after micro-level observations and experiments will be described precisely in the next chapter (chapter-6).

5.3. Influence of Vegetation on Geomorphic Processes

The cover of natural vegetation of the terrain reduces the rate of denudation to a great extent. The role of thick undergrowth is much prominent in this regard. Roots and creeping branches of such vegetation fasten tightly the weathered rock fragments even in the days of excessive rainfall and vigorous surface run-off passing over them. Thus transportation of that materials decreases manifold.

Every hollows and notches of the mountain shows slower rate of excavation on account of thick blankets of small plants and grasses protecting them from any type of denudation though these points are the sources of rivulets. The mountain flanks crawling at ubac sides are also covered with thick undergrowth of shrubs and dense forest woods. Those portions are mostly uninhabited due to lower rate of insolation and the landforms show little traces of anthropogenic activity. Naturally the slopes of such landforms display much resistance to denudation.

Exogenetic forces attack severely on the slopes situated on adret sides of the Range and its associated ridges because of direct supply of solar energy. Dense growth of plants hinders them at primary level. But as soon as weathering processes start on rock masses lying on that slopes subsequent processes of mass wasting and erosion are also accelerated. Rapid excavation of gullies and rivulets are noticed frequently in such rockmasses, downcutting of glens becomes rapidier, and slopes retreat at the fastest rate. The quick recession of adret side of the Rimbick ridge with much resistant ubac side of it (which is also facilitated by pro-dip structure) has thus given rise to a typical 'homoclinal ridge'.

The mulch of coniferous trees growing over middle and high altitudinal belts of the Southern Singalila Range supplies large amount of humic acid to the underlying regolith which ultimately produces a special type of soil well known as black hill soil. This soil exhibits low pH values (less than 5.0). Silicification is also a common phenomenon in this soil, especially over the slopes of steep gradient (more than 50°). The rate of erodibility on such soil increases manifold.

5.4. Influence of Animals (including Man) on Geomorphic Processes

Role of animals, except man, is little in deviating the rate of denudation. Termites may build occassionally conical landforms of small size (less than 2m in height, as stated in chapter-4) which are very common features on the Kingsa danra and Sabarkum ridge. Burrowing animals sometimes accelerate the rate of erosion at the points of their venture. But the most important animal is man who influences tremendously on the rate of geomorphic changes over the mountain. The fact is much true as the Range has been well inhabited for the last two centuries. Deforestation has been taking place at all places which show low gradients (generally less than 15°) for construction of their houses as well as setting up arable lands.

Since early 1990's pressure on land of the Southern Singalila Range has eked up beyond any estimate due to rapid growth of population (local inhabitants coupled with travellers). Many tiny hamlets have been converted into large settlements. Narrow trek-paths have widened enough to make boulder-strewn tracks, or even to bituminous roads.

For all these constructions topography at the construction points has to be modified by removing soil and rockmasses. Thus man-inducing denudation is a common phenomenon over the mountain. The landscape is degraded much more by the expansion of arable lands. Since the crops are harvested seasonally they neither fasten the surface materials nor participate in the process of new soil formation. During heavy downpour loose soil and rock granules of the cropping fields are washed away downslope. The event invites havoc many times.

To protect his house and road lying at vulnerable sites man builds concrete walls across the steep slopes. Fences made by bamboos or stones are erected along the edges of arable land. Through these activities man sometimes acts as an agent of constructive geomorphological processes too.

Chapter 6 | Geomorphic Processes modifying the Topography of the Range

6.1. Introduction

It is obvious that the present surface configuration of the Singalila Range is the result of differential geomorphic processes, both of past and present types, acting over the mountain. The combined action of such processes leads to maintain equilibrium state of the tract not in a unit mass but in parts. Following the concepts of Chorley and Kennedy (1971), the state of the region may be accurately marked as 'Metastable dynamic equilibrium' condition. In such condition a slight change in the activity of any type of geomorphic processes alters greatly the scenario of topographic characteristics. The threshold can be abrupt or gradual depending upon its triggering factors like temperature and moisture. Both of them are important elements of climate and their spatial variation has been accounted in the chapter-5. But here they are discussed only for their role in controlling the processes.

The role of temperature mainly concerns with its daily range as well as the annual fluctuation above or below the freezing point. Moisture involves the intensity of precipitation, especially of rains, size of raindrops, amount of surface run-off, and percolation of water through the soil and rock strata. As Ollier (1969) says, "Several climatic conditions affect the rapidity and depth of mechanical weathering; others affect leaching, groundwater recharge and salt movement, biotic weathering, and erosion. Some climatic effects are direct, others operate through their effects upon vegetation and soil."

Though there is not a single Meteorological station on the Southern Singalila Range the weather records taken by the author during his prolonged field surveys across the region help to apprehend much of the weather and climatic conditions prevailing here. It is evident from those records that the daily range of temperature on the mountain remains very low (less than 8°C) throughout the year. Consequently weathering on the surface rock including physical and bio-chemical processes becomes slower than their normal rate. Whereas the annual fluctuation of temperature is very high which, specially above and below the freezing point, plays an important role in mass wasting and erosional work, sometimes in a combined way. In winter and spring, nocturnal frost action is a common phenomenon in the ground rock penetrating often at some metres of depth. It causes waging of firn in the rock fractures, spalling off and pebbling on the bare surface, and ultimately solifluction on the gravelly slopes. In the early spring times melting of snows and frost rejuvenate the springs and rivulets.

Due to enhanced amount of discharge in the rivulets erosional activities increase enormously resulting in taluvial deposits at the breaks of ridge-slopes. The heavy showers in the summer months swell the stream water many fold with increasing erosional rate hundreds of times than that of the waning period. Different types of mass wasting are also common phenomena in this season and are found widely all over the mountain: sliding masses and avalanches being the commonest forms amongst them.

For giving an analytical description all the degradation processes occurring in the region may be grouped into three common sub-heads: Weathering, Mass wasting and Erosion. On account of high altitudes and intermittent upliftments of the tract till recent traces of aggradation processes are very rare, especially above 1800m.

6.2. Weathering

Weathering, according to its well familiar definition, is the assemblage of rock altering processes without transportation of product materials. Thus it is distinguished from other denuding processes where the exogenic energies are all restored as potentials. However when the constituent minerals of a rock react with water (neutral or slightly acidic with the incorporation of CO_2 , NO_2 etc.) the soluble materials are carried away either in solution or in percolation.

The term weathering has been derived from weather as the process is run under the influence of differential weather elements. The prevailing cool and temperate conditions, especially the winter snow cover over high altitudinal belt of the Range makes a dormant period for both vegetation and micro-organisms. Thick layer of dead leaves or needles and other parts of plants are accumulated over the land surface. Rain and snow-melt water seeping through that layers create organic compound and CO_2 which chelate and hydrolyze metallic cations from that humus body; and ultimately result in silica-rich clay residue. Abundance of clay minerals in the surface soil prevents water from free penetration in the underlying rock and increase overland runoff. The slope of landform is thus modified with gentler gradients after clothing with creeping soils and debris flows: the features are very common all over the ridges of the Southern Singalila Range.

Though the effect of chemical weathering reaches only a few metres into the rockmasses, processes of mechanical weathering, especially hydrofracturing, go down into deeper section. Any type of rock including hard granite, cannot withstand the huge pressure generated by freezing water confined in its fractures. The fractures are widened with the growth of ice as well as are deepened with the downward movement of super-cooled water pushed by the bulging of ice lying above it. The two combined actions ultimately transfer the large rock mass into many fragments: from boulders to granules in sizes. Such types of weathered materials are very much conspicuous across the slopes on both sides of the main Range.

The effects of diurnal and seasonal variations of temperature are not so great on the crags of immense size which are composed of much non-metallic substances. But their important role is clearly visible on the bare granular substances having large grains of metallic compounds. With the aid of precipitation these granules are rapidly oxidized. Decaying rocks with a thick cover of ferric compounds are well abundant along the Range especially between Lamedhura and Tumling.

Sheeting and jointing in surface rocks by cambering are also common all over the ridges. But these are caused mainly by the release of overlying loads: thickness of which exceeded 2.5km over the present body of the Southern Singalila. Fragmentation of rocks into pebbles, even in mineral grains is also a common phenomenon at the sites of faulting caused by recent movements. Old fault-scarps have, however, been modified enormously by prolonged actions of sub-aerial erosion leaving very little of weathered materials.

6.3. Mass Wasting

All types of downslope movement guided solely by gravitational force are categorised in the process of mass wasting. Though the definition ignores the presence of water, it plays a significant role in this system where the potential energy restored in the weathered materials is largely converted into kinetic type. The first part of water's role is to enhance the steepness of hill slopes through surface erosion and to create seepage force through subsurface flows. The second part is probably more important where water acts as a lubricator of the moving masses across the slope-surface. Thus rain water as well as other kinds of precipitation reveals an indirect but distinct effect on this method of land sculpturing. Considering the nature and speed of movement we may classify the wasting systems acting upon our study region into the following sub-divisions:

A. Slump and Slides:

On the higher sections of the Range and ridges slump of debris is frequently occurred as a thick cohesive mass wetted by fresh water either from snowmelt or spring shower. The upper surface of a slump block is slightly convex while its basal part remains concave upward. Whole mass is diverged outward and elongated towards downslope – the elongation ratio being higher with steepening the slope. Formation of rills and gullies is a common feature found on these masses.

The debris slide is, however, found in the lower part of the ridges and is the main designing factors of colluviums along the stream-beds. Rock slide and block glide are two other types of slides which are all along the middle parts of the hill slopes, especially along the free faces. All these are propelled by the sine component of the gravitational force, whereas aided weight of water from heavy monsoonal rains acts as their triggering factor. The increasing area of slide prone zones in the region during the last two decades is mostly due to the increasing rate of anthropogenic activities which include the illegal construction of settlements over unstable slopes and indiscriminate clearing of forests for fuel wood and building materials of log-houses.

B. Solifluction and Rock Flow:

Solifluction or soil flow is a conspicuous feature along the uppermost section of the Range stretching from Kayakatta to Phalut where top soil layers are heavily saturated with water during monsoon period and go through freeze and thaw action in winter months. The activated layers, 50-150 cm in thickness, being composed of immature solum, mulch and rock fragments flow gently downslope (few cm per day) with gradients not more than 7°. Alignment of rubble-heaps, almost parallel to contour lines, stands as residue at their abating zones.

The process of rock flow is similar to solifluction but occurs with relatively rapid velocity (some metre to tens of metre per day). The composition varies from pebbles to large boulders, generally mixed together, which is frequently found along the steeper slopes of the mountain (from 15°-55°). Such type of flow occasionally blocks a rivulet and causes widespread destruction in its downstream area.

C. Avalanches:

These are the most rapid mass movements found along the cliffs of the ridges (having gradients more than 50°). Steep western slope of Sandakphu and Sabarkum peaks show the best example of this type of wasting process. Almost vertical falls of rock and debris are disastrous events to the local people as these destroy roads, houses and cropping fields with occasional loss of lives too. Large scale avalanches take place during the monsoon months especially at the last stage of heavy showers. Sometimes they clog the stream courses and flush floods occur after sudden collapse in the deposited materials by tremendous pressure of water arrested above them. The region experienced such havocs almost in every valley sections in the years of excessive rainfall like 1899, 1968 and 1999. Very large but segmented avalanches also generated by the violent tremor of Bihar-Nepal earthquake on 15th January, 1934. This shock also invited other types of mass wasting and reactivated many fault-line scarps too.

6.4. Erosion

In transportation of loose materials (products of weathering and mass wasting) from high to low altitudinal zones of the tract none but water again plays the most important role as cool but humid climate is presently prevailing over the Range. Effects of glacier and wind are almost absent today though they were also significant in many times of the past geological ages. The activities of running water, however, fluctuate enough with the variation of climatic elements, particularly the amount of precipitation. In the higher elevations the work almost ceases during the winter months due to ice covers, while it reaches its maxima in the monsoon period. The conversion of energy, from potential (residual after mass wasting) to kinetic, reaches its topmost level in the process of erosion. But most of it is lost in frictional work of internal turbulence on flowing water; only 2-4 percent is used for running the mechanisms of denudation itself (Rubey, 1938).

The capacity or transportation power of a water channel depends on surface gradient, amount of discharge, nature of transported materials and, above all, climate - the last one influencing very much the former factors too. Thus the fluvial processes are now fully dominating all the erosional activities found over the Southern Singalila Range. They began to sculpture past landforms with the setting of existing climatic conditions: just after the end of the last glacial age .

Fine texture of faults and joints helps to emanate innumerable springs all over the terrain which increase not only the number of headstreams but also enhance the area under denudation. The flow of that springs varies seasonally – maximum discharge comes out during spring (added by meltwater) and monsoonal months (rainwater plus pressurized seepage water). Their dissolve materials often change from silicates to ferric within a same altitudinal belt with same rock composition: a consequence of obviously the effect of micro-climatic aspects. Some headstreams of the Rato (denoting red colour in Nepali) khola and the springs issued from the south-western face of Tonglu are the best examples of such event.

Since the maximum rainfall of the region occurs from monsoon clouds which attack the ridges on their adret sides: slopes of these sides are eroded vigorously leaving asymmetrical valley profiles for all the headstreams. The leeward portions of the ridges remain more stable with gentler slopes and slower transportation methods through the channels. The feature is clearly understood along the valleys running E-W, e.g. the upper section of the Partham khola.

The climatic influences on erosional work are much impressive in the mid-valley section of the main rivers especially along the fourth and fifth orders (designated after Strahler's method). The deep glens with terraced side-walls depict the late Pleistocene episodes stage by stage. In fact, these portions were firstly denuded by preceding channels of the rivers which established themselves in some time of an interglacial age (evidently the last one). The uppermost terraces lying between 2300m and 2600m are nothing but the relics of their previous planation surfaces. The middle and lower terraces are, of course, the witnesses of recent upliftments of the region (in Holocene). The knick points are almost absent for the first cases due to prolonged subaerial erosion, whereas the converging points are prominently marked with cascades (mostly perennial in nature) for the latter types. Erratics can also be noticed in the mid-valley section of the rivers which provide good instances for the action of the last glacial age across the entire tract.

Chapter 7 | Structural Control over Topographic Revelation

7.1. Introduction

"Geologic structure is a dominant control factor in the evolution of landforms and is reflected in them". W.D.Thornbury (1954) used the term 'structure' in a broader sense to depict all the crustal materials along with their all types of nomenclature as well as physical and chemical properties. In the Southern Singalila Range main constituent rocks are metamorphic gneiss; and granite and granitoids of igneous origin (felsic group) which cover most of the upper parts of the Range. These are highly crumpled, overthrusted as a gigantic Nappe, broken by transverse faults at some places, and badly jointed at each part of the mountain. Variation in climatic conditions in different altitudinal belts has made the strata susceptible to varied types of exogenetic processes. As a consequence landforms produced in the region provide a large spectrum in terms of geomorphological characteristics.

7.2. Topography in relation to Underlying Structure

Tectonic force has been elevating the Range since its early days. But the surface topography in a particular area of the region as seen today is mostly the reflection of responsive attributes of rock strata to the exogenetic processes acting over them. Since the central axis of the Range represents a Nappe structure, and the section of anticlinorium of a Nappe is the most fragile part of such an elevated mass, the lid portion has completely been worn away by differential weathering and subsequent erosional processes. Wavy summit level presently stands over synclinorium - the part lying below the axial plane of the giant Nappe. Naturally it is much compressed, rigid and resistant to denudation processes. Peaks and other minor crags mostly composed of hard, compact rock masses often protruded over the summit line are nothing but the frontal parts of the synclinorium structure. The scarplets produced by transverse faults (across the summit line) occurring during neo-tectonic movements are, however, weathered badly and worn down deeply. These zones are conspicuously marked by mineralization of rock fragments which are stressed at friction layer; and also by the presence of springs at the base of those scarplets.

Some transverse faults extended on the both sides of the Range are occupied by deep glens of headstreams. They have little amount of discharge but can show vigorous activity of corrasion only by the assistance of weak structure along their courses. The ridges are, however, mostly composed of synforms – the sections are compressed very much and resistant to denudation. Sabarkum ridge, Rimbick danra, Lali danra – all provide good examples of such landforms. At the footwall of a large fault scarp or a fault-line scarp the depth of solum and regolith increases manifold. That part is generally used for cultivation and setting up human settlements. Gurdum and Hagetham can be cited for instances of such landscape.

Gravitational collapse (sackung collapse) is a common phenomenon in connection with nappism of a mountain and the Southern Singalila Range is not exception to avoiding such incidence. Here it happens by two ways – one by transverse faulting and another by downslope movement of huge rock masses from the summit section. The depressions of Kalipokhri can be cited for the event of first type – the pair of sagging parts being located just above two transverse faults occurring at very short distance (within 50m). Due to crustal shortening both the depressions are deep but narrow. They are, however, situated at different tiers owing to the differential height of the faulted blocks.

Downslope movement of weathered rocks from the summit section causes isostatic imbalance in the mountain mass. As a result the summit rises through invisible impulses. While the basal part, where the rock masses are accumulated, goes through gradual sinking. Both relief and ruggedness of that portion of the mountain thus increases in due course. The collapse of this type can easily be identified on different portions along the western flank of the Range, especially near Sabarkum peak. High relief at the south of Sandakphu is also the consequence of collapse and sliding of rockmasses from the peak area.

In general the covering rocks of the Range are hard metamorphic types such as gneiss, migmatite and milonite which are intruded elsewhere by hard igneous rock granite. This is why the mountain has withstood all denudation processes for many geological ages. But the rate of denudation is not same in all parts – minimum on the summit level as cool climatic conditions permit little chemical weathering along with the process of fluvial erosion. On the contrary the rate of chemical weathering and erosion (both corration and cavitation) is found maximum in low altitudinal zones where higher temperatures prevail in surfacial layer of atmosphere as well as top layers of rock strata.

This is why maximum values of relative relief and dissection index are found below 2100m – along the mid-Rammam valley and adjacent dales of Siri khola and Lodhoma khola.

The structure of rock strata and the rocks composed in them exhibit significant control on the development of landforms in the mountain understudy. Nevertheless they are mostly innate and unique in their responsive character and distribution, depending upon endogenetic processes (including the process of rock cycle) acting in between them. Exogenetic processes modify their shape and produce different types of topography each of which bears the genetic imprints of parental body after coding with weather elements.

7.3. Development of Slopes and their significance

Slope is the most important feature of a landform. It is a geometric representation of surface configuration of any part of the terrain which is developed by deep interaction of two or more geomorphic agents – one of them being at least activated by endogenetic force. The Range and riges of the Southern Singalila, as discussed in chapter-1.3, have originated from tectonic movement at their initial stage – first by upwarping, folding and faulting of mountain masses. Thereafter exogenetic processes start to modify them. First order slopes, developed solely by tectonic activity, are rare on Singalila Range; whereas second order slopes, modified by denudation processes, are found around the topmost parts of the Range like Sandakphu and Tonglu peaks. The slopes descending in south of Sandakphu peak are highly formidable - more than 65° at several points. This side reveals the frontal part of nappe with brittle structure. Whereas slopes towards north of the peak are gentle enough - not exceeding 35° at any point. Slopes of the latter side follow dip of the strata showing little effects of erosional processes.

The slopes of Tonglu peak are, however, show high gradient in all of its scarp faces – ranging from 25° to 45°. It may be considered as a typical ‘Hogback’ – very similar structural form found in Tiger hill, 10km SSE of Darjiling town. Headward erosion of the river Chhota Rangit has been directed towards the peak in recent ages. Consequently the gradient of south-eastern face of that peak is increasing rapidly.

Slopes of third or, even higher order are produced by combined actions of degradation and aggradation processes acting on a landmass which is affected frequently by tectonic movements. Major parts of the Range, except the summit section, exhibit such types of landscape. Planation surfaces and associated slopes lying in mid-altitudinal belt (between 2350m and 2600m) generally show third order – firstly by tectonic upheaval, secondly by glacial erosion, and lastly by the modification of fluvial processes running at present.

Gradient of landscape is gentle for such surfaces – less than 10o along with slightly steep up and downslopes – ranging from 10° to 15°.

Fourth order (or higher) slopes can be noticed below 2100m. This section has always been sculptured by fluvial processes but with varying intensity – the intensity magnifies just after each upliftment of the region. Enhanced potential energy restored by such elevation is used in quicker action of corrasion especially along the central portion of the valleys leaving terraces on their both sides as relics of older valley-floors. Most parts of these terraces are resistant to annual recession (either by regular mass wasting or by erosion) because they are defended by buttresses of hard bedrocks. Very old terraces are, however, worn away with the passage of time by different types of denudation processes. Several segments of them lying on weaker structures (points of intersecting fault planes, planes of unconformity, end part of thrust, etc) are diminished in a shorter period. Deep glen of Pathey khola represents the best example of such features where traces of terraces can hardly be noticed. Gradient of valley walls of this stream exceeds 55° at many sections.

Scarps with high gradient are also found at Rajabhir- lower Daragaon section (along the Rammam valley) and west of Gurdum village (towards the Gurdum khola). The awesome scarps (gradient ranging from 45° to 50°) developed in the first case are the result of neo-tectonic upliftment of the section with surprising rapidity – around 20mm per annum! While the scarp looking over the Gurdum khola is a typical fault-line scarp caused by a high angled reverse fault cutting across the nose of Sandakphu ridge. The face is being retreated by continuous effect of the collapse of hanging masses lying on the upthrough side as well erosional work acting upon that portion. Inclination of fault plane initially was about 75° which can still be marked at its uppermost part stretching for 70m from the top (at the cremation ground). The steepness of the middle part showing vertical height of about 200m has, however, lessened slightly – around 60°. It is due to accumulation of eroded masses coming down from the top. While the lowermost part covering 150 m has a milder slope – less than 25°. Huge amount of debris being detached from the hanging wall has been heaped upon this part. Wasting masses from upper part are spread over them and make a gentle slanting slope on which terracing for agriculture is now a common practice.

Except some scarp-like portions (having high dissection indices) major landscape of the Southern Singalila Range and its ridges shows moderate to slightly steep slopes. Catchment area of the Rato khola exhibits the mean directional slope around 14°. The same for the catchment area of Siri khola is 11°, for Lodhoma khola 13°, and for Chhota Rangit 12°. Western flank of the main Range, extending from Phalut to Sabarkum, represents higher value of mean directional slope – 25°; while the latter part, from

Sabarkum to Thakum gets 18°. The southern flank extended below Tonglu peak slopes down at a mean angle of 20°, whereas the east-end scarp of Deorali danra shows slightly higher value – 22° . Mean directional slope of Upper Daragaon is also high – 18°, but the value for Samanden area is very low – 8°! The latter is nothing but a segmented part of the mid-altitudinal planation surface stated above.

Chapter 8 | Evolution of Drainage System on the Tract

8.1. Introduction

Water flowing in the course of a stream or river is subject to two main forces – gravity of the earth which acts in the downslope direction for moving the discharge; and friction of bedrocks which opposes downslope movement. When the first one superceeds the latter the discharge moves downward at an acceleration of ‘g sinα’, where ‘g’ is the acceleration due to gravity and ‘α’ is the angle of slope. As a result erotional activities of the flow start firstly with the process of deepening of the channel and later by the process of widening of the course. The ratio between deepening and widening of a drainage system, however, depends mostly upon the elevation of the tract – being greater over high mountains like the Southern Singalila Range.

Once a valley is established in a region the interstream areas along with the slope of the valley sides begin to play important roles in the degradational activities of the stream. The upper portions of the Singalila Range as well as its wide flanks are the source areas of three large river basins – the Rammam-Bari Rangit in the east, and Tamur and Kankai Khola in the west. The summit line of the Range acts as the principal water divide between the said basins.

The majority of local streams and rivulets of the region have originated in Early Holocene epoch: many of them being consequent following the gradient of the past glacial valleys; but some of them being obsequent due to tectonic instability of the terrane. The stream-heads and gullies are obviously guided by the latest faults and weather joints. The drainage systems thus developed over the region are of two types: Pinnate, to the north of Sandakphu and Joint trellis, from Sandakphu to Manibhanjyang. The landscape produced by the first type shows relatively rounded hills with gentler gradients; while the second type forms ridges with very steep slopes vulnerable to rapid denudation.

All the headstreams of the rivers lying in both sides of the Range are dependent primarily on rainfall as there are no permanent glaciers over the Range. Winter snows, however, provide a huge amount of water after their melting in spring time.

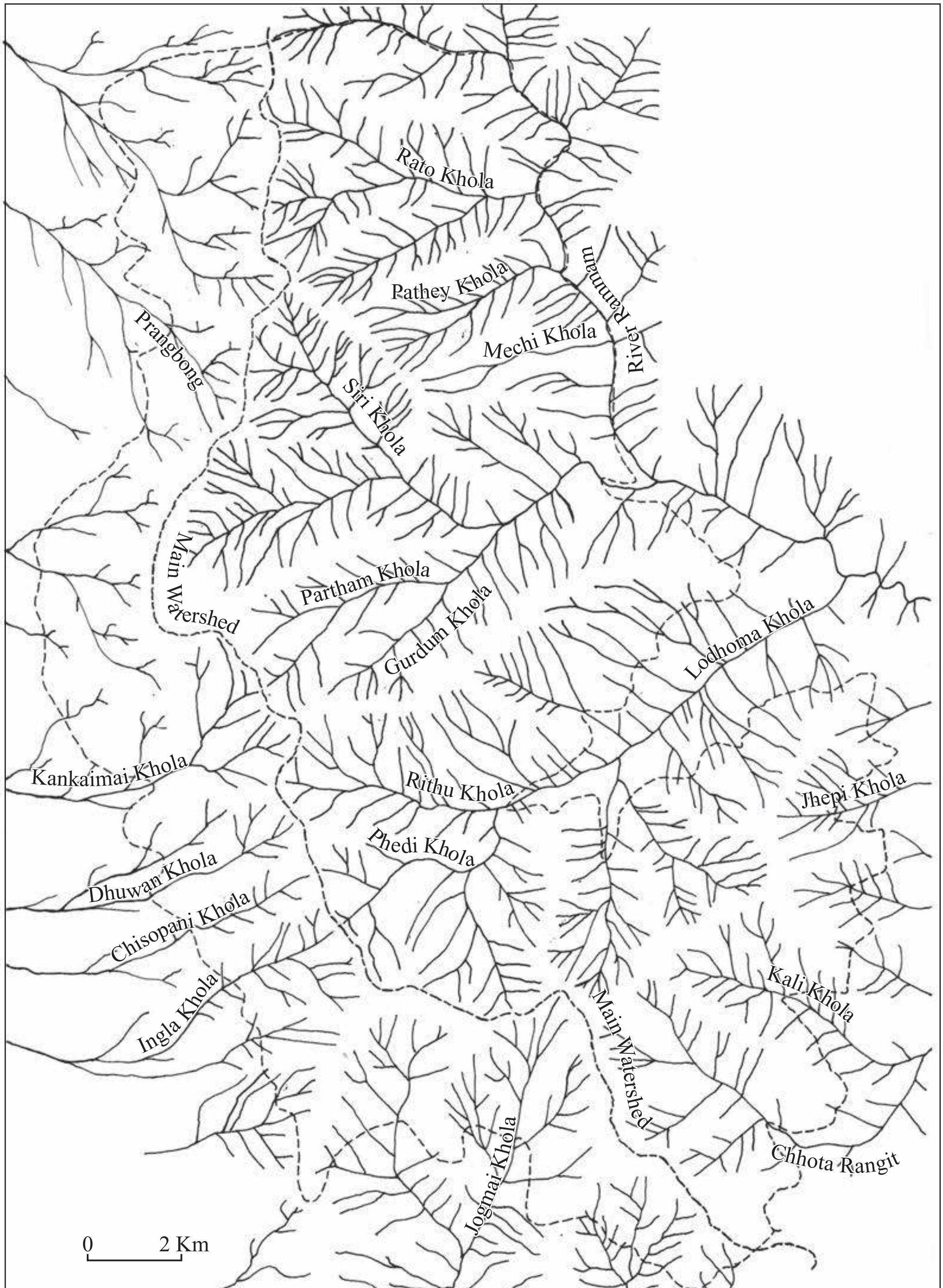
8.2. Drainage System developed on the Eastern Flank of the Range

The main headstream of the river Rammam (or Rangbong) originates from a small lake 'Mong doe' lying little north-east of Phalut peak at an altitude of 3400m and flows eastward for 7.5km along a narrow, boulder-strewn valley until it reaches the end-slope of the Kingsa danra, about 800m north of Gorkhey village(2200m). Here the stream turns its direction southward, passes by the settlements named Rammam and Daragaon, and changes its direction again eastward near Rajabhir.The length of the south-flowing section is 10.5km along which the stream descends abruptly from 2200m to 1300m through a series of rapids and cascades. The valley of the river is narrow still now, but its depth increases towards south. Near Rajabhir the stream meets with its largest tributary – the Siri Khola and becomes a fully-discharged river with a formidable gorge having a depth of more than 700m. Rapids tend to be diminished after this sectin, erosional activities weaken and boulder deposition starts. A dam has been constructed 1.5km east of Rajabhir for generation of Hydel power (in 1990's, capacity 35 megawatt). Alterating steps and pools are conspicuous features throughout the course of river bed until it reaches the dam.

After crossing the obstruction of man-made dam the river Rammam flows sluggishly across a wide valley floor showing braided channels caused by large accumulations of sand and pebble deposited on the floor. The course of the river is more sinuous, though the direction of the valley remains fixed at east. The cross profile of the valley widens rapidly after intermingling with another important tributary, the Lodhoma khola and the depth of the velley also decreases thereon. Near Jorethang the Rammam joins the Bari Rangit at an elevation of 450m. The length of the last section, i.e. from Rajabhir to Jorethang is 24km. The valley of Rammam has entirely been set up along the Main Central Thrust, and hence it can be regarded as the oldest drainage system in the region under study. The terraces formed along the valley are relatively stable and almost horizontal - very much noticeable in between Rajabhir and Goke (a village lying little west of Jorethang). The width of the terraces, however, varies widely – exceeding 200m at Samanden and Goke. From source to Rammam village the gradient of the river-bed is very steep - 1 in 9.4. The steepness increases more in the next stretch extended from Rammam to Rajavir – 1 in 6.5, but falls abruptly in the last segment, from Rimbick to Jorethang – 1 in 41.0.

The stream Rato khola is the first right-hand tributary of the river Rammam. It started to set its valley after the retreat of last glaciers from the region. The stream follows an elongated depression guided by a prominent fault-line which had developed on the

Streams and Rivers: Southern Singalila Range



eastern side of the Range most probably in Oligocene epoch as a shoving effect of the Main Central Thrust. The depression is confined by the Kingsa danra in its north and by the Molley danra in the south, runs for about 6.5km, and terminates at Gorkhey. All four headstreams of the Rato khola start their journey from large hollows created both by chemical weathering and corrosion. The hollows are located at the base of the main watershed connecting Phalut and Sabarkum peaks the elevations of which vary from 3450m to 3400m. After merger of shallow channels of all the headstreams the main stream descends abruptly through a densely forest-clad, deep, swampy glen with bed clogged with reddish clays. Last 1.5km of the Rato khola shows little gradient as it reaches to the local base level, i.e. the valley floor of the master river Rammam. The said portion also exhibit narrow terraces genetically which are 'ingrown' type.

There are two small streams developing their valleys confluence points of which lie in between Samanden and Rammam villages. The first one, Pothay khola, descends from the southern slope of the Molley danra at an elevation of 3350m cutting a very deep but narrow ravine within a distance of merely 4.5km. After reaching at 2300m gradient of the flow becomes gentler and runs further 1.5km before plunging into the master river. The second stream, the Mechi khola, emanates from the northern slope of the Sabarkum danra at an altitude of 3200m. It then descends rapidly through a series of cascades, excavates a deep glen, and ultimately debouches into the master river after traversing a very short distance of 4km. Both the streams are very young in age (late Holocene) and their valley bottoms are deposited only by boulders with no prominent terraces along the valley sides.

All ravines and rivulets originated on the great arcuate slope lying on the eastern flank of the Singalila Range and confined between the Sabarkum danra in the north and Rimbick danra in the south discharge into a single large stream – Siri khola which itself is the largest tributary of the whole Rammam drainage system. The origin and morphology of the 'khola' will be depicted in details later (in chapter- 11).

The headstreams coming down from the north-eastern slopes of the main Range lying in between Bikhebhanjyang and Tumling are principal feeders of the Lodhoma khola. The valley of this stream is bounded by Rimbick danra in the north and by Deorali danra in the south – running almost parallel to each other. Thus the basin of Lodhoma khola gets a trapizoidal shape – the fourth and lowermost side (860m at the confluence point) resting upon the master river Rammam. Among the three topmost tributaries of the Lodhoma Rithu khola may be considered as the first one. It rises on the slope of Bikhebhanjyang at an altitude of 3150m, flows through a boulder-strewn ravine (5.5km) manifested with numerous large cascades and joins the second tributary near phedigaon. Mean gradient of the stream is 1: 21.The glen of the latter, Phedi khola (extended from

Gahribans to Phedigaon), is, however, open type showing insignificant cascades throughout its length (5km) as well as lesser gradient – 1:14 .

After Phedigaon the drainage system takes its well known name, the Lodhoma khola, which runs through an astonishingly open strath adorned with terraces of different ages – from early Quarternary to recent. Several large springs and innumerable rivulets descend from the bounding ridges and increase the volume of discharge manifold in the main channel. Monggong Khola is the most important among them causing a plight for local people by its destructive flow during the heavy monsoon showers. Lower part of the Lodhoma khola (after Lodhoma Poloce station) exposes Permian strata along its valley walls, while the immature terraces on the valley bottom indicates the rejuvenated action of the stream after neo-tectonic upliftment of the area.

The Chhota (little) Rangit is the last right-hand tributary of the Rammam-Bari Rangit drainage system. It shows its source on south-eastern slope of Tonglu peak at an altitude of 2900m. The rivulet then descends abruptly into the main valley near Majhua showing an impressive gradient of 1:21. According to geological age the valley stretching downward from the said village is very old and has been set up along a major fault, the Boundary fault, occurred in Miocene epoch (as stated in chapter-2). Terraces extended on the both sides of the valley also depict the series of tectonic episodes – from Pliocene to Holocene ages. There is a large alluvial fan at the confluence point of the rivers Chhota and Baro Rangit. Most of its constituent deposits are of Holocene age.

8.3. Drainage System developed on the Western Flank of the Range

There are innumerable gullies and rivulets originating from the slopes lying in between Phalut and Sandakphu. All these feed a small river Prangbong which itself is a tributary of Hinwa Khola. The main two headstreams of Prangbong descend from the western slopes of Sabarkum peak – the northern one is more vigorous and is extending its length by headward erosion on the western part of the peak proper. The gradient of this rivulet is very high – 1: 2 for its first stretch, bed is boulder-strewn and manifested with slender but high cascades. The second headstream rises 3km south of it which shows a wider glen with gentler gradient – channel bed being deposited by dilluvial materials. All these streams originate in the area consisting of badly weathered rockmasses, the rate of downcutting is exceedingly high.

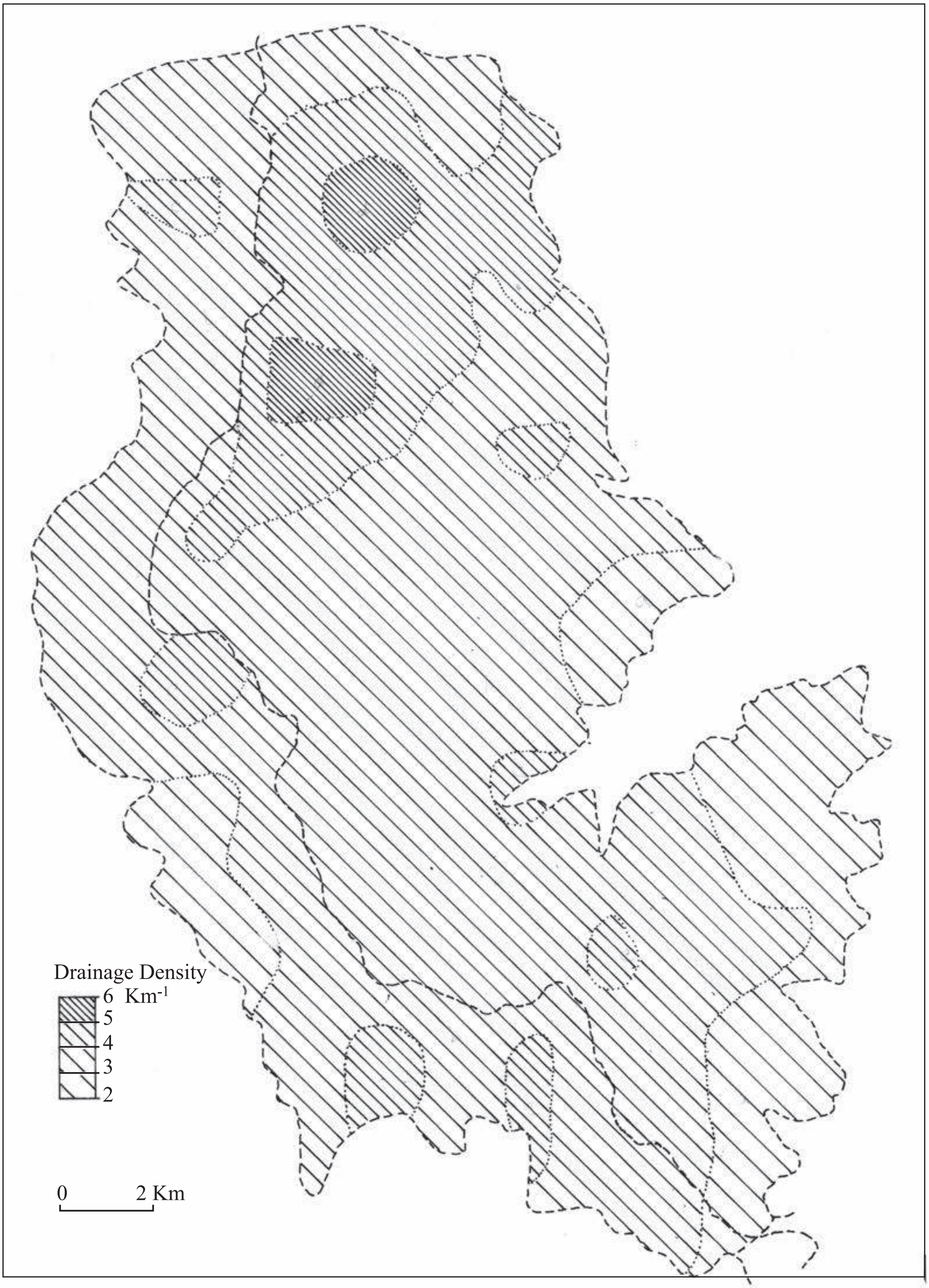
The arcuate slope lying in the south of Sandakphu which is confined by Lali danra in its south is the catchment area of a small stream Kankaimai khola. It also shows a tremendous gradient for its first stretch of 2.5km – 1:2. The channel bed is characterized by huge deposition of boulders as well as minute fragments of pebble and finer sandgrain. Since it flows along a fault of neo-tectonic origin, the process of valley deepening is astonishingly high – more than 20cm/yr below Bikhebhanjyang.

Dhuwan khola and Chisopani khola emanate from the springs situated below Batasi and Kayakatta respectively (altitudes around 3000m). Both of these torrents do not show any unique chateristic along their channels except high gradient and dilluvial depositions at their bases.

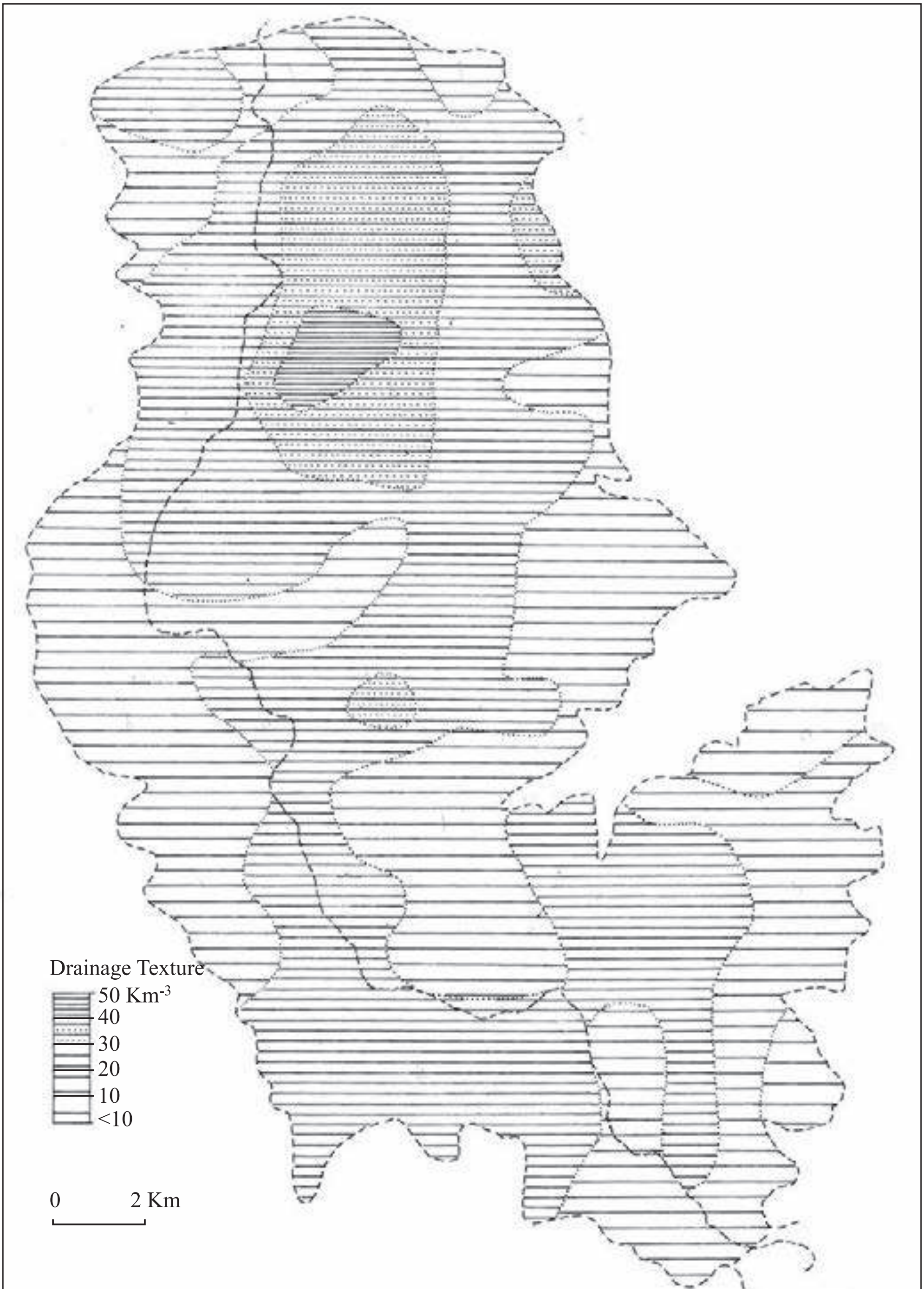
Ingla khola is an important stream in Ilam district of Nepal. The source of its main headstream lies to the west of Gahribas at an elevation of 2600m. The valley of the stream is wide (more than 500m near Nanthala, just 3.5km from its source) and well-terraced on both sides. The earliest depositions of its uppermost terrace date back to mid- Pleistocene epoch.

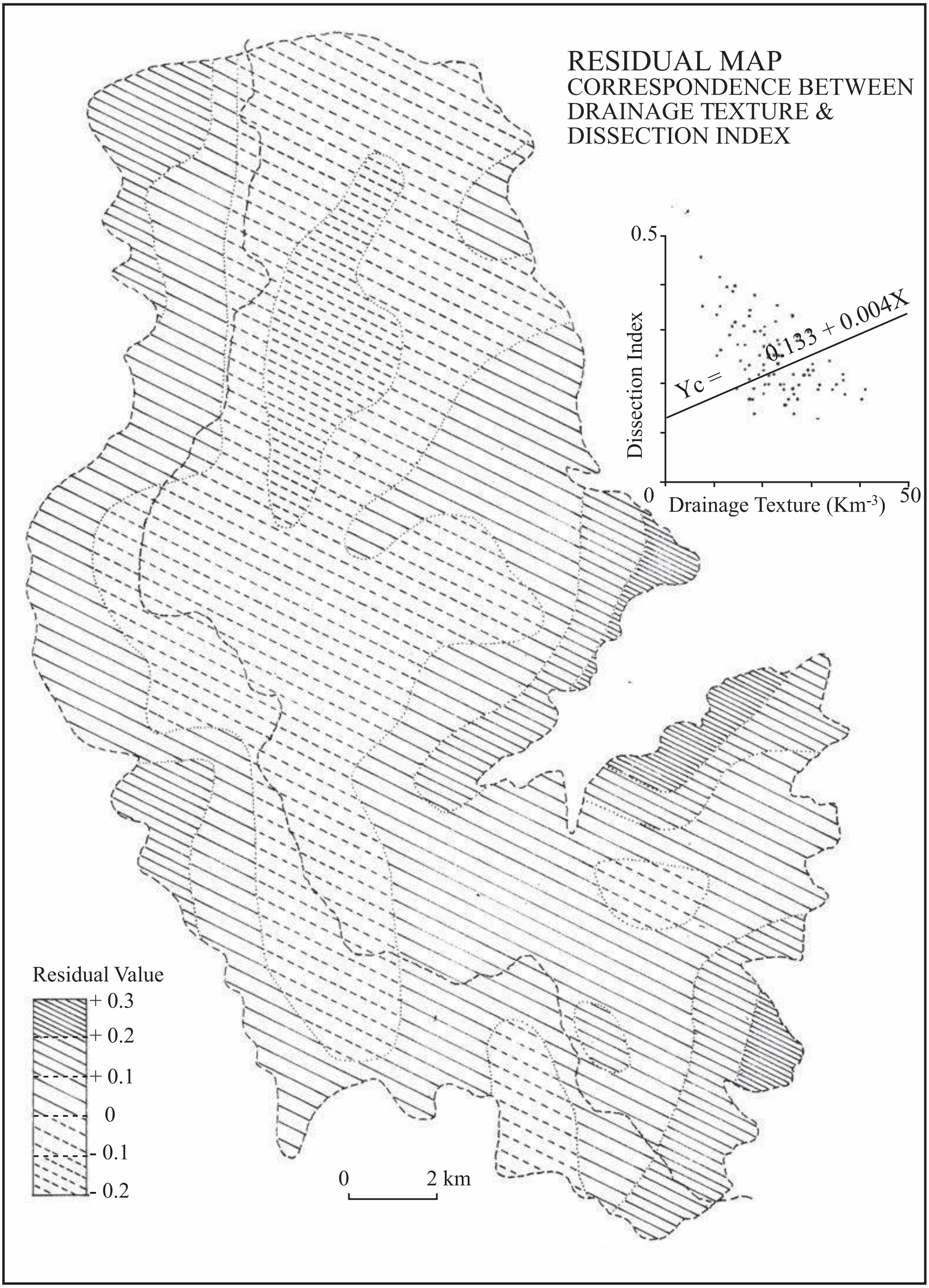
The southern slopes of the Range lying in between Jaubari and Gurans, and the western slopes extending from Gurans to Manebhanjyang emanate innumerable springs and jhoras which ultimately feed the drainage system of Jogmai Khola. It has a large picturesque basin with a well-established dendritic pattern of its own. The headstream of this stream lies on the western shoulder of Tonglu peak (at 2950m). Thence it descends rapidly through a ravinous gorge and collects many spring-waters lying below Gurans and Tumling – some of them issuing reddish flows owing to the presence of ferraginous materials in badly weathered rocks and regoliths covering the area. The stream Jogmai Khola is the largest tributary of the southflowing river Debmai or Kankai Khola which is an important river of the south-eastern Nepal.

Drainage Density: Southern Singalila Range



Drainage Texture: Southern Singalila Range





RESIDUAL MAP
CORRESPONDENCE BETWEEN DRAINAGE TEXTURE & DISSECTION INDEX
0.5
Dissection Index
Yc = 0.133 + 0.004X
0
Drainage Texture (Km-3)
50
Residual Value
+ 0.3
+ 0.2
+ 0.1
0
- 0.1
- 0.2
0
2 km

Chapter 9 | Hazards : The Accelerators of Topographic Modification

9.1. Introduction

Our planet earth has already passed 4.5 billion years and faced many devastative phenomena which altered the surface configuration spectacularly within a very short period. That natural events caused a lot of threat to living organisms, even to Homo sapiens after its arrival on the planet. These phenomena are termed as 'Hazards' considering their destructive impact on mankind. They are just like denudational processes, but the speed in their activies is very rapid causing immense change in surfacial landscape. Thus they act as the accelarators of topographic modification. After the beginning of human civilization many activities of man has also created hazard-like effects on the earth's surface which have reached to him in adverse condition too.

Hazards are henceforth defined as 'phenomena that pose a threat to people, structures or economic assets and which may cause an overall destruction. They could be either manmade or naturally occurring in our environment'.

The natural hazards occurring on the Southern Singalila Range may be grouped into four main categories – Tectonic, Meteorological, Geomorphological and Anthropological. All these types of hazard along with their impact on topography are described briefly in the next paragraphs.

9.2. Tectonic Hazards

i. Earthquake:

The location of the Singalila Range on the plate margin causes it susceptible to earthquake (bhuichalo in Nepali) with high intensities. According to seismological mapping the region belongs to fourth quake zone though the mountain itself or its sub-layers has never been the epicentre of a violent quake during the recorded times. The terrane has of course been shaken many times by the tremors originated in its neighbouring areas. The most destructive amongst them occurred on 15th January, 1934 (magnitude around 7 on Richter-scale), whose epicentre was situated at Bihar-Nepal border, 200km away from the area. Large landslides and rockslides were found all along the Range after that oscillation. Another violent earthquake has occurred in very recent time – in North Sikkim (7.2 on Richter-scale) on 18th September, 2011 resulting in widespread landslips and slumps along the steep slopes of the ridges.

Besides that two violent earthquakes, the study area was shaken for many times. The shocks experienced in the region as well as whole Darjiling Himalaya have been recorded since 1842. During the same decade two simultaneous shocks were felt 27th and 28th February in 1849. A tremendous vibration was observed during the Shillong quake (more than 8 on Richter-scale, estimated) on 12th June, 1897. Several mild shocks were also felt during the Dhubri quake (6.5 on Richter-scale) on the 3rd July, 1930. The tremor with high intensity (8.4 on Richter-scale) was felt again in the evening of 15th August, 1950 the epicentre of which was located near the International boundary of Arunachal Pradesh (then NEFT, North-East Frontier Tract). The destruction of course, was not so much widespread in those cases because the seismic waves were largely diffracted by the deep thrust boundaries lying around the mountain.

Including civic loss, rockslides, slumps and other means of mass wasting are the immediate consequences of any earthquake, either being strong or weak in intensity. For instance, the tremor of 14th February, 2006 showed magnitude of medium type - only 5.7 on Richter-scale, but the amount of destruction could not be ignored due to its close proximity of its epicentre - just north to the Rammam Valley. New slide zones were opened up along Kingsa danra and on the slopes extended below Danragaon by that shock. Large fractures were also observed in many village buildings after that event. The Gangtok earthquake of 19th November, 1980 (5.9 on Richter-scale) also affected the tract by opening some slide zones, especially along the Rimbick danra. The East Bhutan earthquake of 20th September, 2009 (6.3 on Richter-scale), however, left the region almost unaffected.

The last physical alterations, though not in large scale, experienced here after the Lamjung earthquake (8.1 on Richter-scale) occurring on 25th April 2015. Sliding of rocks and debris were noticed all along the slopes lying to the west of the mountain. The natural process of landscaping was continued by its aftershocks for more than a month. Spectacular change was caused by the Mirik tremor on 27th April 2015 though the magnitude of it was not so high – only 5.1 on Richter-scale. It accelerated the processes of mass wasting in many parts of the southern section of the Range, i.e. on the Rimbick danra, Lali danra and along the slopes of the main Range from Kalipokhri to Manebhanjyang fortunately without loss of civic lives. Jeep routes across the ridges were broken at many places and old slide-zones were reactivated obliterating large segments of foot-tracks. Locations of perennial springs were also shifted, either toward up or down slopes, by that tremor.

ii. Changes In Water Table:

The neo-tectonic movements as well as climatic changes in the region affect greatly the water tables inside its rock strata. The compressed and crumpled granite-gneissic structure (which is itself an impermeable stratum) obstructs the infiltration of water downward. Consequently the topmost layers, which receive ample water, either from rains or from melting of snow, remain well-saturated throughout the year. The sacred lake of Kalipokhri and the swamps lying at the heads of the Siri khola and Rato khola never dry up due to the same reason.

The Thrust-planes in the Range act as the main source of jhoras because each of them issues a series of springs with perennial water flows. They freeze only in winter months when day temperature remains below 0°C. On account of gravity collapse or upwarping of strata in between a pair of Thrust planes the position of water tables often changes. The springs emanating from such changing tables remain active for some years and become dry in later period. A good example of such fluctuations in water table can easily be identified just below the Sandakphu peak. The flow of the main spring issued from south-eastern face of the summit (about 15m below the top level) which is the principal source of drinking water has been waning for the last two decades, while the second one lying below the PWD bungalow has been showing a very thin and intermittent flow since 1999.

The Kalipokhri area lying south-east of Sandakphu is one of the largest depressions over the Southern Singalila Range. It is located at the sharp bend of the main thrusted block where the direction of tectonic forces is diverted. The depression consists of two parallel sags of which the lowermost one has formed a picturesque lake with deep black water. The area of the lake is, however, shrinking in recent years. The overfolding of rock structures on both sides of the depression associated with crustal shortening is causing its reduction in size. The sagging part lying south-east of the lake is, however, situated at higher elevation (12m above the waterbody of the lake) and remains dry throughout the year. It is also being narrower and deeper day by day. The mouth of a long cave extended from westernmost corner of that furrow has been closed recently by subsidence of roof-top boulders on account of squeezing of strata progressing here silently but steadily.

The Chandupokhri, located near Thakum (6.5km from Sandakphu), has desiccated since the early years of the 21st century. Downward shifting of the water table below the lake area coupled with huge mass wasting from surrounding mounds has chocked the basin completely though it was the largest lake along the summit line till 2000. The bed of the lake is left completely dry in dry periods.

The depth of the water-logged shallow depressions found across the Chitrey danra are, of course, reducing rapidly due to various anthropogenic factors (particularly due to the construction of roads and houses). These were the natural habitats of an endangered species of salamander where they are now found rarely.

The alignment of springs around Tonglu and Kaiyakatta is also shifting downward. The water tables situated below Shikhargaon and Jaubari are almost waning in moisture-content because of indiscriminate clearing of forest woods around the villages. On the contrary the condition of the wet strata has remained unchanged in the catchment areas of the Siri khola during the observed period. Tectonically this portion is relatively stable in respect to other areas of the Range and, consequently it is less affected by the neo-tectonic movements. Moreover the said portion is densely wooded – showing little imprint of human activities.

9.3. Meteorological Hazards

i. Storms And Thunders:

The shape of the Singalila Range is unique as it stands as a long and narrow sinuous wall reaching high above the valley-floors (altidunal differences often exceed 2000m) lying on its both sides. Hence it is obvious that the mountain always faces extreme push and jab effects of the low to mid-altitude tropospheric disturbances. Some of the disturbances are closely related to the upper tropospheric Jet streams blowing over the Great Himalaya, while the others are produced by the branches of the South-West Monsoon flowing by the sides of the Range through lower part of troposphere.

The common hazards experienced in the region are violent storms coming from a particular direction in a particular season. Most of the storms of winter and spring times are originated from the downthrust effect of the Jet stream. They come generally from the north and blow as blizzards across the mountain with chill and biting effects on living organisms – both floras and faunas. The speed of the gales frequently exceeds 100 km/ hour. They shove tremendously upon the bare crags causing rapid mechanical weathering and sweep away all the loose materials from the rock pinnacles. The storms during the monsoonal months are, however, milder in nature. They blow from any direction except the north and their speed seldom goes up to 80 km/ hour. Hailstorms are originated locally in spring-time. They help to make the arable lands wet and are thus beneficial to the farmers. They are known as 'ola' in Nepali and 'oshino' in Tibetan.

The summit section of the mountain experiences heavy lightening during the monsoonal months. Since the altitude of this part varies from 2900m to 3600m, it occasionally falls between the two layers of cumulous clouds and evidently is electrified. The immediate effect of the lightening is forest fire, in a limited or an extended scale, in the coniferous forests across the tract. The event of such flaggration may sometimes turn into devastation. All the fir forests stretching from Sabarkum to Thakum were severely damaged by the forest fire occurred in 1992. Dry, charred fir woods with unnatural figures are still found in the area which remind of that fierce event.

The fire in the coniferous forests may also be broken due to rubbing of tree-branches during high wind and producing glows which are spread quickly in surrounding trees. No extinguishing measures or techniques have yet been established in this area. It is rather a common phenomenon in pre-monsoon period. Such type of forest fire starts generally with thunder and a devastating effect in the forest is broken out rapidly. The last significant forest fire broke out above the Gurdum village in 1999 by which a fir forest of most than one square kilometre was destroyed completely.

ii. Excessive Precipitation:

Heavy downpour during the monsoonal months is a typical meteorological hazard occurring in the terrain, which affects badly on the weathered slopes of the Range. 20cm of downpour within 24 hours is not uncommon in this area. On the contrary heavy snowfall is another hazard getting in winter months. The rock surface over the mountain is occasionally covered with more than 50cm of snow at a single spell. The effect of snowfall is clearly seen after its melting in the following sunny days. It accelarates chemical weathering in the rock masses along with solifluction on the hill slopes, feeds the torrents, brings cold waves over the summit levels sometimes causing live-loss and stops the transport system for several days over the peaks.[1] The trek-paths descending from the Peaks are severely damaged after the snowmelts. These tracks are negotiated cautiously even in late winter days when the winter snows are thickened into hard neve and become slippery to go across them.

iii. Flood and Drought Problems:

Because of disbalanced hydrological cycle prevailing over the Range, its different parts experience simultaneously the flood and drought conditions for each year. Generally the upper parts of the mountain covered with stunted vegetation show dryness especially in the premonsoon months. In the early spring, however, these parts become moist with innumerable jhoras due to the melting of the winter snows. The alignment of jhoras is generally found to be related with the gully formation. Consequently they often disappear and reappear with the changing pattern of the gullies. For instance, in the catchment area of the Rato khola some jhoras disappeared along the contour strip of 3000-3400 metres during the late 1990's, but have reappeared in recent years due to reactivation of the former gullies.

The flood problem is obviously a prominent feature in the lower parts of the mountain especially along the river valleys during the monsoon period. The torrents carry heavy loads of dilluvial materials along with large boulders and deposit them at the breaks of slope. The profile is thus modified each year after the inundation. Excessive rainfall at a single spell often causes flash floods (bhal in Nepali) in the lower valley sections. Such devastation happened in September, 1999 when incessant downpour occurred through a whole week. The amount of discharge of the streams particularly on the eastern side of the Range began to increase at an accelerated rate from the very first to fifth days. It increased their transportation capacity hundreds of times and accumulation of pebbles and boulders disturbed their longitudinal profiles even making series of unstable dams in many cases. On the sixth and seventh days those dams started to break one by one (from top-level to lowermost section of each stream) resulting immediate floods in the downvalley areas. Shifting of channels was noticed at some places, level of water rose more than 10m above the normal river beds, and quick recession of river banks (at the concave parts which receive maximum shove of hydraulic pressure) was continued for several days even after the stoppage of that shower. Some houses collapsed along the slope of valley-side, especially near Sepi.

9.4. Geomorphic Hazards

i. Gully Erosion:

Gully erosion is, in the study area, the most important geomorphic hazard. The main affected parts are obviously the summit levels and their steep sides. The gullies are nothing but extensions of the headstreams of any local drainage system. Thus the gullies above the Sandakphu khola, Pratham khola and Konkaimai khola are steepening the hill slopes as well as are affecting the International boundary running along the main water parting. The headstreams of the Rithu khola are also affecting the eastern slope of Kayakatta-Batasi ridge severely. As a consequence of this gully action the easier approach-road to Sandakphu, once proposed to climb directly from Phedigaon located in Upper Lodhoma valley was abandoned.

The overgrazing of bovine animals, especially of Dzoes (aroused from male Yak and Cow) aggravates the condition of some gully heads. Examples of such 'geomorphic plight' are found extensively in the meadows spread over the mountain slope lying in between Sabarkum and Thakum.

ii. Rockslides And Boulder Deposition:

Rockslides form one of the most rapid land instability events. They are generally restricted to deforested steep hill slopes and vertical cliffs. Generally the vertical cliffs are continuously maintained by slipping of screes and the height of a cliff is continuously reduced by the deposition of materials at its base. The concave slope developed by the deposition becomes longer and ultimately its uppermost segment reaches to the appex of the sliding point. Finally the cliff is modified into a gently sloping talus. The northern part of Sandakphu peak, especially along the Sandakphu khola shows such modified profile due to rock sliding process for prolonged period.

The deposition of boulder also displays an important role in the changing profile of a hill slope like the first stretch of the Rimbik Danra looming towards the Gurdum khola. Since the area is composed of hard gneissic rocks, the mechanical weathering over the ridge-top results in huge boulders and pebbles; while small rock fragments are rarely visible except in the valley bottom of the said stream. With the passage of time the deposition of boulders and large pebbles heightens the section of the breaking slopes. Ultimately the undulating profile becomes smoother and an open concave slope is set up. This type of concave profile has nicely been developed in the headstream of Kankaimai khola originating below Bikhebhanjyang.

iii. Landslides And Landslips:

The main causes of regular landslide (pairo in Nepali) and landslip in the area under study are instability of rock structure and excessive attack of rainwater (in monsoon months) upon them. Since the entire process of sliding masses, either being rocks or being loose debris, is solely guided by the gravitational force, the gradient of a hill slope plays the most important role in the movement of materials.The velocity of the sliding mass, on the contrary, depends upon the sine component of the plane of movement. Thus the velocity (along with momentum and carrying capacity of masses) enhances rapidly with the increase in gradient of land surface. As the maximum slope is found over the Range along its contour strip between 2600m to 2800m, the maximum landslide and landslip occur in this altitudinal range. Two huge slide-prone sections are, however, found between Bikhebhanjyang and Sandakphu. They are of course guided by local faults. The fault scarps lying to the north and west of Jaubari, and the same to the east of Gumbadanra are also infamous for regular landslide and slipes. The high and steep fault-line scarp above Gurdum village provides a fair example of slope retreating process by continuous landslipping.

Besides the faulting (along with large rupturing) slides of landmasses may happen by crumpling and subsidence of rock layers, vibration in strata by earth's tremor or storms with high velocity, seepage of rainwater through the underlying fractures of large rockmasses, and above all by natural processes of weathering. Some large landslides occurring over the tract, recorded by the author, are listed below:

Sliding Area	Year	Genesis	Damaging aspects
i) Kaiyakatta-Batasi	1997	Subsidence	Forest trees
ii) Jaubari	1999	Seepage of rainwater	Forest trees.
iii) Lingsaybong	1999	Seepage of rainwater	Cropping fields & huts
iv) Upper Siri khola	2001	Subsidence	Forest trees & Treak Path
v) Rajavir	2008	Subsidence	Cropping fields & huts
vi) Lekh kharka	2006	Subsidence	Cropping fields
vii) Mushay pakha	2009	Subsidence	Cropping fields
viii) Tonglu-south	2009	Subsidence	Forest trees.
ix) Lower Siri khola village	2008	Seepage of rainwater	Cropping fields & Treak Path
x) Jawleygaon	2013	Subsidence	Buildings & Roads

iv. Debris Avalanches and Soil Slump:

Debris avalanches are common features across the lower part of any gully. This is not always a primary type of geomorphic hazards (generally the result of the gully erosion and landslip), but plays an important role in changing landscape of any area. The steep south-western phase of Sandakphu is the best example of this type of geomorphic process. The sagging part of the Rimbick Danra after the subsidiary peak beyond Bikhebhanjyang also exhibits some huge accumulation of debris avalanches as well as soil slumps which ultimately results in landslips over the headstreams of the Rithu khola.

The velocity of mass going through avalanche or slump often exceeds 100m/sec depending upon the nature of flowing material (more loose, more velocity) and the height of fall along with the gradient of the falling plane. On a perpendicular fall, the velocity obviously guided by the equation '$v^2=2gh$', where 'g' =acceleration due to gravity and 'h' = the height of fall.

Besides the two main areas exhibiting Debris avalanches and soil slumps in regular manner other vulnerable sites across the Range are enumerated below:

Affecting area	Genesis
i) Lower Daragaon	Soil slump
ii) Lamedhura	Soil slump
iii) Sabarkum-west	Debris avalanche
iv) Upper Siri khola village	Debris avalanche
v) Guranse village	Soil slump
vi) Kalipokhri-south	Soil slump
vii) Bikhebhanjyang	Debris avalanche
viii) Hagetham	Soil slump

9.5. Anthropogenic Hazards

Although affecting smaller in areas the anthropogenic factors are not negligible to make distressing incidents on the Southern Singalila Range.The main factors creating the hazardous effects are the following:

a. Improper land use,
b. Rapid spread of hamlets,

c. Extension of roadways and increase in number of vehicles.
d. Unplanned growth of homestays and hotels,
e. Huge influx of happy but unaware tourists, etc.

Improper land use, especially extension of arable lands over steep hill slope is the main anthropogenic factor for opening new slide zones in different parts of the Range. Both sides of the Rimbik danra, for instance, have badly been affected by enormous terrace cultivation since 1980's. But no restriction has yet been imposed by local authorities. Thick pasturing of yaks and dzoes near the summit level and that of cows along mid-altituinal belts also causes heavy soil loss and acceleration of other types of mass wasting. The mountain slopes in and around Kalipokhri area show the best example of such destructive process. The retreat of Snow leopard from the forests of South Singalila Range and the decrease in number of other carnivorous animal lairing in the forests in recent years have caused in rising number of wild boars. These ungulate animals dig soils on the hill slope with their tusks for searching bulbous roots. This behaviour obviously accelerates the process of mass wastng along that portion.

Rapid growth of population over the tract has enhanced number of new settlements during the last three decades. For construction of these settlements and for providing fuel wood, some sections of the Singalila National Park have been cleared. The Nepal side of the mountain is now almost devoid of large trees due to the same reason. The pressure of these settlements not only allows the sliding as well as slumping processes over the mountain surface but also affects the perennial nature of water tables. This event is reducing the flows and number of local springs and jhoras.

Extention of roadways is essential for over all development of the region under study. But the right method should be followed in their construction. Optimum width of the roads and necessary detouring in their extention are two important factors ought to be maintained so that structure of natural hill slope is least disturbed. Ply of heavy vehicles is very dangerous for mountain roads as they eke out the possibility of breakage in road set up on fragile topography.

Many new homestays have been grown in different parts of the Range during last two decades. These cause huge loss in forest resource. Large number of tourists comes to famous view points located on the terrain each year merely to enjoy the scenic beauty. They ignore all perceptions regarding the mountain environment, leave their garbages (including plastic materials!) here and there, collect samples of rare specimen, and above all make threatened their lives too by consuming alchoholic drinks excessively.

9.6. Hazard Mitigation

The geo-environmental hazards described above cause a huge economic loss as well as some civic loss too. Since the area is far away from the administrative center on both sides of the International boundary, the modern techniques for controlling these hazards are yet to be applied. Thus the mitigation measurements in this area are always depends on hereditary skill and perception of the hill people. There are certain numbers of hazards, which cannot be checked completely; but undoubtedly their risk intensity may be reduced considerably by adopting advanced knowledge of environmental sciences and the efficiency in preparedness. Every individual hazard may be analyzed in relation to its most effective controlling technique. The measures applied by the local people may be arranged according to the intensity of any hazard.

The perception of the 'sons of soil' regarding the mitigation of hazard is now increasing to some extent. This is a very encouraging response for the settlers as well as for the entire ecology of the mountain. The success of individual efforts to check the deforestation is now being responded by the young people though they cannot find any alternative for the fuel woods. The success of collective efforts to control the hazards related mass wasting is also responded by almost all people. They try to help in reconstruction of the roads affected by any hazard and try to propagate the news of any such disaster all over the region by rapid relay system.

1. Three yak herders – a father and his two young sons died in January, 2016 on the Goth (pastureland), little south-west of Sabarkum peak on account of severe blow of chill northerly winds for some days continuously. The herd of their yaks, of course, went back to their village.

We can think of environment as a machine which we need to control. However, such control can be achieved only if we fully understand how the geomorphological machine works.

Edward Derbyshire, 1979

Part III
Case Study

The hills are shadows, and they flow
From form to form, and nothing stands;
They melt like mist, the solid lands,
Like clouds they shape themselves and go.

In Memoriam - Alfred Lord Tennyson

Chapter 10 | Physiographic Uniqueness of Sandakphu Peak Area

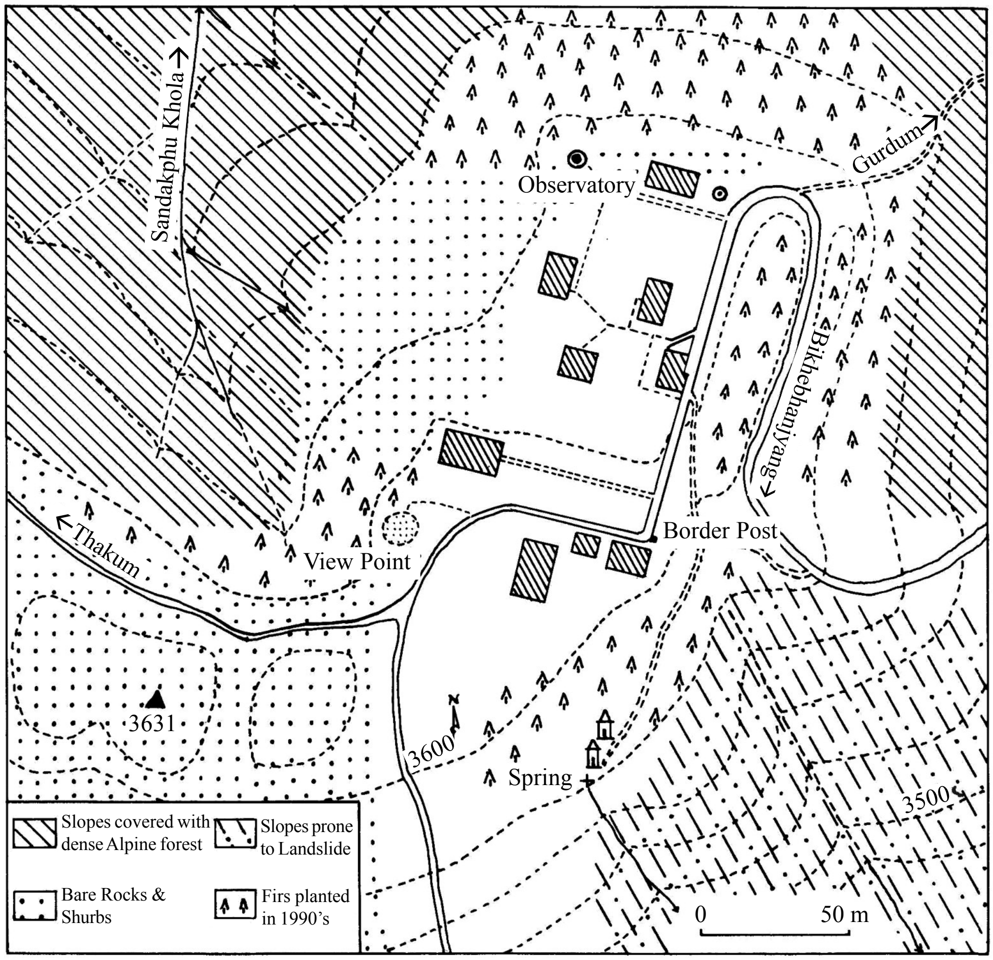
10.1. Introduction

A peak or a protruding mass of rocks lying on a mountain or hill may be created either by constructive forces acting inside the lithosphere or by destructive ones acting over the surface of the planet. Energies released from the first set of forces are originated within the planet, e.g. the energy set free after an orogenic movement. Upwarping or thrusting occurs by first set of forces resulting in a series of highlands over the lithosphere. While the degradational processes propelled by the latter ones create splendid slopes on that elevated grounds. These slopes possess a wide variety of geometric shapes depending upon the nature of degradation and project sometimes high vertices above them generally composed of harder rock layers in relation to surrounding lowlying areas. The peak Sandakphu (3631m) has also been created by simultaneous action of both types of forces: first one by 'Nappism' in the mountain of Singalila and the second one by sub-aerial denudation acting over the region. The combined effect of all multi-functional processes through prolonged geological ages has given the summit a marvellous but graceful craggy shape in one hand: while on the other hand the isostatic compensation in low density granite-gneissic strata (due to the removal of upper layers of the Nappe) has shoved the place at an exalted position. This is a very unique configuration of the spot making it world-famous top with amazing vistas on all of its sides.

10.2. Site And Situation

The summit area of the crescent shaped peak Sandakphu (27°06' N, 88°00' E) is little less than three hectare where all Trekkers' Huts, Private lodges and camps of para-military forces are situated in a congested manner. International Boundary line divides

Sandakphu: Physiographic Characteristics



Last survey : November, 2018 (Army Camp not shown)

Contour interval : 20 m

the topmost portion into two unequal parts – northlying two-third belonging to Indian territory leaving southlying one-third in Nepal. The view point of the peak stands on the brink of the western slope – just north of the Boundary line. A tiny observatory (glass walled in all sides) also exists on a small outcrop of rocks on the north-western part of this summit. A cluster of temples has been set up on a rocky terrace of the southern slope (about 15m below the summit top) guarding a spring – principal source of drinking water of the place. Main approach road (made of boulders) ascending from Kalipokhri traverses the peak area at first SSE for about 100m, then 50m WNW, and lastly again 100m in a serpentine extension towards south-west. After making a large curve, convexed westward, the road runs northwards for Sabarkum via Thakum. A trekpath descends abruptly from the head of the approach road towards Gurdum village. Another road, still under contruction, descends from the southern tip of the peak which encircles the southern slope of the mountain and joins the main approach road at Bikhebhanjyang (2.5km from Sandakphu, altitude 3200m).

10.3. Top-layer Lithology

The lithological study of the peak reveals the composition of hard rocks –almost all of them being the result of regional metamorphism. Gneiss of Archaean age is dominant in the strata with occasional intrusion of igneous bodies (granite and granitoides) which might have been originated by melting of ancient rocks and reconsolidation afterward through rock-cycle process. Thin, lenticular layers of schist are, however, found elsewhere being embedded in the gneissic strata. These are fragile very much and exhibit maximum grade of metamorphism as well as crumbling in their laminas. Since the summit is represented by the tip of a huge synclinorium the rockmasses are brittle and easily susceptible to denudational processes. Two rocky crags stand at the south-western end of the area (westernmost one being the highest – 3631m) in which squeezing of strata is quite distinctive. Quartz and fedspathoids are found abundantly along the thrust planes and at the lower part of scarplets.

10.4. Weather Elements

The high altitude of Sandakphu makes the air pressure very low – little more than 650hPa. Amount of suspended materials in the air is much low – about 1/50 of the amount found at sea level. On the contrary the effect of sunlight becomes more exaggerated on the summit than that of the adjacent valley-bottoms. The thin but clean air allows very high solar intensities and consequent rate of evaporation. Complex setting of landscape causes the surface gainer with varied exposures of daylight. Since the top rises high above the lower layers of troposphere it shows the capacity of receiving higher levels of insolation including ultraviolet and cosmic rays. In regard of receiving u-v rays the summit attains very high marks – 110 to 120 per cent depending upon the inclination of sunrays. The ray affects the physiology of local vegetations, especially retarding their growth rate. It has adverse effects on the faunal body too. In case of man u-v rays causes deep tans on skins and sunburns. The rays having wave lengths less than 320μm may cause skin cancer and weaken the immune system. The cosmic rays affect the survey instruments badly and often disturb in tele-communication system.

Since the peak advances southward and rises high above the valleys surrounding its three sides – east, south and west, the top enjoys longer daytimes and receives higher amount of solar energy. For this reason temperature always remains higher than that on Sabarkum and Phalut (though both of them are little lower than Sandakphu). As a consequence rock and soil surfaces become dry enough in the period of rainless days.The valley-wall of the Sandakphu khola flowing through the northern slope is, however, experienced shorter daytimes resulting in a moist surface layer.

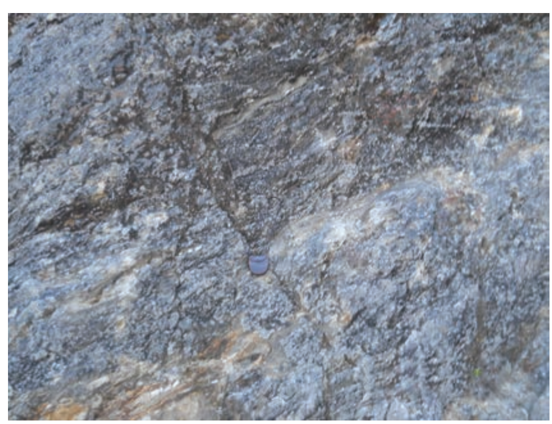
Location and gradient of slopes also cause a wide variation in receiving of insolation. Steep free face lying in the south just below the summit-head is heated less than the gentler part of the slope lying in middle portion of the peak because the latter is more perpendicular to the incoming sunrays (as per latitudinal location). East and west-facing slopes are affected more distinctly by solar radiation. The east-facing slope (overlooking Bikhebhanjyang) is heated by morning sun a large amount of which is used to evaporate frost and dew. When the ray reaches on the west-facing slope in the late hours of a day, surface of that side already becomes dry. Thus insolation shows its more effectiveness in heating the slope of that part.

The process of differential heating on different parts of the peak becomes, however, complicated on account of the veil of clouds and fogs. In monsoon period dense cover of cumulonimbus clouds lowers very much the effect of sunlight on every parts of the peak. In spring and early summer afternoon clouds reduce the effects of insolation over the top and its western slopes slightly because most of those clouds are stratus type and are almost transparent. In winter, eastern slopes get lower amount of solar energy than the normal due to the mantle of extensive fogs. At mid-day hours the fogs exist no more and the peak gets full attack of insolation.

9a. Projected end of synclinorium: South of Thakum

9b. Unconformity between
Late Proterozoic (hard Quartzite)
and Permian (soft Quartzite) strata

9c. The hamlet: on the down
throw side of Gurdum fault



9d. Reverse fault in small scale: near Kaiyakatta

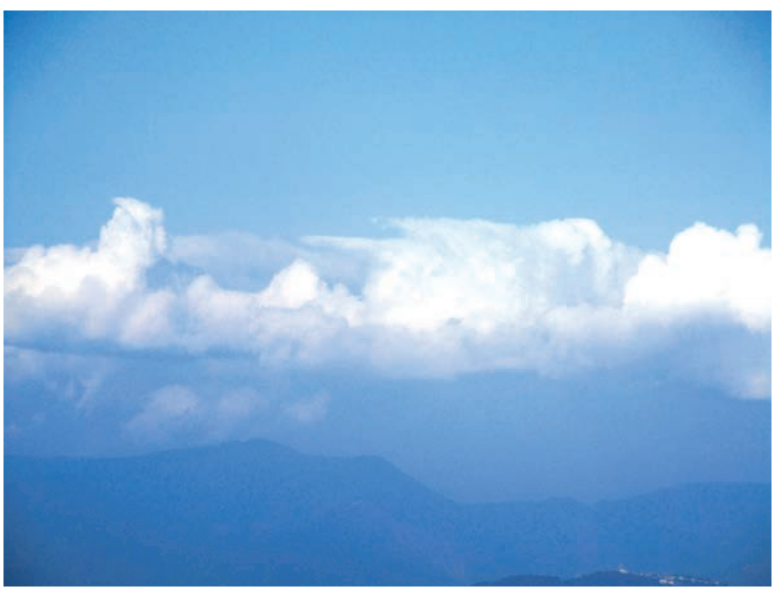
10a. Gneissic boulder in gigantic size: beside Sandakphu Observatory

10b. Crumpling in schistose stratum: below Sandakphu summit-crag

10c. Milonite: above Rammam

10d. Migmatite: north of Gorkhey


11a. Cumulonimbus cloud


11b. Altocumulus cloud

12a. Thick frost and verglas on Sandakphu

12b. Accumulation of water drops through cloud-net: Kalipokhri-2001


13a. Snow-covered Sandakphu


13b. Frozen Kalipokhri-January, 1995


13c. Clear waterbody of Kalipokhri- October, 1996


13d. Charred Fir-trees: near Thakum

14a. Firs: near Sandakphu

14b. Blue pine in Rammam forest

14c. Aconite with other types of surface vegetation, below Sandakphu

14d. Juniper on Sabarkum ridge

14e. Hemlock in Rammam forest

15a. Full bloom in Magnolia near Gahribas

15b. Lychopodeum at Samanden

15c. Little plant of a tree-fern:
Rammam forest

15d. Orchid in Rammam forest

16. Rhododendrons in different hues