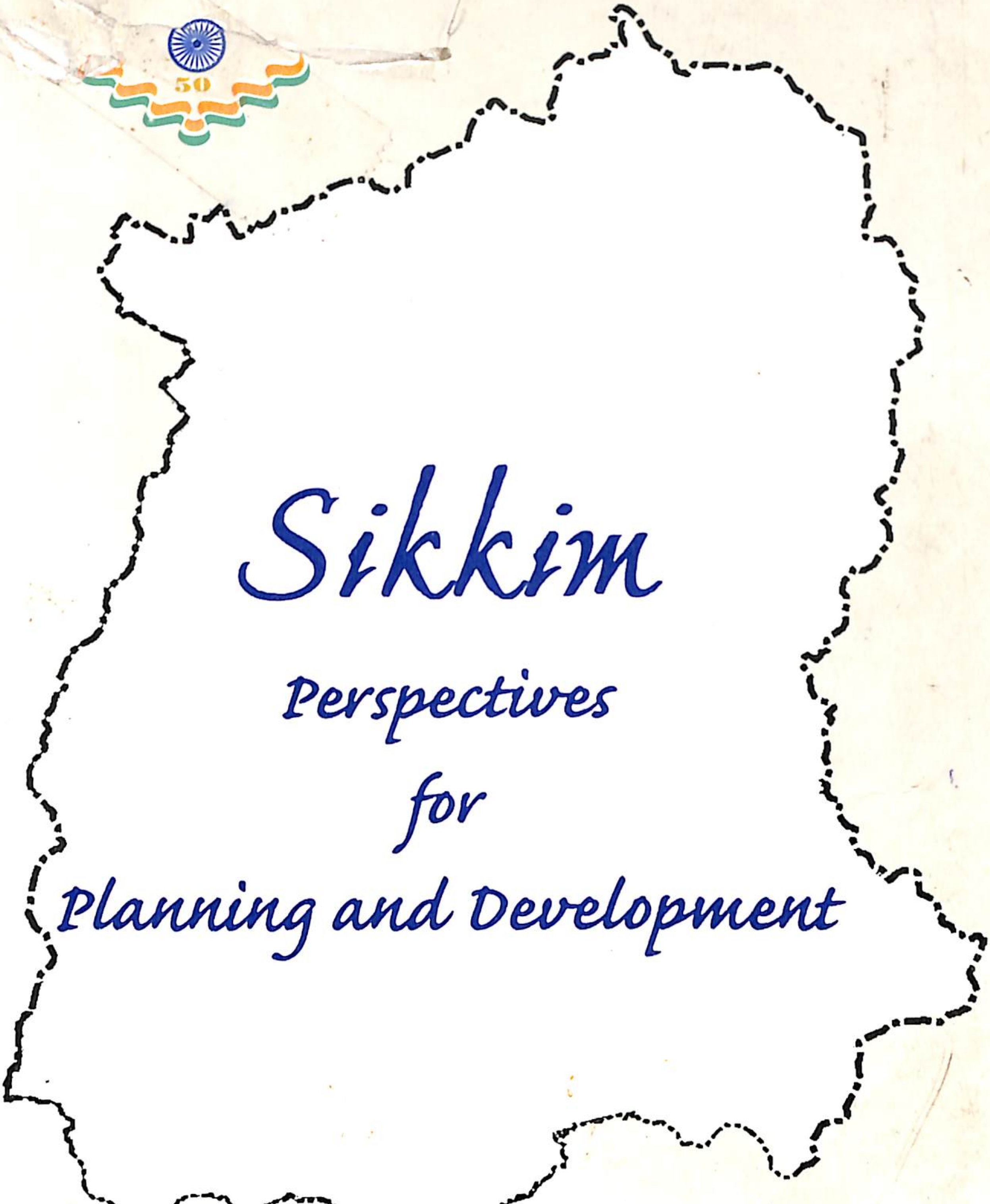

Sikkim

Perspectives for Planning and Development

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PREFACE

Himalaya is one of the youngest and greatest mountain systems of the world stretching almost 3200 km east-west. Sikkim situated in the eastern Himalaya became the 22nd state of India in 1975. It is a small state having hilly terrain spread over 7096 km^2 with elevation ranging from 250 to 8595 m above msl. There are 440 villages, 8 towns, and 4 districts with a population of 406457 as recorded in 1991. Four major ethnic groups of people namely Lepchas, Bhutias, Nepalese and Limbus live in Sikkim. The climate of the state varies from cold temperate and alpine in the north and north-east to subtropical in the south more dependent on the altitude. The main occupation of the people is farming and only 12 per cent of the land is available of cultivation. Nearly 6000 species of plants are found here and is a hot spot for both floral and faunal diversity. The net state domestic product of Sikkim at constant prices increased by 3 times from 1981 to 1991 and per capita income doubled during the period. Sustainable development in Sikkim could be achieved by focusing the improvement of the quality of livelihood options of households by harnessing local mountain niches which are compatible with the mountain specifications. In order to do this our knowledge on all aspects of development has to be sound and we have tried to put together most of the information that are available in Sikkim in this publication. We expect that this edited volume can be used as a core document in sound planning for development as we march towards the 21st Century.

This book has been chapterized into seven thematic sections and also with a section on selected bibliography for Sikkim. There are 53 articles under (i) physical background, (ii) culture, socio-politics and education, (iii) resource status and biodiversity, (iv) agriculture, animal husbandry and horticulture, (v) energy, health, food and economy, (vi) ecology and environment, and (vii) perspective planning and industry. These articles are contributed by specialists from the state and outside who have worked in Sikkim.

CONTENTS

GEOMORPHOLOGY OF THE SIKKIM HIMALAYA

S.C. Mukhopadhyay

The Sikkim Himalaya is constituted, by the physiographic or geologic terrains viz. the Tibetan Himalayan Zone, Higher Himalaya, Lower Himalaya etc. This greatly undulating terrain is representative of a drainage of well-marked, composite and highly complex peculiarities in its development. Mention should be made of old suites of landforms which are found to have developed in the setting of young-landscape throughout its stretches from the upper intervening Piedmont zone to the lower southern alluvial plains including the rejuvenated river valley. It has been observed that the diversity in litho-techno landform units of Sikkim Himalaya is greater than any other sub-basins of the physiographic or geologic terrains within the Eastern Himalayas being noted for its climatic, geologic and tectonic domains. Evidences of glacial retreats are also found in the upper parts of this area.

Introduction

In the Sikkim-Himalaya, the distinct micromorphological features of the Sikkim/terrain include terraces and floodplains, valley-side slopes and landslide slopes, alluvial cones of different types and generations, tors, kettle-shaped depressions, terrace-isles, sickle-shaped rags, bevelled plains, undulating plains with deeply-dissected valleys, glacial or periglacial deposits, related sedimentary structures, crevasses soil series or polypedon, gorges etc. The Sikkim terrain exhibits also various climatically induced landform suites, and the landform assemblages containing relict elements in the profiles arising from the time lag in response varied geomorphic and pedogenic processes and environmental changes. These micro and other, meso-topographic forms have been produced by the trunk stream Tista and its innumerable tributaries- one of the important, agents of denudation and deposition which has been engaged in attacking and moulding the emerging forms in the upper and burying others mainly in the lower reaches.

As a potential control of form prevalent climatic variation is as important as the existing structural variation in the attainment of differential weathering status and the four-tier terrace and floodplain formations in the Sikkim terrain. The orientation of the horseshoe shaped river, i.e. Tista basin and the location within the Himalayan mountainous landmass have controlled its relationship (i) to the trend of geological structure, (ii) to the passage of glacier e.g. Pauhunri, Zemu, Talung etc. in the uppermost reaches, (iii) to the headward communication of the effects of tectonic, isostatic and eustatic movements in sea level (the Bay of Bengal) specially in its lower most reaches over the Great Bengal Plains. It is important to note that the slope (48°54') to dynamic equilibrium is also largely controlled by those erogenous factors while dynamic equilibrium in morphological systems, is to be found in most of the climatic zones. Morpho-systems also include the events of slope- angle and its transformation which are related to the processes of linear-erosion, slope-wash, gravitative transfer etc. These processes are found to be reinforced by the changed climatic situations particularly associated with catastrophic meteorological phenomena viz. (i) rapid down pours of high intensity, mainly local in range and connected with convection currents or the passage of cyclones e.g. which occurred in the year of 1968 in Tista basin area, (ii) long-lasting continuous rains of lesser intensity and regional extent due to advection of oceanic air masses, (iii) periods of rapid warming, bringing about quick melting of snow and ice as well as ground-thaw often accompanied by precipitation. Regarding the basin characteristics the author has considered the distinctive 'components of form, of the main river Tista and its tributary-basins e.g. (i) a channel net work, (ii) a suite of valley-side slope, (iii) a perimeter, and (iv) an outlet which are also included in the morphological systems. These morpho-systems are closely connected with the litho-tectono-structural setting of the Sikkim area.

Morphogenic Systems

These morphogenetic systems are found to differ appreciably in the five distinct climatic zones negotiating the ten geo-units at different elevations in the Sikkim-Himalayan area. Its general climatic types are Caw, Da, H etc ; (Trewartha 1954). Here the author has made an attempt to interpret the landforms on a geo-unit or zonal basis in association with climatic succession. It also include the references of the prevalent relationship with the denudational and depositional processes responsible for fashioning the land surfaces of Sikkim-Himalayan area. These five climatic zones from upper to lower are:

(a) Frigid zone above 4000m. (glacial, periglacial and fluvio-glacial processes),

(b) Cold zone between 2500 to 4000m. (periglacial, fluvio-glacial and fluvial processes at higher altitudes)

(c) Cool temperate zone between 2000 m. to 2500 m. (fluvio-glacial and fluvial processes at higher and medium altitudes)

(d) Warm temperate zone between 1000 m. to 2000 m. (fluvial processes), and

(e) Subtropical zone upto about 1000 m asl. (fluvial processes at lower altitudes)

Let a brief treatment of these geo-units in group along with the peculiar topographic expressions relating to the morphological systems be presented in the following paragraphs.

The three geomorphic units-as a, b and c in combination have formed the major portion of the Northern part coinciding with the Upper Tista Basin. This upper section stretching about 100 km, West to East, has occupied a significance is found as marked by the presence of glacial, periglacial, fluvioglacial evidences indicating the occurrences of related fluctuations particularly in climate, timber-line and other associated effects in the context of mountain ecology and environment.

Some unique features are observed in its mountainous terrain with scenic splendour, glaciers of nival climate where on snowfall exceeds ablation, shimmering lakes of various sizes and shapes like Green Lakes and others, alpine medows, deodar-oak (coniferous), birch-rhododendron-juniper (Sub-alpine and Alpine) forest, terraces along the Tista and its innumerable tributary valleys of various origin and varied valley-aspects along with rich floral and faunal wealths, etc. Actually, this northern part with varied and diverse environments forms a unique and conspicuous land-mark within the Sikkim area. The Pauhunri (Tista-source), Zemu and Talung glaciers are found to have engaged in the erosional works mostly through abrasion, scouring and plucking while the adjacent periglacial processes down hills function through permafrost, ice-wedge, seasonal ground ice, frost sorting relating to cryonival morphogenesis, Presenting a geomorphic contrast to the middle and lower parts of the basin marked by comparatively subdued relief relating to lateral plantation and accretion, sweep, slop-wash, slides and slips, scourage and filling, abandoned channel filling (fluvial) etc. processes, this northern part within Greater Himalayan terrain majestically stand in their variegated landscapes with accompanying glacial-periglacial-fluvioglacial processes set in a frame work of (apparent) severs simplicity, primeval glory, uncommercialized nature, high and strong relief. An important aspect of this area is the immense accumulations of debris and silts in the form of debris cones, rock-glaciers and alluvial fans, and the related problems which arise out of the transporting of such huge amount of debris-silt materials to cause landslides, debris avalanches, floods and other hazards The work of transporting of such debris is associated with an annual cycles as the major bulk of these are being removed in the monsoon and also during the snow melt period. It is marked by higher range of variability and uncertainty where an annual variation of more than 25% is not uncommon.

Transporting rates of the debris become as high as twenty times the normal particularly in catastrophic environment. Huge amounts of silt are also derived from the upper reaches of the elevated watershed areas. A number of glaciers of different sizes (Table 1) move over their beds of Greater Himalayan terrain, reducing to powder (rock-flour) mainly by friction large quantities of surface-rock. This variety of powdery rock-flour when mixed with melt water form the so called glacier-milk which is found to have transformed further to consistency of thin mud during the situations of the peak melt discharge in subsequent stages. However, this point of debris and silt production and their transportation relating to the occurrences of changes in the phase of these glaciers-advance, recession and stable conditions like the other parts of the Himalaya, needs our immediate attention. These changes in the glacial-phase of the upper Tista basin section have extended the elated multifarious effects in the area of water management with a special reference

Name of the glaciers	Altitude (m) Upper & Lower	Location		Alignment	Magnitude (km)		Height of the snour (m)
		Latitude (N)	Longitude		Length	Breadth	
Pauhunri	7010	88"54'	27°57'	NE-N-SW	4.2	1.0	5150
(Tista-source)	6100	88°55	27°59'				
Zemu	6000	88°15'	27°41'	N-NE-E	26.0	1.7	4150
	4250	88°28'	27°46'				
Simvu	6800	88°17'	27°41	NE-NW-NE	9.5	1.4	5300
(Simvo Gl)	5500	88°18'	27°44'				
Green Lake	7100	88°11'	27°50'	SE-E	9.0	0.9	4720
(Tent Peak-Nepal Gap)	5000	88°17'	27°46'				
Lhonak	7320	88°14'	27°53'	N-NE-E	6.5	1.6	5020
(North & South Twin Gl)	5250	88°14'	27°56				
Tumrachen	4870	88°21'	27°49'	NE-E-SE	4.8	0.8	4400
(Hidden Gl in SW)	4580	88°24'	27°50'				
Passanram	6100	88°20'	27°42'	NE-S-SE	8.0	0.7	3960
(Tong Shyong Gl in W)	4400	88°21'	28°38'				
Zumtu	6700	27°43'	88°23'	SE-E-SE	6.5	0 6	3660
(SE of Siniolchum)	3970	27°41'	88°25'				
Talung	6750	27°41'	88°21'	S-E-SE	14.5	1 2	4210
	4300	27°36'	88°18'				
Tong Shyong	5790	27°41'	88°15'	SE-S-SE	7.2	1 0	4420
	4570	27°37'	88°08'				
Alukthang	6790	26°36'	88°11'	SE-E-SE	6.4	0 6	4100
(NE of Forked Peak)	4420	27°34'	88°14'				

to the landslides and floods towards lower reaches. The Pauhunri, Zemu and Talung glacier as the result of huge ice-cover in this part of the Greater Himalaya have fluctuated between wide limits in the past and certain fluctuations are still going on even today. Such fluctuations are found to have accompanied many notable changes in the various fields like (i) the production and the transport of debris, (ii) floods and siltation of reservoirs, (iii) vegetation cover (Timber-line' and (iv) others associated with the cooling effects of these groups of glaciers in Sikkim Himalayas.

Most of the glaciers are situated in the Main Himalayan Range, and the distribution of the ice cover is controlled by the (i) elevation of the ridges in the northern Sikkim area, (ii) the orientation of the slopes, and the (iii) amount of precipitation. mention should be made of the varied height of snow line which is dependent primarily on (i) heat (radiant energy from the sun), and (ii) atmospheric moisture (monsoon-precipitation). The variation in moisture distribution i.e., greater in the Eastern Himalaya compared with the drier Western Himalaya is essentially responsible for such occurrences of relatively lower elevation of snow line in the east. These factors like orientation of the slopes, precipitation along with other local aspects have caused the development of intra-valley variations in the elevation of the snow line relating to Zemu, Talung, Pauhunri glaciers in the northern part of the area.

The influence of precipitation on the extent of glaciation is dramatically observed on the divides between some tributaries to the upper Tista on the north and west. Generally, the south facing slopes have a smaller ice cover. The variation of the elevation of snow line mainly in southern and northern slopes is well illustrated in the boundary ridges of Zemu glacier, for example. Kanchenjunga to the north western part is noted for its greater concentration of glaciers some of which are found to move east wards e.g. Zemu, thus feeding the Tista tributaries e.g. Zema-chu, Lhonak-chu and others. This upper most sector is dominated by frost action and related traces of landforms being evolved under glacial, periglacial and fluvioglacial processes. There are evidences of dissociation of these streams like Zemu-chu, Lhonak-chu, Talung-chu, Tomya chu etc. during the Post-Pleistocene period (inter-glacial). The north and western sectors within the Greater Himalayan Zone have largely been influenced by the tectonics as well as climatic changes since its evolution. Besides the peculiar landscape-configuration this is an area of unsurpassing beauty with loftily Peaks, glacial lakes, terraced hillside slopes, superb Himalayan meadows, unique wild flowers, three to four-tier terraces and Nature's rock-gardens. In other words, the entire scenery may be regarded as a religious sanctuary of the Hindus-Buddhists, most reasonably for being a strategically vulnerable area, far too inaccessible either. The northern parts of the Sikkim-Himalaya in and around (i) Chhateng-Lachen-Zema-Yakthang-Lhonak Yabuk-Green Lake-Zemu glacier sector, and (ii) Mangan-Lingtam-Talung sector in the north western segment, and (iii) Lachen-Lachung-Dongkya La-Pauhunri (Tista-source) glacier sector in the north east between 2500 to 4500m. elevations, have been investigated by the author. These three significant sectors constituting the northern most part with glacial domains exhibit many remarkable glacial, periglacial and fluvioglacial landforms at various ecological sites being located at different elevations in the Sikkim-Himalaya. These landforms offer special treatment relating to the studies on Pleistocene climatic changes in terms of (i) retreating of Zemu-Talung-Pauhunri glaciers of more than 20 km. back with a vertical drop of 1500m. and above, (ii) dissociation of a few tributary valleys being originated from these glaciers e.g. Zemu-chu, Lhonak-chu, Tumrachen chu etc. (iii) formation of valleys of various origins and gravely-alluvial terraces by comparatively rapid down cutting followed by more leisurely valley widening, reaggradations, and other varied phenomena including cryonival morphogenesis as referred earlier. The Pauhunri-Zemu-Talung glacial domains in the crest zone of northern part are found to have associated with some notable changing topographic expressions. These topographic expressions are (i) elevated terraces and glacial out wash terraces, (ii) formed during both Pleistocene and Post Pleistocene periods including cryoplanation terraces and constructional gelifluetion flats or terraces etc. and (iii) lakes of various shapes, sizes relating to the glaciolacustrine features of varied origin, (iv) extremely steep-sided valleys both of V-shaped and U-shaped connected with occasional interlocking spurs at different sites, (v) distinct gorges of various dimensions and shapes (I-shaped), (vi) tills (sheets) including intertill deposits like lacustrine materials, wind blown sands and outwash sand-gravels with immature soil profiles developed mainly during interglacial periods, (vii) swales and basins along with innumerable lenses of sand and gravels as are found in extensive till sheets of glacial outwash thus indicating traces of lithologic differences, (viii) different types of valleys (hanging valleys) trough-shaped valleys lateral ablation valleys, asymmetrical valleys, dells or dry valleys including dead ice wastage as well as other associated features like knob and kettle relief etc. (ix) hillside and valley-side slopes being influenced by the processes of mass movements like slump, mud flow, debris avalanches or avalanching, nivation, niveoaeolian slides, solifluction-frost creep, frost heaving, sheet wash and suffusion, (x) soil stone, polygons and taliks-like features (tjaele), (xi) channels of rocks and valley trains, (xii) frost shattered rock-strewn undulating surfaces, and fan like structures down slopes along with other characteristic fragments of rocks set in varied hill slopes (gneissic rocks).

The other features are- entrenched meandering and straight channel patterns in the lower part, wide level surfaces (of various sizes and origin) with occasional cover of grasses and swamps or boggy areas in places e.g. Green Lake plains and north western plains, varied drainage texture and complex type (deranged) of drainage patterns with swampy inter stream areas in some places. Deranged patterns with swampy inter stream areas in some places. Deranged patterns are marked by an irregular stream courses which are found to have joined, for examples the Green Lake-swamps and like, and occasionally flowed out of the lake-swamps. This drainage pattern is typified by the occurrence of a few short tributaries like mere threads of water which are intensified during rains or storms, cirque and nivation cirque (floor), in the Zemu-Talung etc. glacier, cryopediments, frost riven cliffs and scarps, cryoplains cryopediplain, and like relating to cryonival morphogenesis, e.g. patterned ground features, crevasses or deep cracks, aver the Zemu-Talung-Pauhunri glaciers, lateral and end moraines, as found to the north west of Tomya chu-Yabuk for example glacial trough and sickle-shaped troughs (Sichelwannen) and other plastic scouring forms relating to sub-glacial erosion, truncated spurs, escarpment and tors (granitic), thermo-erosion gullies, as ice wedges (syngenetic ice wedges in loose deposits, epigenetic ice wedge in solid rocks) on slopes thaw out, pingo 5-100 m open system and scarps and the like. These long and relatively narrow glaciers feeding the Tista and its tributaries are of distinctive types and exhibit the different sections with typical features relating to erosional and depositional activities.

Here, Section of ablation, valleys with shoulder and heads or high steps, basins and narrow sections, valley-side benches, U-shaped cross profile and steps in the longitudinal profile, tributary valleys, section of accumulation, glacial deposition including moraines- lateral and end moraine till, firn field, plastic section and glacier terminus section or snout of glaciers and others. These glacierised zones in the upper northern Sikkim Himalaya also contain features of glacio fluvial erosion and deposition particularly in the preglacial which were guided by the source of debris and the drainage which followed courses being influenced by the ice (fall). It includes the several episodes of glacio-fluvial activity (dead-ice wastage) during recession when distinct drainage systems came into being and found it, ways in the directions of the ice-surface slope with a beginning upon the ice from ice-melt, snow-melt and rain, and drainage also came from ice-free mountain terrain in subsequent stages. The sub-glacial erosion, for example, relates to the peculiar plastic scouring forms particularly the sickle-shaped troughs and their varieties. The periglacial zones are connected with cold climates and permafrost system (tjale) which have affected the morphological systems thus modifying the operation of geomorphological processes in and around Yabuk (3,962 m asl)- Green Lake plain area (4500 m asl, Poki chu, Tumrachen chu, Langpo chu, Naku chu etc. valleys).

Neotectonics and Landscapes

The Sikkim-Himalaya is an uplifted and tilted mountainous terrain which has been divided into several large elongate sub-parallel tributary valleys like the Rangit, Rangpo Chu, Rongni Chu, Rang-Rang Chu, Lachung Chu, Ranikhola, Rora Chu, Takchom Chu, Geilkhola etc. An important feature of the Tista drainage basin is the remarkable way in which geological structure and the character of the underlying rocks are expressed in the landforms. Lineation in the topography has been largely controlled by structural and tectonic elements. The Sikkim-Darjeeling Himalaya which sustain the Tista and other drainage basins are classic areas in neotectonics. There is a close relationship between the tectonic patterns and the landscape of the Sikkim Himalayan terrain set in the tectonically active (neotectonics) Eastern Himalayas and also Bengal deltaic plains. The different landscape-elements, including suites of glacio-fluvial landforms, drainage and channel patterns have been largely influenced and reformed in recent times, The major morphotectonic lineaments, thrust or folded belts extending from the Bay of Bengal to the Eastern Himalayan sector are of critical significance since most of them are involved in the evolution of present variegated landscape of the Tista and surrounding drainage basins. Different segments of the Regional Tectonic settings of the Tista basin area in the Eastern Himalaya, as a whole, are associated with the corresponding geomorphic units which exhibit the typical landform associations. The Regional Tectonic setting of the Eastern Himalaya beyond the Bhagirathi-Hooghly channel includes

(i) Brahmaputra Basin, (ii) Bengal Basin, (iii) Eastern Himalaya fold belt, (iv) Shillong platform and Mikir hills, (v) Surma Basin, (vi) Naga-Lushai Arakan Yoma fold belts, and the others like Central Burma Molasse Basin, Trans Himalaya Region etc. the other hand the physiographic lineament is primarily along East-West, while several spurs are aligned in North-South directions. The Tista with its major tributaries and the other rivers like Jaldhaka, Torsa, Mahananda, Manas etc. have cut up the elevated rugged mountainous terrain into several morpho-units, which also known as 'geomorphic sites' or dynamic ecological sites' being separated from one another by deeply incised valleys with terraces, dissected hills, valley-side slopes and gorges etc. The contiguous valley areas of the Tista likewise display the effects of thrusting or over-thrusting, recumbent folding associated with structural disturbance or dynamic metamorphism relating to tectonic activities in recent times. It is obvious that current landform changes in the slope-transformations, deformed terrace-deposits, dynamic ecological sites and particularly in morphogenetic balance of the Tista basin are believed to be the reflection of the influence of fundamental crustal fractures of recent origin. Sikkim-Himalaya is under the domain of active deep-seated fundamental crustal fractures. These fracture lines are aligned from Bengal, Deltaic Plain towards the Trana-Himalayan zone and Padma-Jamuna-Tista morphotectonic lineaments along with Main Boundary Fault etc. This undulating terrain is also typified by the notable discontinuous (broken) lineaments which have brought about remarkable modification in the riverine features like raised and dissected terraces and floodplains along the river valleys. A detailed discussion or implication of all these major morpho-tectonic lineaments in the developments of morpho-regions and their subsequent changes in different aspects is beyond the scope of the present volume. It is relevant to mention about the Neogene Siwalik and Permo-Carboniferous Gondwanas which are found almost continuous along the foothill zones. These formations are aligned almost East-West direction from the western border area of the Central Sikkim-Himalaya upto the Siang-Dibang valley with a few breaks. Towards northern parts occur traces of metamorphites of several grades and crystalline rocks. Beyond the Sikkim-Himalaya the mountainous terrain area is characterised by the East West trending Tsangpo and Its nearby arcuate and general lineaments along with Red-river fault extending ESE-WNW. These are also well expressed in the surface by characteristic drainage and channel patterns, glaciated valleys-lakes, ellipsoidal blocks etc., (Mukhopadhyay 1982).

The broad North West South East morphotectonic lineaments are significant in the study of Sikkim terrain particular of its drainage and channel patterns- with reference to the Brahmaputra drainage system and the Bengal basin. Those lineaments of geomorphic significance are termed after the names of important rivers like Tista, Jamuna, Padma etc. which also include a number of small fractures, boundary fault or a series of thrusts. As an example, the Northern mountainous terrajn in the upper parts of the basin, is typified by the large arcuate lineaments with distinct North-South fractures. The lower reaches of the main Brahmaputra are found to have largely guided by the underlying structural conditions e.g. Jamuna lineament incidentally, the NW-SE Tista lineament seems not to be involved directly with the total drainage developments except of the upper reaches far beyond the Main Boundary Fault (MBF). The basin area is roughly delimited by the Tista in the north and Padma lineaments in the south respectively. While the former lineament is extended from the lower Bengal Deltaic Plain to the higher (Tibet Plateau) Trans-Himalaya through the intervening upper segments.

The Constituent Multicyclic Landscape-Elements

The constituent elements of the multicyclic landscape of the Tista basin area negotiating the higher Eastern Himalaya and lower Bengal Deltaic Plain in Eastern India are- (i) a series of ridge and vales, (ii) hills of various shapes and origin, (iii) cirque glaciers, (iv) till sheets (v) glaciated valleys and lakes including kettles, lenses, dry valleys, (vi) truncated planated surfaces, (vii) wide level surfaces of various shapes, (viii) small rhomboidal and ellipsoidal blocks of flat plains, (ix) rugged hill-slopes along with marginal ledges, (x) landslide slopes and (xi) deeply incised (meandering) valleys with gorges, (xii) three to four-tier terraces (glacial and fluvial) with rock benches (xiii) continuous deformed fluvial terraces and floodplains along the rejuvenated valleys, (xiv) antecedent (anteposed) river, (xv) alluvial cones of multiple generations, (xvi) well marked scarps and spurs (interlocking), (xvii) gullied-surfaces, (xviii) valley-side slopes and valley pediments, (xix) sharp and ridge-like strewn divides with inter-stream uplands, (xx) extensive braided, meandering channels including ancient channels (xxi) several scarps including composite scarps etc. The assemblage of these various landscape elements evolved under varied environments has brought about many notable fluvial and glaciofluvial features. The Sikkim landscape complex containing particularly the suites of landforms like terraces and floodplains, gorges, alluvial cones etc. shows the effects of dynamic geomorphic processes along with interactions between the controlling forces. Many peculiarities in the suites of landforms and contrasts in the attainment of 'range' of features in different morpho-units have been manifested in the magnitude spectrum of the Sikkim terrain. Actually the Sikkim-Himalaya is an ideal play ground where the different geo-complexes like climate-soil-vegetation climax system, water balance, rocks (petro-variance) eustatic, tectonics (epeirovariance) etc. have largely controlled to shape its polymorphic characters. This terrain reflects the effects of a recurrent and comparatively rapid uplift set on a truncated planated surfaces in the Eastern Himalayan zone and adjacent plain areas repeated lowering of the base level has taken place consistent with rejuvenation of the Brahmaputra drainage system. Of all these types (landforms) much stresses are given on the typical riverine features like the terraces and floodplains, and level surfaces at different altitudes which have been regarded as environmental indicators in fluvial geomorphology (Mukhopadhyay 1978, 1980, 1982). These suites of landforms relating to the study of ecosystem of mountains and plains are significant in the work of establishing both qualitative as well as quantitative interaction between the various components of the geocomplex.

Major Geomorphic Units - The Processes and Mosaic of Environments

Considering the development of distinct landscapes, soil and drainage features. The terrain has been classified into several geomorphic units from north to south with a varying altitude and climatic conditions. These geomorphic units are (a) the Pauhunri (Tista) and Zemu-Talung glaciated areas, (b) the periglacial areas in the fringe & of the former, (c) the higher northern mountainous terrain, (d) the southern rugged hilly tracts, (e) the rejuvenated Tista valley and the Rangit valley.

The Sikkim-Himalaya is noted for its remarkable ecological diversity and contrasting topographic expressions as well as varied morphogentic conditions. These five distinct geomorphic units (a to e) have exemplified the truth of the above statement concerning with the involvement of complicating of the Sikkim terrain in its varied phenomena and peculiar processes. Most of these geomorphic units with their distinct landform assemblages, resulting from a set of endogenous and erogenous factors, have represented well the cause and effect relationships like a process-response model.

These suites of landforms an have been observed mainly in the asymmetrical valley-side and hill-side slopes of the trunk stream Tista and its tributaries like Lhonak chu, Zemu chu, Tasang chu, Lachung chu etc. indicate unmistakably the dominance of glacials periglacial and fluvioglacial environment in the respective sectors relating to the glacial retreat and associated shrinkage and desiccation of valleys, and processes of invigorated dissection- down cutting, suffusion and toe-erosion by the Tista. The modifying processes also include solifluction, debris avalanches, slides, slumps, mudflows, debris flows, congelifraction and congeliturbation both in the local summit and base level areas within the northern Sikkim-Himalayan terrain.

Mention should be made of the peculiarities of the terraces developed along the Tista valley at an elevation of 2500 m. and more asl. The terrace peculiarities relating to their altitudinal variations, constituent materials containing fluvioglacial deposits along with soil-vegetation complex and others like traces of the changing situations of glacial-snouts, nature of the distant lateral and end moraines, till sheets etc. have provided many interesting clues on the evolutionary processes of the typical landscape patterns set in the upper part of the Tista basin. Reference should be made of the remarkable high terrace flanked by an extremely steep gorge developed in the Tista valley particularly to the south of Lachen village (27°44'N; 88°33'E, 2730m. approx.).

These terrace-gorge etc. landforms in the higher Tista terrain may be regarded as an environmental indicator relating to occurrences of alternate aggradation and degradational processes during the Pleistocene and Post-Pleistocene periods in the recent past distinct Pleistocene terraces with flattish plains or relatively even surfaces particularly between the two confluence-zones like (i) Tista-Zemu chu in the north at Zema (27°45'N: 88°32'E., 2650 m.a.s.l. (approx.), and (ii) Tista-unnamed small tributary to the south (27°43'N. 88°34'E, 2630 m. approx.). It is relevant to mention some vital points on land use patterns as are found to be influenced by the aspect of the upper basin. The villages like Lachen (27°44'N.; 88°33'E., 2730 m. approx.), Chhateng (27°43'N., 88°34'E., 2646 m. approx.) along with a few other temporary settlements i.e. huts locally known as goth, for examples, are located in this terrace-zone which is largely utilised by the local inhabitants or shepards (known as Lachenpas) in terms of farming and grazing grounds e.g., chamris, choru, sheep, mules, cattles, yaks a few etc. animals being delimited by the contiguous forest-clad hilly surfaces away from the valleys. This wide flattish plain with gentle undulations and the adjoining uneven surfaces in such mountainous terrain contain stretches of grass lands intermixed with forest vegetations, and have been under grazing mainly by sedentary local Lachenpas and also by migratory graziers in the nearby elevated mountain slopes to the north-north and west at 4300 m. and above. As the grazing-pressure becoming more intensified with increasing rate of population and growing demand, the grass cover exhibits signs of deterioration in many sectors.

The hill-slopes are characterised by the formation of a symmetrical valleys (tributaries), spurs, escarpments (granite) and free-face with a talus slope below thus bringing about variety in this Pleistocene terrace site. The constituting terrace materials relating to stratigraphic successions have been used as meaningful indicators of environments like glacial, periglacial or fluvioglacial particularly of the successions of characteristic episodes since Pleistocene period. Further upstream at an altitude 3000 m. and more, the different types of valley asymmetrical, dry valleys or dells, and Pleistocene terraces-cut and fill terraces, dryoplanation terraces, (constructional) gelifluction terraces or flats of various origins have been identified. The normal topographic forms found so far in the valley areas have been replaced by the peculiar forms with changing processes under higher altitudinal cold environments like Periglacial and Glacial environments. For example, fluvial morphogenesis has transformed into cryorival morphogenesis along with associated forms as cryopediments, frost riven scarps, cryoplain, dry valleys, fossil thermokarst basin, cryoplanation terrace and tor-like, features, ground patterns of former ice wedge polygons including gelifluction deposits- bedded screes and other products of frost creep and slope wash relating to Periglacial mass movements. It is northwestern Zema (27°45'N; 88°32'E. 265 m asl.) and Yakthang-Yabuk (27°47'N; 88°25'E, 3962 m asl.) area in the west, and north eastern Yumthang (27°50' N; 88°42' E, 4000 m. approx., asl.) area in the east may be described as a typical Periglacial landscape. This zone displays an abundance of features suggestive of Pleistocene frost action, and also a set of subdued landforms which was moulded by that frost action and by gelifluction during a succession of cryergic episodes.

Generally, the Yabuk-Green Lake plain area adjacent to the margins of Zemu-Talung glaciers in particular has been considered to illustrate the effects of periglacial processes in the northern and north-western part. In the periglacial zone intensive linear erosion (thermo-erosion) and planation relating to cryogenic processes have brought about many notable features like broad trough-shaped valleys, thermo-erosion gullies, small dry valleys, cryopediments (in granites) or glacis and cryoped in plain, nivation hollows, frost-riven cliffs, frost-riven scarps, cryoplanation terraces and tors, cryoplain, asymmetrical valleys, pingo and other forms of patterned grounds. It is necessary to explain the mechanism and morphological properties of these glacial-periglacial and laciofluvial processes which have distinguished the upper parts from the middle and lower parts. Thermo-erosion is the combined thermal and mechanical activity of running water relating to the thermal effects of the water which accelerate erosion. Thermo-erosion causes the valley-widening in periglacial zones. The intensive linear erosion essentially takes place in periglacial zone relating to cryonival morphogenesis specially in the upper valley sections of the Tista and its tributaries. Developments of thermo-erosion gullies 5 m. and more in depth and broad trough-shaped valleys are found to have associated with the later stage of linear erosion relating to the thawing of ice wedges on steep slopes and subsequent sapping the valley sides.

Other related landforms due to thermo-erosion are dells, cryopediments, cryopediplain, crysoplain, pingo etc. Dells are characterised by their flat floor, gently inclined sides and reach lengths of several hundreds of metre, widths of several tens of metres and depths of several metres. Actually, dells are small dry valleys shallowly cut in large number along the slopes of the Periglacial zone running straight down the direction of slope. Their initiation begins as a result of local permafrost degradation and the thawing of ice-wedges. Solifluction, sheet wash, and other cryogenic processes are found to have engaged actively in the fashioning of these valleys in the subsequent stages of its development. Because of the greater humidity along their floor lines, the dells act as the main denudation and transport lines on periglacial slopes. Their frequent development on slopes have given them a particular morphological importance in subaerial modelling. Like linear erosion the other aspect of erosion as extensive planation forms an important process of periglacial environment. Pediplanation and sheet denudation relating to cryogenic processes like frost heaving, nivation, frost creep, suffusion, sheet wash, solifluction ert. are significant in periglacial erosional cycles. In regard to the importance of planation it has been observed that it actively occurs both at the local base of slopes and on higher summits as well as elevated ridges along watersheds. The typical 'cryopediments' formed of piedmont planation surfaces at the base of slopes, have resulted from cryogenic processes in the periglacial areas. On the other hand valley cryopediments have developed in valleys which are often found as continuations of Quaternary terraces in many sections. The cryopediments have developed in various rocks and cut across rocks - of varying resistance. The principal process leading to the development of cryopediment is the retreat of steep slopes caused by frost weathering and the sapping of slopes by nivation. In the modelling of gentle foot-slope, many different processes play a part, especially solifluction and sheet wash. Of great significance are the dells along whose axes there is greater moisture content in the floor deposits, and a consequently the active layer above the permafrost is thicker. The gentle foot-slope is protected by permafrost from further denudation, the slope serving only as a surface of transport of the material that has descended the scarp.

The cryopediments extend from the main valleys into lateral valleys even joining by pediment passes over watersheds. As the cryopediments coalesce, a regional planation surface develops called a cryopediplain. Further, planation surfaces in the periglacial zone develop on summits and watershed ridges. The summits and watershed ridges of the periglacial zone often exhibit a distinct stepped topography. The planation process usually begins by the formation of nivation hollows. As they widen and merge, and because of the retreat of rock steps termed 'frost-riven cliffs' and 'frost-riven scarps', cryoplanation terraces develop. on the summits, several steps of successive cryoplanation terraces are often to be seen. As they merge, a cryogenic planation surface termed a 'cryoplain' develops. With regard to periglacial climate is characterized commonly as having very low annual temperatures, many fluctuations of temperature above and below freezing, and strong wind action, at certain seasons at least. Areas presently having such a climate are usually denoted as tundra areas. At the present this type of climate is limited to high latitudes and high altitudes. Intensified frost action marks these areas made of gneiss, augen gneiss, pegmatites etc.. and solifluction and patterned ground features are particularly diagnostic. A typical periglacial climate differs substantially from a glacial climate mainly by the aridity and the negative heat balance of the ground surface.

In the elevated regions the periglacial zone has not been well defined climatically, being delimited so far rather on the basis of occurrence cryogenic phenomena. But most typical periglacial zones with characteristic landforms relating to permafrost with considerable thickness occur in and around Yabuk (3960 m)- Green Lake plain set in high north western mountains where the glaciers excepting the snout (Zemu) were insignificant. The development of cryogenic phenomena is connected with the freezing of soil and the phase transformation of water. Ground freezing can be perennial (ground temperature below freezing point for more than two years), seasonal (several months) and short period (from several hours upto days). The core of the periglacial zone comprises the region of perennial ground freezing with permafrost. Beyond Yakthang (3,050m) - Tomya chu line, the Yabuk-Green Lake plain surface is conspicuously marked by the development of different heaps of frost shattered rocks, distinct channels of rocks forming fan-like structures at the base of hill-slopes, traces of the snout of glacier, soil polygons,, patterned ground features (stone nets, stone stripes, stone rings, earth hummocks or palsen, earth stripes, block fields or felsermeere etc.), related to solifluction deposits, lakes and others which are intimately connected with periglacial processes like congelifraction, congeliturbation, solifluction along with naval or niveo-aeolian actions. The author has discussed the relevant points on the principles of mechanism and morphology of such processes being concentrated in the upper most parts of this Sikkim terrain.

The periglacial zone in the mountain ranges, in and around Yabuk for example, is characterized by the occurrence of extensive cryogenic planation surfaces (cryoplanation terraces, cryopediments etc. Normally, the permafrost indicates much lower temperature. The activity of cryogenic processes is concentrated in a short period in spring only (when the area becomes dry, and the cryogenic process become less active). In autumn, the temperature decreases rapidly, the active layer freezes, and the effects of geomorphological processes are small. The origin of permafrost and the operation of geomorphological processes and the related changes of rock properties manifest themselves naturally during the operation of geomorphological processes and the development of specific cryogenic forms. Permafrost is a dynamic system adapting itself to the changing conditions of the environments as most of it is linked to present climate-soil-vegetation, relief, hydrological conditions and the activities of man. In any consideration of permafrost dynamics, and also therefore, of the development of landforms, the temperature, thickness and origin of the permafrost are of greatest importance. In low temperatures permafrost is stable and the development of landform is slow. Around 0°C, permafrost dynamics are, on the contrary, much more active and the development of specific cryogenic forms takes place. Permafrost thickness also plays an important part. The exact permafrost thickness has not yet been recorded in the Tista basin area. Here, a thickness of more than 500 m. is assumed. The origin of permafrost is of considerable geomorphological significance, mainly because it affects the distribution of ground-ice in frozen rocks, and especially in sediments. The dynamics of permafrost, that is, its aggradation and degradation, are of unusual significance for the development of landforms in the periglacial zone. Increase in the negative thermal soil balance results in a decrease of permafrost temperature. Because of this, permafrost aggradation also begins to result in a decrease of the thickness of the active layer and this in turn affects the dynamics of the geornorphological process. Depending upon its mode of origin and development, permafrost usually contains various kinds of ground-ice. 'Texture ice', involving ice crystals from some tens of millimetres upto a few centimetres in size, forms a typical cryogenic texture in the case of rock freezing. This texture is defined by its form, dimensions and the distribution of ground-ice crystals in the frozen rock.

In the case of the development of epigenetic permafrost, vertical freezing dominates. The cryogenic textures can, therefore, be utilised for an analysis of permafrost facies and to reconstruct the geomorphological conditions of permafrost development. Geomorphological investigations and an analysis of areal photographs, Satellite imagery of various parts of the north and north-western part containing periglacial features (Pleistocene), revealed many interesting facts about relict periglacial phenomena, typical periglacial landscape relating to cryonival morphogenesis and also post-cryogenic textures. It has been found that in the case of permafrost degradation at the end of the Pleistocene, a suites of landforms as pseudomorphs of ice wedges and like were preserved in the earlier periglacial zone. Broadly speaking, post-cryogenic textures have been observed primarily in slope deposits and also fine-grained surface deposits marked by high porosity and friable nature which contain pseudomorphs of ice wedges of various sizes including texture etc. During permafrost degradation ground ice thawing and changes of rock properties take place. On steeper slopes, solifluction and mud-flows develop owing to over saturation of soils with water from melting ground ice. These movements naturally result in the disturbance of cryogenic textures. On gentle slopes or in the case of a lower degree of saturation of soils with water, rock consolidation takes place without any disturbance of the textures. In place of ice crystals, fine cracks are preserved, forming a so called post-cryogenic texture. During permafrost thawing, considerable changes in volume, consolidation of sediments and relief changes must have taken place which have not yet been sufficiently evaluated by geomorphologies and Quaternary geologists.

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AN OUTLINE OF THE PHYSICAL GEOGRAPHY OF SIKKIM

Maitreyi Choudhury

The state of Sikkim is a upper part of the Tista basin. The landscape of the state owes much to the drainage network of the river Tista. All the major river of the states are southerly flow. The northwestern part of the state is highly elevated and therefore remain under snow cover almost through out the year. The resultant topography is that of a typical glaciated one, characterised by cirques, aretes, glacial troughs and morainic deposits. There are numerous glacial lakes which freeze during winter. Many of the lakes are choking with sediments. In recent years, there is a noticeable reduction in the size of some of the larger lakes of Sikkim.

Introduction

Small though in size, the state of Sikkim is unique from the point of view of geographical aspect. The sheer location of this Himalayan state attracts researchers from different parts of the world. It arouses as much interest among the new researchers as among the veterans.

The geographical location of Sikkim is invaluable for India. A cursory glance at the location of Sikkim in the map of India reveals the extraordinary strategic importance of the state. Sikkim shares international boundaries with three neighbouring countries, viz. China, Nepal and Bhutan. Although barely 114 km. long and 64 km wide, this tiny mountain state deserves much attention.

The Physical Landscape

Topography: The topography of Sikkim is characterised by great variation in elevation. The range of elevation is enormous. At places it is as low as 250 m. while at the other extreme it is as high as 8500 m. By virtue of its location in the Lesser Himalayan Zone, the topography is out and out mountainous.

The state is griddled by high ridges on the North, East and West and thus looks like an amphitheatre. To the North the convex arc of the Greater Himalaya separates the State from Tibetan Highland. A number of peaks built up of crystalline rocks accentuate the demarcation between Tibet and Sikkim. The longitudinal Chola range separates the state from Tibet in the eastern side while the Singalila range, another longitudinal offshoot of the Himalayan arc, marks the boundary between Sikkim and Nepal in the west.

The griddling ridges on the three sides of the state contain some imposing peaks and high altitude passes. The exalted peaks of Kanchenjunga (8595 m), Siniolchu (6895 m), Pandim (6706 m), and high altitude passes like Nathu La (4728 m), Jelep La (4040 m), etc. are all located within this Himalayan state. Following are the important peaks and passes located in Sikkim

Sectors		Peaks (above 6000 m)		Passes
Northern Sector:	i)	Lhonak	i)	Chorten Nyima La
	ii)	Sentinel	ii)	Naku La
	iii)	Chorten Nyima	iii)	Kongra La
	iv)	Khora Khang	iv)	Tsak La
	v)	Khora Tso Gna Khang	v)	Bam Tso La
Eastern Sector:	vi)	Pauhunri	vi)	Say Say La
			vii)	Ghora La
			viii)	Khanchung La
			ix)	Pata La
			x)	Thangkar La
			xi)	Nathu La
			xii)	Jelep La
			xiii)	Batang La
			xiv)	Doka La
Western Sector:	vii)	Jonsang	xv)	Jonsang La
	viii)	Langbu	xvi)	Khang La
	ix)	Pyramid Peak	xvii)	Daiu La
	x)	Tent Peak		
	xi)	Nepal Peak		
	xii)	Kanchenjunga		
	xiii)	Kabru		
	xiv)	Talung		
	xv)	Rathong		

Geomorphologically, the State of Sikkim belongs to the upper part of Tista basin. In fact, the boundary of the Upper Tista basin virtually marks the state boundary. The present landscape of the state owes much to the drainage network of the river Tista. The structural slope of the land is from North to South, hence all the major rivers of the State have southerly flow. However, small streamlets appear from almost every corner of the state and run on all possible directions. They have dissected the land so intricately that there is no sizeable piece of level land anywhere in the state. The north-western part of the state is highly elevated and therefore remain under snow cover almost throughout the year. The resultant topography is that of a typical glaciated one, characterized by cirques, aretes, glacial troughs, and morainic deposits. Besides, there are numerous glacial lakes which freeze during winter. The freezethaw action at the shores of the lake give rise to typical periglacial features, such as patterned ground and solifluction deposits (rock wastes). Similar landscape features are also found all along the Northern and Eastern highlands.

The present landscape of Sikkim is in a state of rapid evolution. The ongoing glacial, periglacial, glaciofluvial, fluvial and pluvial activities are continually reshaping the face of this young mountain topography. While the swift-flowing rivers are transporting loads of eroded materials by chiselling the valley side slopes, many of the lakes are choking with sediments. In recent years, there is noticeable reduction in the size of some of the larger lakes of Sikkim.

The glaciers of Sikkim

A substantial area of Sikkim lies above 5000 m above msl, i.e. above the snow line. The snow peaks of Sikkim are visible from the plains of North Bengal even during the hottest summer months. Quite an extensive area of Sikkim remains snowbound round the year, especially in the northern, eastern and western parts. The snowfields of Sikkim give rise to several medium and small sized glaciers. They are: Tista Khangsa glacier (below Pauhunri Peak, North Sikkim), Khangpup Khangsa glacier (North Sikkim), Lhonak North and Lhonak South glaciers (below Lhonak Peak, North Sikkim), Langbu glacier (below Langbu Peak, North Sikkim), Chungsang glacier (below Pyramid Peak, North Sikkim), Tent Peak glacier (below Tent Peak, North Sikkim), Nepal gap glacier (below Nepal Peak, North Sikkim), Zemu glacier (below Kanchenjunga, North Sikkim), Hidden glacier (between Chungsang and Zemu glaciers, North Sikkim), Talung glacier (below Talung Peak, North Sikkim), Zumthul Phuk glacier (North Sikkim), Rathong glacier (below Rathong Peak, West Sikkim).

Excepting the first two of these glaciers, all descend from the eastern slope of the Singalila range and thus can be called the Singalila group of glaciers. All these glaciers are cirque glaciers. Most of these glaciers extend eastward, almost parallel to each other. The largest and most important among them is the Zemu glacier. Almost all the glaciers of Sikkim give birth to some streamlets. The Tista Khangsa, as the name suggests, is the breeding ground of the river Tista. The melt water of this glacier accumulates in a tarn (glacial lake), the Chho Lhamo. The spill water of Chho Lhamo and a series of small glacial lakes ultimately forms the head water of the river Tista. The Lhonak glacier gives rise to the Goma Chhu or Lhonak Chhu, which is a sub-tributary of the Tista. From Zemu glacier rises the Zemu Chhu, one of the chief feeders of the Tista. Yet another important river, the Rathong Chhu, originates from the Rathong glacier and contributes to the Rangit river.

The River System of Sikkim

There is only one major river system in the state of Sikkim, that is of the river Tista. The Chola range in the east and the Singalila range in the west determine the boundary of the Tista. The entire state is drained by the Tista, its numerous tributaries and innumerable sub-tributaries.

The master stream Tista originates from a glacial lake Chho Lhamo located at the northeastern corner of the state. On its journey to the plains, the river receives scores of tributaries from either sides of its course. The tributaries coming from the east are more in number but shorter in length and have less amount of discharge, while those coming from the west are fewer in number but much larger and conspicuous. The latter, i.e. the right-bank tributaries of the Tista have developed their own elaborate drainage network and have formed second order drainage basins. Consequent the amount of discharge of these tributaries is greater. The right-bank tributaries are more voluminous due to the fact that all of them have their feeders in the high mountain glaciers. The glaciers like Lhonak, Zemu and Rathong in the west heavily feed the right-bank tributaries. In comparison, many of the left-bank tributaries originate from seasonal rain and semipermanent snow-fields, hence are ephemeral in nature. The major tributaries of the Tista within the state of Sikkim are listed below:

	Tributaries	
S.No.	Left-bank tributaries	Right-bank tributaries
i)	Chhombo Chhu	Zemu (Lachen) Chhu
ii)	Lhasa Chhu	Rangyong Chhu
iii)	Kalep Chhu	Rangphap Chhu
iv)	Gyamthang Chhu	Rangit Chhu
v)	Burum Chhu	
vi)	Gey Chhu	
vii)	Tarum Chhu	
viii)	Rabom Chhu	
ix)	Lachung Chhu	
x)	Ong Chhu	
xi)	Chakung Chhu	
xii)	Dik Chhu	
xiii)	Rongni Chhu	
xiv)	Rangpo Chhu	

The most important among all these tributaries is the Rangit. Other important tributaries include the Zemu Chhu, the Rangyong Chhu, the Lachung Chhu, the Dik Chhu, the Rongni Chhu and the Rangpo Chhu.

The Rangit Chhu, a right-bank tributary of the Tista originates from comparatively low altitude area in the south district of Sikkim. However, its chief feeder, the Rathong Chhu originates from the Rathong glacier in the west district of Sikkim. The Rangit receives quite a large number of tributaries on its way to the Tista. Apart from the Rathong Chhu, it is fed by the Rimbi, the kalej, the Rishi, the Roathak, the Rammam and the Manpur Khola. It also receives some tributaries from the Darjeeling hills of West Bengal, namely, the little Rangit, the Jhepi and the Ragnu Khola. After its confluence with the Rammam, the Rangit river comes to be known as the Great Rangit or 'Bari Rangit'. The combined course of the Rammam and the Great Rangit marks the southern boundary of the state. The Great Rangit ends its journey near Melli where it meets the Master stream, the Tista.

The Zemu Chhu, another right-bank tributary of the Tista, originates from the snout of the Zemu glacier. Initially, the river flows due west and is known as Poke Chhu. After receiving the Lhonak Chhu from the North-West, it comes to be known as the Zemu Chhu. The Zemu Chhu meets the Tista near Zema in North Sikkim.

Another important right-bank tributary of the Tista is the Rangyong Chhu. It has four main feeders, namely, the Talung or Rukel Chhu, the Umram Chhu, the Ringpi Chhu and the Rahi Chhu. The river drains the Dzongu area of North Sikkim and debouches on to Tista near Lingthem.

The Lachung Chhu is the most important left-bank tributary of the Tista. The head stream of the Lachung Chhu lies very close to the head stream of the river Tista. Initially the river is known as the Donkhya Chhu and after some distance comes to be known as the Yumthang Chhu. After receiving the waters of the Sebozung Chhu, the Yumthang Chhu comes to be known as the Lachung Chhu. The Lachung Chhu meets the Tista at Chungthang.

The Dik Chhu, a left-bank tributary of the Tista, has two main feeders, namely, the Bakcha Chhu and the Ratey Chhu, both originating from the Indo-Tibetan border ranges in the East. The Dik Chhu flows due west and marks the boundary between the north and the east districts of Sikkim. The Dik Chhu meets the Tista at Dikchhu village.

The Rongni Chhu, another left-bank tributary of the Tista is the combined form of three streams, namely, the Yali Chhu, the Rora Chhu and the Takchom Chhu. All the streams originate within the east district of Sikkim. The Rongni Chhu, also known as the Rani Khola, meets the Tista at Singtam.

The Rangpo Chhu, the last of the left-bank tributaries of the Tista, originate from a lake very close to the Indo-China border. Its feeders include the Byu Chhu, the Lunze Chhu, the Rangli Khola and the Rishi Khola. The Rangpo Chhu meets the Tista at Rangpo, the gateway of Sikkim.

The Lakes of Sikkim

Most of the lakes of Sikkim are glacial in origin, hence, are confined in high altitude areas.

Perhaps the only exception is the Khachodpalri (Khechiperi) lake which is located in a low altitude valley (1945 m) near Yoksum in West Sikkim. The northern part of Sikkim is dotted with fresh water lakes, but due to inaccessibility and difficult terrain, not known to many. Most of them are still unnamed. In the western part of Sikkim too, a few lakes lie in the midst of wilderness, such as, the Lam Pokhari, the Lachhmi Pokhari and the Kathok Lake. The most popular lake of the state is the Tshangu in East Sikkim. However, the most picturesque and one of the largest lakes of Sikkim is the Mey Mey Chhu, which is also located in East Sikkim, close to Indo-Tibetan border. Some other lakes worth mentioning are the Chho Lhamo (5,099 m) and Gurudongmar Chho (5176 m) in North Sikkim and Bitang Chho in East Sikkim.

The Hot Springs of Sikkim

Sikkim has a few mineral springs where warm water oozes out from beneath the surface with a strong sulphurous odour. Most of these are locally known as Dawaipani and Tatopani. The hot springs of Yumthang, Ralong and Phur-Cha-Chu are widely known for their medicinal efficacy. The Ralong hot spring is located on the western bank of the Rangit river near Ralong monastery in West Sikkim. The Phur-Cha-Chu is located on the eastern bank of the Rangit near Rinchingpong monastery in South Sikkim.

The Climate of Sikkim

Sikkim is a land of great climatic contrasts within very short distances. Latitudinally, the basin is located within the sub-tropical climatic regime. But, due to the presence of high mountains, here one can experience climates as varied as temperate, alpine and even arctic type. Elevation plays the prime role in fashioning the climatic types of the State. The differences in the climatic types can be imagined from the fact that the altitude of Sikkim ranges from a mere 300 m above amsl. to more than 8000 m above msl. Their diversity is due not only to the differences in altitude but also to the configuration of the neighbouring mountain ranges which largely affects air movement, rainfall and temperature. The climate of Sikkim may broadly be classified into the following types:

i) **Sub-tropical Humid Type**: The areas lying below 1500 m amsl. experience sub-tropical humid type of climate. Here the day temperatures in summer are as high as 35° C. At Namchi in South Sikkim, the summer maximum is 35° C. while the winter minimum is 6° C. The average annual rainfall is high, but it varies from place to place (1500 mm to 3500 mm) due to variations in aspect. The south-facing i.e. the windward slopes intercept more rainfall than the north-facing, i.e. lee-ward slopes. While Tadong (1500 m amsl) in east Sikkim receives more than 3000 mm. of annual rainfall, Namchi (approx. 1500 m amsl.) in South Sikkim records barely 1550 mm. of annual rainfall. Again Mangan (1310 m) in north Sikkim receives 3200 mm. of annual rainfall while Dentam (1372 m) in west Sikkim records 2300 mm. In the sub-tropical climatic zone, the humid period is very long, extends almost for six months from April to September. Night time showers are common in summer months, thus rendering cool nights even in hottest summer days. Winters are usually cold and dry.

ii) **Semi-temperate Type**: This is experienced in areas lying between 1500 m. to 2000 m amsl. Here mean annual temperature ranges from 8° C. in winter to 26°C in summer. On an average, only in one or two days in a year the temperature drops below the freezing point. Rainfall is usually heavy, with a mean annual of 2400 mm. Rainfall is exceptionally heavy in June, July and August when the south-west monsoon brakes in. Winters are generally dry except some occasional drizzling and very rare snowfall. At Gangtok (1818 m), the mean minimum temperature is 2°C while the mean maximum temperature is 26°C. The average annual rainfall is very high, about 3500 mm. Snow-fall is very rare.

iii) **Temperate Type**: The hill slopes lying between 2000m to 3000 m. amsl. come under this type of climate. Here the annual temperature ranges from 0°C in winter to 15°C in summer. Precipitation is medium to heavy, which occurs both in the form of rain and snow. At Lachen (2697 m) and Lachung (2633 m) valleys of North Sikkim, the average annual rainfall is 1700 mm. Within this zone, the summer months are never hot and the winter months are always very cold. Winter snowing is common. Frosting is also common at nights almost round the year.

iv) **Alpine Snow-forest Type**: This climate is experienced between 3000 m to 4000 m amsl. Here, temperature remains very low for more than five months of the year, i.e. from November to March. Of them, December, January and February are extremely cold. Rainfall begins from the end of May and continues till the month of September. In winter months, precipitation occurs in the form of slit and snow. Tshangu (3840 m) in east Sikkim records 2900 mm. of annual rainfall. The precipitation decreases at regular pace towards North, for example Yumthang (3673 m) records the annual precipitation at 1400 mm. while Thangu (3812 m) records only 800 mm. The major part of this area is uninhabited due to harsh climate.

v) **Alpine Meadow or Tundra Type**: This is prevalent only around the peripheries of the snow-capped areas in the extreme northern, eastern and western sections of Sikkim. The average elevation is more than 4000 m. amsl. Here air temperature is always very low, night temperatures often dropping below the freezing point. Atmospheric pressure is also low and uncomfortable for living. Precipitation is mainly through snow-fall, except in the summer months. Summer is brief, barely of three months duration, when alpine shrubs and grasses appear. For about four months of the year, the ground remains snow-covered and the soils remain frozen. No permanent settlement is found in this region.

vi) **Arctic Type**: The Arctic Type of climate is prevalent only in extreme north-western part of the state where a number of snow peaks soar high above 6000 m amsl. The snow peaks of the Kanchenjunga, kabru, Forked Peak, Talung, Tent Peak, Pyramid Peak, Jonsang, siniolchu, etc. are located within this climatic zone. The entire zone is bare of vegetation and animal life.