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B3: Geomorphological Field Guide Book on DARJEELING HIMALAYAS

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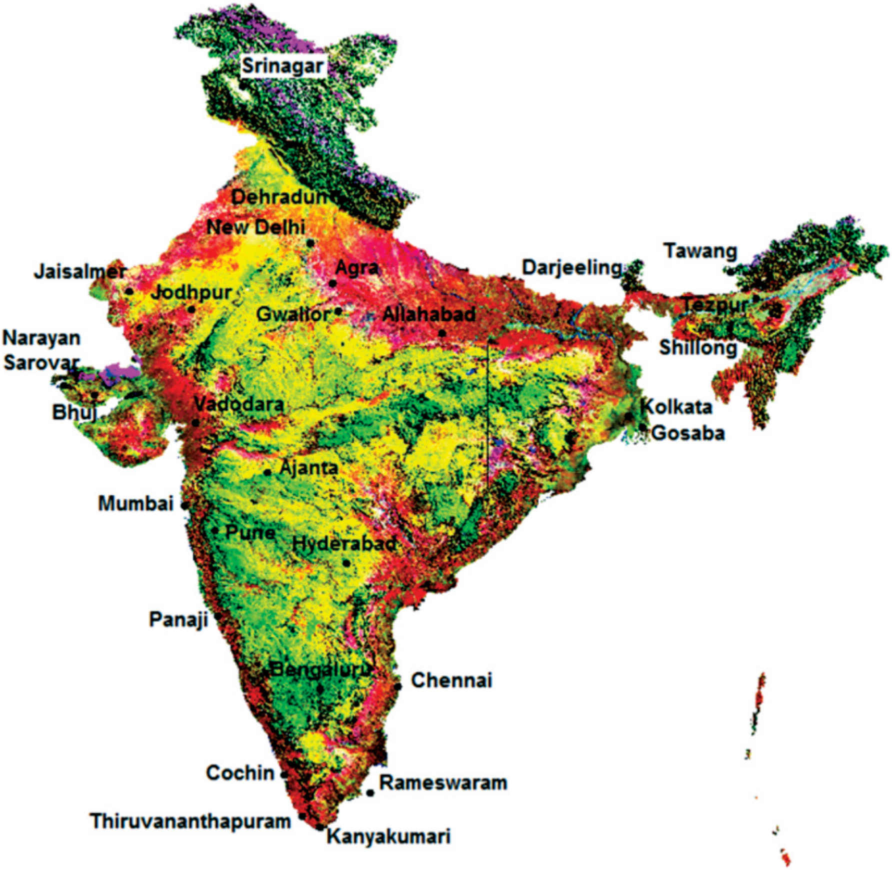

Fig. 1. Image-map of India, showing some places of interest for the 9th International Conference on Geomorphology, 2017 (Map prepared by A. Kar through processing of relevant ETM+ FCC mosaics and SRTM 1km DEM, both sourced from the US Geological Survey site). Boundaries are approximate.

Geomorphological Field Guide Book on Darjeeling Himalaya (12 November to 17 November, 2017)

Itinerary

Date	Places from - to	Stay
12 November 2017	New Delhi to Bagdogra by Flight Bagdogra to Siliguri General briefing and discussion	Siliguri
13 Novemver 2017	Bagdogra to Darjeeling (via Mirik) Stop 1: Balasan-Rohini Alluvial Fan Stop 2: Mirik Dome Stop 3: Simana Basti	Darjeeling
14 November 2017	Darjeeling Town and surroundings Stop 1: Ghum Stop 2: Tiger Hills (04-30am) Stop 3: Old Monestary, Ghum, Batasia Loop Stop 4: Bannockburn Tea Garden landslide Stop 5: Happy Valley Tea Garden Stop 6: Tibetan Refugee Centre Stop 7: Himalayan Mountaineering Institute, Tenzing Rocks	Darjeeling
15 November 2017	Darjeeling to Siliguri (via Kurseong) Stop 1: Ambootia Landslide Stop 2: Paglajhora Landslide Stop 3: Tindharia Landslide Stop 4: Sukna Stop 5: Kurseong	Siliguri
16 November 2017	Siliguri to Kalimpong Stop 1: Sevok in Tista Valley Stop 2: River Lish and Gish Stop 3: Kalijhora – TLDP Stage IV Stop 4: Rambhi – TLDP Stage III Stop 5: Tribeni confluence at Pesoke	Kalimpong
17 November 2017	Kalimpong to Bagdogra Airport Bagdogra Airport to Delhi by flight	New Delhi

Notes

A. DARJEELING HIMALAYAS: AN INTRODUCTION

Darjeeling Himalayas *(Fig. 2)* is located above 300 m contour line in the mountainous part of Darjeeling district and is bounded by latitudes 26°50'00"N to 27°13'05"N and longitudes 87°59'30" to 88°53'E. It has an area of 2417 sq. km, spread over three Hill Sub-divisions of Darjeeling Sadar, Kalimpong and Kurseong, where, according to the 2001 Census, approximately 808,293 people reside. Kalimpong has recently become a separate district. The region is highly prone to landslides, often causing disruptions to socio-economic activities as well as destruction of life and properties.

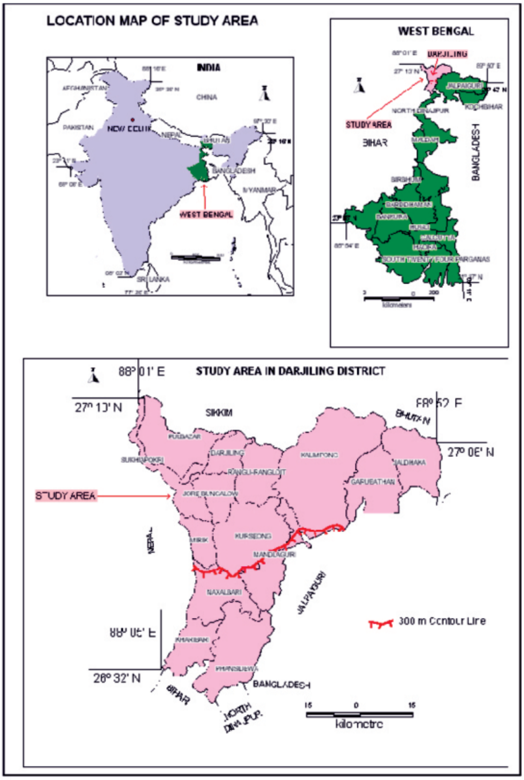

Fig. 2.
Location map of Darjeeling district.

Darjeeling Himalayas has an elevation range of 2000-3000 m, and occurs as the foreland of the Kanchenjunga massif. During the period of summer monsoon, moisture-laden wind from the Bay of Bengal gets obstructed along this foreland, which often leads to heavy to very heavy rainfall. The incessant heavy rainfall causes rapid runoff, which, in the current scenario of extensive deforestation, urbanisation and other activities that encourages high soil loss, favours landslides, floods and mud flows. More often the damages after heavy rainfall events are enormous. The major aims of this field trip are to inspect some of the landslide-affected terrain features, the impact of the landslides on the surrounding landscape, and the land uses that trigger the landslides in the region. Since Darjeeling area is famous for tea growing, some of the tea gardens will also be visited.

Climate

Darjeeling Himalayas is situated in the humid tropical belt with a monsoonal circulation. At Darjeeling town, the temperature fluctuates between -5°and 27°C, while in the plains at the foothills of the Himalayas the temperature varies 4° and 42°C in the plains. The annual precipitation varies from 2000 to 4500 mm, and in an exceptional year it may reach 6000 mm. The rainy season starts by the end of May and continues up to the beginning of October. The mean maximum daily rainfall at Darjeeling is 172 mm but it may reach up to 500 to 600 mm. Of special importance are the continuous rains or heavy rains for 3-4 consecutive days. The mean monthly rainfall and temperature for Darjeeling district as a whole (averaged from several station data), and for the hills and the plains, are given in Table 1.

Table 1. Mean rainfall and temperature in the hills and the plains of Darjeeling district

Month	Hills		Plains		Darjeeling district	
	Rainfall (mm)	Temp. (ºC)	Rainfall (mm)	Temp. (ºC)	Rainfall (mm)	Temp. (ºC)
Jan	14.05	10.53	19.85	17.26	16.95	13.9
Feb	19.96	12.09	21.19	19.6	20.58	15.85
March	48.96	15.56	52.88	23.45	50.92	19.51
April	108.96	18.62	129.56	26.27	119.27	22.45
May	314.32	19.5	228.8	27.6	271.56	23.55
June	662.46	20.72	598.43	29.19	630.45	24.96
July	845.49	21.71	820.32	28.12	832.91	24.92
Aug	644.81	21.88	621.15	28.81	632.98	25.35
Sep	549.84	19.94	47.35	27.35	510.1	23.65
Oct	142.23	18.36	146.32	26.65	144.28	22.51
Nov	24.92	15.23	35.55	23.02	30.24	19.13
Dec	6.39	11.92	14.4	19.11	10.4	15.52

The aerial distribution pattern of rainfall in the region does not show any direct correlation with the elevation. The major factors for the aerial pattern are the exposure towards the humid air masses and the distance from mountain front. The higher rainfall of 3500-4500 mm is recorded at the southern edge of the mountain, but it abruptly declines to 2000-2500 mm northward due to wind shadow. Further north the rainfall increases again to 3000 mm on the elevated hill slopes and then declines below 2000 mm in the valley of the Rangit River (Starkel et. al, 2000).

Geomorphological Background

Relief

Darjeeling Himalaya rises abruptly from the North Bengal plain, the elevation changing rapidly from 100-130 m above sea level (a.s.l) to 2000-3000 m a.s.l within a distance of few kilometres. Once in the hilly terrain, narrow ridges separated by closely-spaced V-shaped valleys become numerous. Convex and straight slopes prevail, where the slope varies between 15°and 40°. It is also not uncommon to find some steep walls with undercutting and rock falls. The zone of Siwalik foothills, which is common in the western Himalayas, is practically absent here. The scarp-dissected front of the mountain reaches an elevation of 1500-1800 m over a distance of 10 km.

Streams, river valleys and channel characteristics

The narrow channels of the headwater streams dissecting the rocky terrain have a slope of 20-60%, which decline to 5% and less downstream in the foothills, where widening of the valley floor takes place. This foothills zone is called the “Terai”, where the wider valley floors are frequently filled up with large boulders transported by debris flow. The main river, the Tista, carries water from the Kanchenjunga Massif and the Sikkim Himalaya through its deep and narrow meandering valley that has been cut in the bedrock. Coming out of the mountains the Tista has formed a vast alluviual fan with many palaeo-channels that were formed by large floods and avulsion. A number of smaller rivers, i.e., the Balason, the Mahananda, the Lish and the Gish, originate in the Darjeeling Himalaya, and have formed braided courses on the plains, which are overloaded with sediments. These streams form smaller fans, the apex part of which could be noticed at the entrance of the mountains. Fragments of higher fan levels with well-develop soil profile are preserved between the alluvial fans. The shape of the terraces and the fan systems on the Terai piedmont zone is irregular, and are partly controlled by tectonics (Nakata, 1972).

The relief of the valley floors and river channels within the mountains exhibits features of youthful stage of evolution, which are characterized by steep ungraded channels, narrow floors, steep and undercut valley sides and hanging tributary valleys. The valley reaches of the Tista and the Great Rangit Rivers in the Darjeeling Hills are characterized by 100-200 m wide valley floors, having straight or sinuous channels with point bars, rare benches of terraces and steep alluvial fans. The valley itself, with a gradient of 2 0/00, has a character of incised sinuous or meandering canyon with vertical undercutting on one or both river banks. The tributary valleys along the Tista canyon have higher gradients of 2-150/00, which become still steeper in the headwaters area, i.e., 20-30 0/00.

A slightly different longitudinal profile of streams can be noticed in the valleys directly dissecting the mountain edge, i.e., the valleys of the Balason, the Mahananda, the Lish and the Gish. Although gradients at the headwaters are steep and are controlled by lithology and mass movement, as in the Tista catchment, the valley floors downstream become broader. Aggradation prevails despite a higher gradient. Finally, the channels in the Terai zone mingle over the alluvial fans and are either dissected in their apex pat (as in the case of the Balason), or continuously aggrade (like in the case of the Lish and the Gish). The Tista and the Mahananda are characterised by frequent avulsions during the last two centuries.

Landscape evolution

The young relief features of the Darjeeling Hills reflect intensive Quaternary uplift and the consequent vigorous valley down-cutting. The present-day uplift in the marginal part may still reach 3-4 mm per year. However, a number of accordant flat surfaces in the hills signify periods of stability in between the periods of different uplifts. Two such level surfaces, named the Gorubathan Surface and the Rangamati Surface, preserve the fragments of elevated fans with boulders, and suggest that during the periods of relative tectonic stability, stream aggradation spread upstream into the hills.

Many valley floors exhibit narrow terrace benches. One of these could be noticed upstream of the Kalijhora Creek along the Tista valley, where the bench thickness is about 40 m. It is formed of loamy sand and fine gravel, indicating that aggradation and delivery of suspended load took place during high floods.

Role of extreme climatic events in landscape evolution

It has been observed that under a dense forest cover the steep mountain slopes are usually stable, in the sense that some equilibrium is maintained between erosion and deposition on them, even during heavy rainfall events. But after deforestation takes place, both the slopes and the river channels frequently pass the threshold of erosion during extreme rainfall events. Shallow slides or slumps have been observed to have formed on the steeper slope segments when the daily rainfall exceeded 150 mm, or after continuous rainfall for about 3 days, totalling 200-300 mm. Such events generally occur once in 2 years.

Darjeeling Himalayas mainly experiences local downpour, but during extreme events like the one in October, 1968, when 600-1100 mm was recorded in 54 hours, there follows an extensive and simultaneous formation of debris flows along the whole length of the slopes and along the gullies. Such events have a recurrence interval of about 30-50 years. Normal flood events generally cause minor changes along the slopes, restricted mainly to incision due to washing of the finer sediments. Under extreme events considerably higher channel aggradation and avulsion take place, which coincide with the transformation of slopes. This simultaneous change in the slope and the channel profile is linked to the direct contact of the slopes and the channels in narrow valleys with the occurrence of rare continuous rains. Deforestation accentuates the process, as was evident from the location of mass-movement sites during October, 1968, when the cultivated fields, devoid of forest cover, were observed to be 10-20 times more numerous than on the forested lands. Under such scenarios the overloaded streams perform more lateral erosion and aggradation than down-cutting. The major exception to this behaviour in the region is River Tista, which does not show any change towards aggradation in its uplifting marginal zone.

Geology and Soils

Darjeeling Himalaya is separated from the foredeep of the Ganga-Brahmaputra plain by two active tectonic lines in the zone of subduction of the Indian block (Fig. 3), which created a sequence of over-thrusts pushed southwards, and deepening to the north *(Fig 3)*. The rock formations from north to south consist of the moderately resistant Darjeeling Gneisses, the Daling Metamorphics of varying resistance (i.e., phyllite to quartzite), and the Damuda Shales with coal beds. the Main Boundary Fault separates the Damuda Shales from the narrow thrust of the Siwalik, built of Tertiary sandy molass deposits. The Siwalik formations are separated from the subsiding Bengal Plain by the active Himalaya Front Tectonic Line *(Table 2; Fig. 3)*. Some fresh tectonic scarps and exposures of Tertiary over-thrust on the alluvium suggest that the movement is continuing. The uplift in the Eastern Himalayas is calculated to be of the order of 0.5 to 2.0 mm/year.

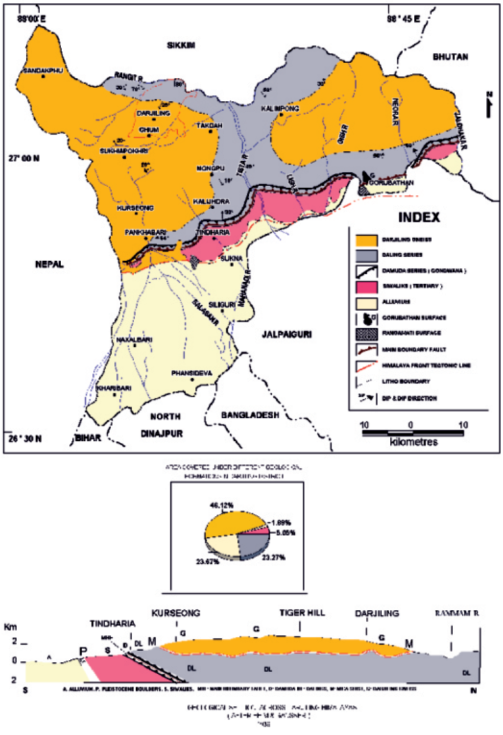

Fig. 3.
Geological map of Darjeeling district.

Table 2. Litho-succession of the Darjeeling Himalayas

Sub-recent and Recent alluvium (Pleistocene to recent)		High-level terrace deposits of gravel, boulder, nd sand, constituting the Terai	
Unconformity			
Structural Unit I	Siwalik Group (Mio-Pliocene)	Upper (400-500 m+)	Pebbly sandstone and conglomerate
		Middle (800-1250 m)	Medium grained micaceous dstone
		Lower (200-250 m.+)	Clay stone, siltstone and fine grained sandstone
Main Boundary Fault			
	Acid intrusive		Quartz vein
	Lamprophyre		
Unconformity			
		Dalingkote Formation (450-600 m +)	Hard quartzitic gritty sandstone (medium-coarse grained) shale, slate, carbonaceous sandstone with crushed coal seams.
Structural unit II	Damuda Group (Permian)	Chunabhati Formation (450-600 m.)	Fine medium grained micaceous quartzitic sandstone.
		Rongtong Formation (350 m. +)	Quartzitic sandstone of variable grain size siltstone slaty shale.
Daling Thrust (Overthrust)			
Structural unit III	Daling Formation (pre-Permian, but age unknown)		Phyllitic schist and quartzite.
Thrust (zone of sheared and lineated felspathic biotite-schist and gneiss)			
Structural unit IV	Darjeeling Gneiss		Coarsely micaceous migmatitic gneiss and schist with eyed lenses of calc-silicates.

Source: Records of the Geological Survey of India.

The mountain slopes are covered with sandy to silty soils, usually 0.5 to 2.0 m thick (up to 4 m on the flat surfaces). They change from red clay soils in the lowest elevation to grey brown forest soils in the higher elevations. Soils are generally permeable but their thickness and physical parameters vary from place to place, depending on the slope gradient, lithology, weathering potentials of the bedrocks and land use.

Landslides

Due to the above tectono-geomorphic setting of the hills and destabilization of the hill slopes by increasing anthropogenic activities, the Darjeeling-Kurseong tract has emerged as one of the foremost landslide-prone areas in India (Basu and Starkel, 2000). Landslides and other types of slope failures, triggered by heavy monsoon rains, now occur almost every year. Ghosh et al. (2012) have identified three main types of slope failure in the area: shallow translational rockslides, shallow translational debris slides, and deep-seated rockslides. The shallow translational rockslides are most common in the area. The Ambootia Landslide of October 1968 is considered to be the largest landslide in modern time, and involved a deep-seated rockslide that continued to remain active for the next 1-2 decades (Starkel, 2010).

Hydrology

The distribution of rain water is regulated rather by the soil permeability than the slope gradient. The assessment of the infiltration rate in some localities showed very high values reaching even up to 70mm/min, but at or near landslide niches they may go down to 2-5 mm/min. However, the high soil permeability prefers/induces subsurface runoff and high seepage pressure. The overland flow is thus very low i.e., after a rainfall of 50mm with an intensity of 0.5mm/min, the overland flow measured only 1-6 litter/min Froehlich et. al, 1989).

An attempt was made by Sarkar (1998) to assess infiltration rates at different sites in Darjeeling town which revealed rapid infiltration during the first 15 minutes, followed by a sluggish infiltration over the nest hour. Forest-covered slopes recorded more infiltration than the non-forested areas, i.e., 39 mm/minute at Katapahar area and only 6.3 mm/minute at an urbanised area near Sailabas *(Fig. 4)*. It was observed that during the heavy monsoon rains most roads acted as the surfaces of high runoff/overland flow. One study on a slope of 17^{o}near St. Paul's School showed that the peak runoff reached a high of 80% of the total rainfall *(Fig 5).*

In the river channel, the hydrograph shows frequent peaks during the rainy season. In the Tista River the mean annual fluctuation exceeds 5 m, but during extreme events it reaches 20 m (e.g., during the extreme flood of 1968). The fluctuation of discharge depends on the size of the basin and on the duration and extension of heavy rains. In the case of the Mahananda River, the discharge fluctuated during 1985-87 between 0.7 to 758 cumec (Sarkar, 1989). The runoff coefficient reached 60-80% and the calculated specific runoff during extreme events exceeded at least by 10-20 m3/km2 in the 2nd and the 3rd order stream catchments (Froehlich and Starkel, 1987).

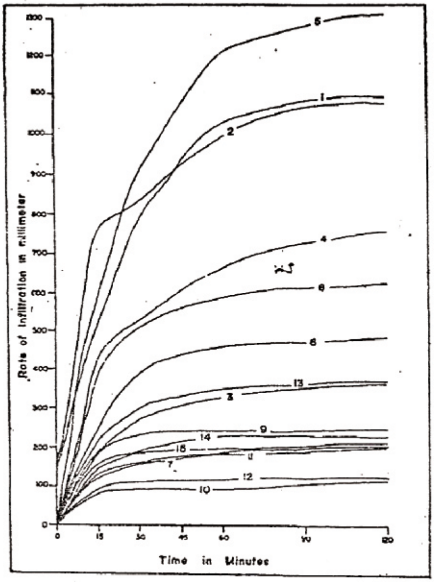

Fig 4.
Infiltration curves of 15 sites in and around Darjeeling town.

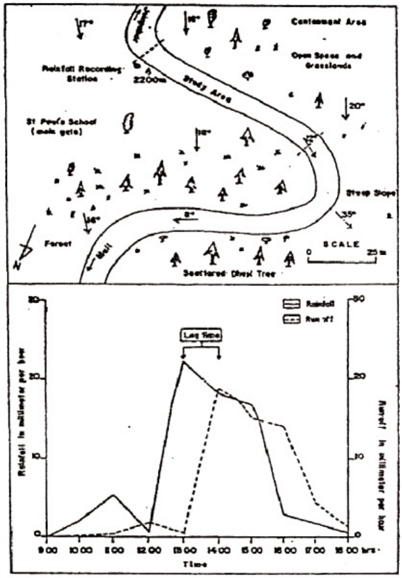

Fig. 5.
A typical rainfall run-off curve for the area.

Vegetation

There are three distinguished vertical zones of evergreen forest in Darjeeling Himalayas (Schweinfurth, 1968). The tropical forest belt reaches the elevation of 900-1000 m a.s.l., characterised by the Sal forest (Shorea robusta). The sub-tropical belt between 900-1800 m a.s.l. supports mixed vegetation with Castanopsis, Machilus, Schina, etc. The upper forest belt up to the peak of the mountains is represented by temperate species such as Quereus, Acer, Batula, Alnus, Rhododendron, and the exotic Cryptomeria japonica.

Socio-economic Aspect

Darjeeling district comprises of four sub-divisions, namely Sadar sub-division, Kalimpong sub-division, Kurseong sub-division and Siliguri sub-division. The Darjeeling hills area is spread over the first three sub-divisions. Siliguri subdivision is in the plains. Kalimpong has recently become a separate district.
Population growth and Natural resources

British East India Company took over Darjeeling from the King of Sikkim in 1835 when only 100 souls of Lepcha community were the inhabitants. With the construction of the Pankhabari Road in 1840 and of the Hill Cart Road in 1869, and following the development of tea plantation, the population of Darjeeling started to increase rapidly in every decade.

The first official census of the district was carried out in the year 1871-72 when the total population was found to be 94712, with an average population density of 81 persons per sq mile. However, this census was subsequently found out to be defective, and the results appeared wrong.

The regular influx of immigrants from Nepal, and gradual residence of people from different parts of India since 1980s helped to create a multi-lingual and multi-cultural society in the area. Very high population growth was observed in the urban areas and road-side village market areas. The Census data on population in different hill sub-divisions of Darjeeling district for 1981 to 2011 reveal a steady growth of population during the last four decades. Kurseong and Kalimpong sub-divisions are registering higher growth percentage *(Table 3)*.

Table 3. Total population in the three hill subdivisions of Darjeeling district (1981-2011)

Subdivision	1981	1991	2001	2011	% Change (1981 to 2011)
Sadar	281346	347912	388107	310576	10.4
Kurseong	111302	146640	177264	140721	26.4
Kalimpong	158726	190266	225220	202239	27.4
Total	551374	684818	790591	653536	18.5

The steady growth of population in Darjeeling hills area since 1872 is mainly due to two reasons: first, the development of tea industry, and second, the influx of settlers. The job opportunities provided by the Tea Estates attracted huge work force to their tea gardens from the plains, and many more came in as job-aspirants. According to the 1911 census, the Tea Estate workers accounted for more than two-third of the total population of the district. When the tea industry passed through a serious crisis during the end of Nineteenth Century, prices fell greatly between 1896 and 1901 and many Tea Estates were no longer able to work at a profit. A few gardens closed and few others had to reduce their work force. Despite the fact that Darjeeling's tea industry was revived somewhat after the independence, and its fame for quality products maintained, the age-old plantations, worn-out and obsolete machineries and stiff competition from new gardens in other parts of the country and elsewhere became worrisome. Trade and commerce, especially related to tourism, started to flourish in and around Darjeeling town and Kalimpong. The major work force, however, remained with the Tea Estates. Surprisingly, a look at the Census data from 1981 onwards reveals that the workers always constituted less than 40% of the total population *(Table 4)*.

Table 4. Percentage of workers in population of Darjeeling district (1981-2011)

Subdivision	1981	1991	2001	2011
Sadar	35.7	32.0	34.4	38.0
Kurseong	34.6	31.19	35.7	36.6
Kalimpong	37.4	35.9	358.8	39.0
Total	36.0	33.1	36.0	38.0

Land use

The dominantly forest landscape of Darjeeling hills started to change when commercial tea plantation began in the mid-19th century. The British started to build roads and establish the first tea garden in 1850-60, which activities necessitated forest clearance. By the end of the 19th century more than 200 tea gardens were developed, spread over 200 sq. km area. The major concentrations took place along the two main roads and reached up to an elevation of 1800-2000 m a.s.l. The area under forest diminished steadily from 51.5% of the total area in 1901 to 38.27% in 2014 due to the ever-increasing population pressure, and also due to the slash and burn system of cultivation. This is despite the fact that a Darjeeling Forest Division was established in 1878 to restrict deforestation and to start new forest plantation.

Presently the district has its 22.5% of land under tea plantation and 37% under other cultivations *(Fig. 6)*. The main crop is tea, but during the past 50 years tea economy is under increasing threat, leading to abandonment of many tea gardens. Also, most tea bushes are older than 80 years, and so have declining productivity and quality. Other cultivated areas are expanding rapidly due to population pressure. Maize, potato, millet, paddy, orange, cardamom, ginger and vegetables are grown on the narrow slope terraces. Due to shortage of land, even the steeper slopes are put under cultivation.

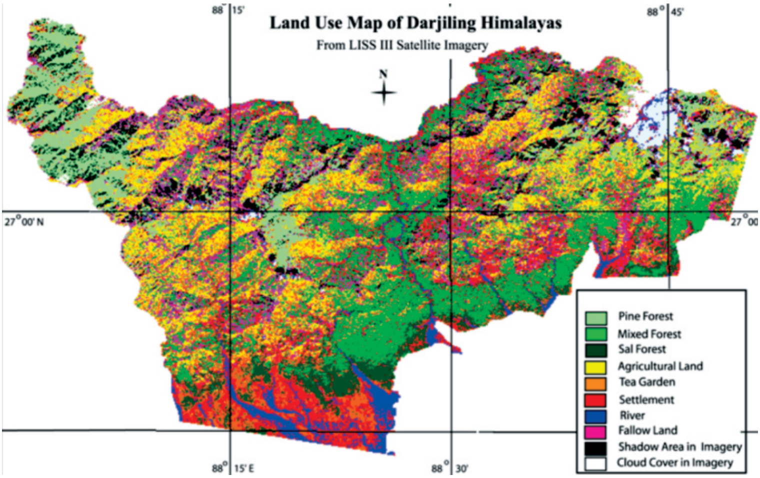

Fig. 6.
Land use in Darjeeling Himalayas.

As tourism is becoming more popular, the towns are getting more crowded, creating problems of space for house construction, as well as for water and other amenities. In the towns many houses are being constructed on steep slopes with weathered rocks, making them unstable. Construction of many new roads is destabilizing the slopes. As a result, the susceptibility of the land to landslides is increasing manifold during heavy rains. As deforestation progressed, the drainage system got impacted, and it led to the paucity of water for the urban localities. The natural resources of Darjeeling Himalayas need immediate conservation measures and a viable land use plan for sustainable resource use.

Places of Tourist interest

There are many places which attract the tourists in huge number. The places are as follows:

Tiger Hill, Batasia Loop, Chowrastha and Mall, Peace Pagoda, Roch Garden and Ganga Mayeea Park, Botanical Garden, Padmaja Naidu Himalayan Zoological Park, Himalayan Mountaineering Institute, Dali Monastery and Ghum Monastery.

B.DESCRIPTION OF THE FIELD SITES

Day 1: 12/11/2017
New Delhi to Bagdogra Airport by Flight
Travel to Siliguri
Stay at Siliguri.

The first day will be spent in discussing the travel routes, the general characteristics of the area, and the logistics. During the period of visit two separate trips will be made from the base, Siliguri, to the mountains. The first trip will be made to Darjeeling. Returning back from there a trip will be made from Siliguri to Kalimpong.

Day 2: 13/11/2017
Siliguri to Darjeeling via Mirik
Stay at Darjeeling

The route from Siliguri to Darjeeling passes first through a flat-lying “Terai” terrain with lush green crop fields and tea gardens, with occasional rivulets, and then climbs gradually up the hills through a narrow road flanked by forest plantation, or tea gardens. Landslide scars can be seen at places. At least three halts will be made to appreciate the geomorphic features along the road.

Stop 1: The Balason – Rohini Alluvial Fan (on way to Dudhia and Mirik)
The rivers coming down from the Himalayas to the wide, open plains of North Bengal have developed a number of alluvial fans. Between the 300 m contour in the north and the 75 m contour in the south, these alluvial fans coalesce to form a piedmont zone. The fans between the Balason and the Rohini rivers cover an area of about 40 sq. km, and can be considered as the best-developed on way to Darjeeling. The two streams are the tributaries of the Tista River, and have catchments in the Himalayas. The variability of slope and sediment texture along these fans roughly determines the broad land uses on the fans. Land use is dominated by the tea gardens (45%), followed by forest (39%) and arable land (10%). The evolution and morphology of the fans are briefly described below.

Fan evolution

The fact that some thick boulder beds unconformably overlie the northward-dipping Siwalik strata (Pliocene-Pleistocene) at the base of the Eastern Himalayas suggests that the boulder formations originated sometime during the Pleistocene period, especially following a phase of uplift, tilting and partial denudation of the Siwaliks. This was also the period when the higher parts of the Darjeeling Himalayas were experiencing widespread glaciation. Periglacial conditions prevailed in the Manebhanjan-Sukhiapokhri-Ghum range (N26°57′ to N27°00′; E88°00′ to E85°20′). The main stream, the Balason River, and its major tributaries, the Rakti and the Rohini, brought down a large volume of periglacial debris and solifluction materials, which eventually got deposited as coalescing alluvial fans when the streams reached the foothills (Kar, 1962, 1969; Godwin-Austin, 1968).

Fan materials and modes of deposition

The fan materials are coarse-grained and poorly-sorted, and have developed immature sediment profiles (Basu and Sarkar, 1990). Usually gravels, cobbles and boulders predominate, while the quantities of sand, silt and clay are much less. The coarsest and thickest deposits occur near the fan heads. The maximum grain size and sediment thickness decrease rapidly towards the base of the alluvial fans. The roundness of coarse grains increases with increasing distance from the apex of the fans. Intermittent flush floods and mass movements are the notable modes of deposition here. Bank erosion and avulsion are also quite common.

Fan segments

Three broad zones can be identified on the fans. These are depicted in *Fig. 7 and Fig. 8.* Table 5 provides some important characteristics of these fans.

Table 5. Characteristics of alluvial fan segments

Segment	Area (sq. km	Area (% of total)	Slope (degree)	Materials	Major processe	Major land uses
Upper	10.23	25.70	3.5-10.0	Coarse-grained gravels, cobbles and boulders	Flash floods, debris-flow, solifluction and steam action	Forest, tea garden
Middle	18.26	45.87	1.5-3.5	Medium grained sand-silt with occasional boulders	Stream action and stream floods	Forest, tea garden, arable land
Lower	11.32	28.30	1.0-1.5	Fine grained sand, silt and clay	Stream action and stream floods	Forest, tea garden, arable land

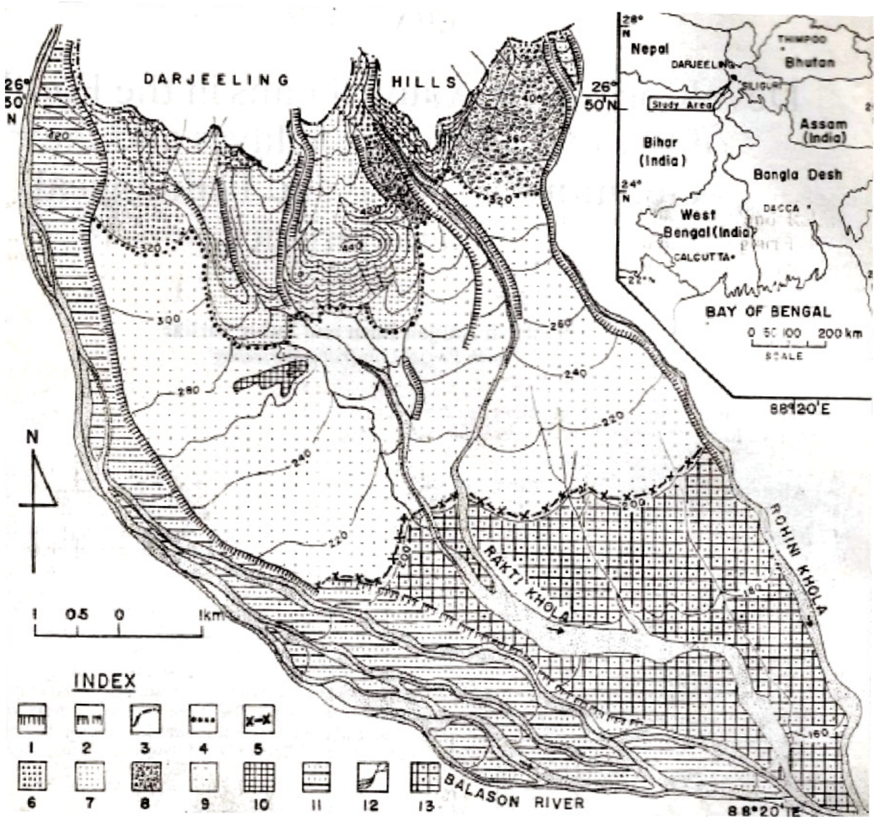

Fig. 7.
Geomorphological map of the alluvial fans between the rivers Rohini Khola and Balason. Key to legend: 1. scarp, 15-25m; 2. scarp, 5-10 m; 3. limits of the Darjeeling Hills; 4. lower limit of the upper fan; 5. lower limit of the middle fan; 6. slope wash and mass movement materials; 7. landform due to mixed processes, including slope wash, mass movement and alluvial deposits; 8. boulder beds; 9. middle fan; 10. elevated tracts due to resistant rocks; 11. floodplain of Balason River; 12. river; 13. lower fan.

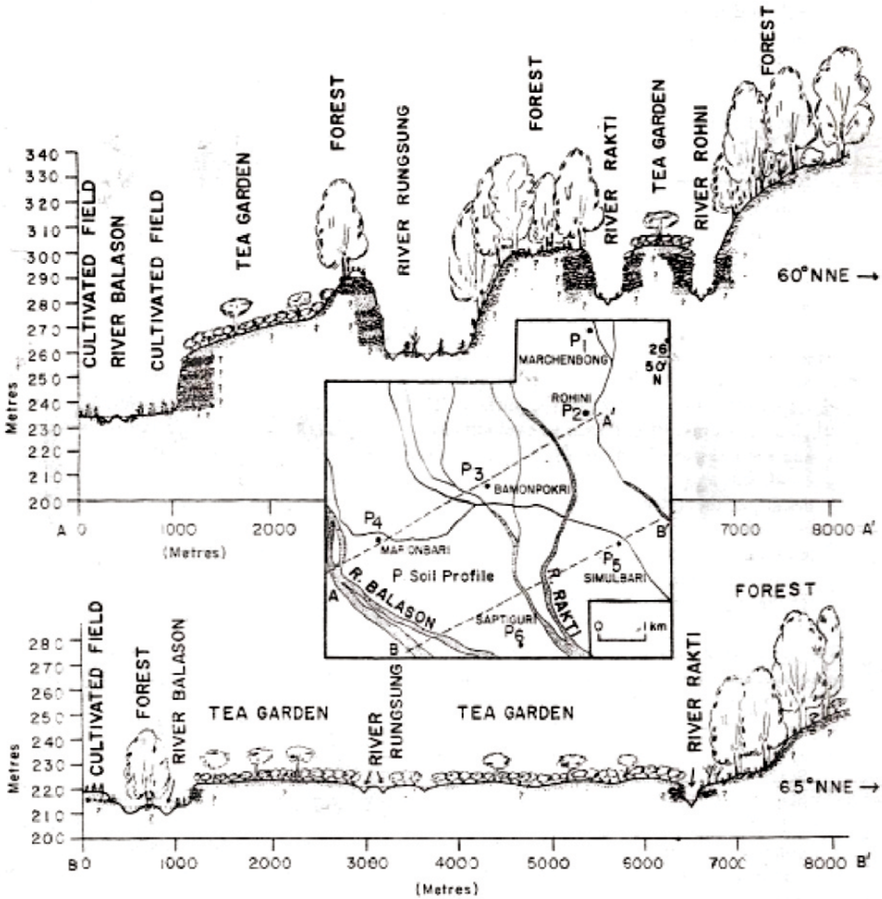

Fig. 8.
Cross-profiles, showing stratigraphy and land use on the alluvial fans (source: Basu, S.R. and Sarkar, S. 1990).

Stop 2: Mirik

Mirik is a picturesque tourist spot nestled in the serene hills of Darjeeling district, and is the headquarters of Mirik subdivision. The name Mirik comes from the Lepcha words Mir-Yok, meaning "a place burnt by fire". Mirik has become a popular tourist destination for its climate, natural beauty and easy accessibility.

The centre of attraction at Mirik is Sumendu Lake, surrounded by a garden named Savitri Pushpaudyan (after Savitri Thapa, a martyrsd soldier of the Indian National Army, INA) on one side and rows of pine trees on the other. An arching footbridge, called Indreni Pool (named after Indreni Thapa, a martyr soldier of INA), links the two sides. A 3.5-km-long road encircles the lake and is used for a walk and to to view the Kangchenjunga Peak on the far horizon. It is believed that the lake is of tectonic origin, but so far there is no work to substantiate the view.

Another geomorphic attraction in the area is a domal topography. Although it looks like a dissected intermontane plateau, the sediments in the core part indicate that the landscape originated due to glacial deposition *(Fig. 9).* Most parts of the landscape are now deforested to make way for tea cultivation. It has encouraged the formation of chutes that have aggravated the landslide events.

Fig. 9.

Deforested Mirik domes, a major cause for landslides in the area

Stop 3: Simana Basti

Simana Basti is a village in Sukiapokhri Tehsil of Darjeeling district, and is located 79 km away from sub-district headquarter Sukhiapokhri and 69 km away from Mirik on way to Darjeeling. The village is very close to Nepal border. The route to this border village provides a breath-taking view of the Himalayan landscape.

Day 3: 14/11/2017
Darjeeling town and surroundings
Stay at Darjeeling.

Darjeeling town, with a population of more than 200000, is a major tourist destination in India, especially as a summer resort. The town was connected with the plains by railways way back in 1881. In June 1950, following a catastrophic rainfall of more than 1000 mm, the town was severely affected by numerous landslides. Although Darjeeling has not experienced such a calamity after that event, the population explosion in the town is creating numerous problems for its inhabitants. Among these, water for drinking and other household purposes is becoming a highly scarce resource. Construction of houses has increased manifold, so much so that urbanization is now spreading downhill, as there is no room in the upper part of the town. Desperate efforts to stay within the town limits are forcing people to build multi-storied houses on unstable steeper slopes with highly weathered rocks, which are endangering the life and property of the inhabitants. The day will be spent on visiting some of the important places in and around the town.

Stop 1: Ghum

Ghum, situated at a height of 2250 m above mean sea level, and located only 6 km away from Darjeeling on the Siliguri-Darjeeling highway, is a small market town, as also a major watershed divide between some of the important stream catchments in the region. The E-W orientation of the ridge section here is a reason for its high cloudiness, higher humidity and long-duration precipitation. The crest zone is overgrown with Crytomeria japonica forest.

Ghum is famous for having one of the highest railway stations in the world for the more than a century-old railway line from Siliguri to Darjeeling, called the "Darjeeling Himalayan Railways" (also called the "Toy Train"). This small-gauge line was earlier the only means of bulk transportation of men and materials from the hill to the plains and vice-versa in slow-moving carriages, but as road transport facilities improved in the post-independence era, it lost much of its relevance. Yet, it continued to have a huge tourist attraction, and therefore, the Indian Railways tried to maintain the track and the carriages despite the technology becoming obsolete and difficult to maintain. Till very recently this railway line was a UNESCO World Heritage Site.

Construction of the Darjeeling Himalayan Railway started in 1879 and the railway track reached Ghum on 4 April, 1881. Until 1878, the journey from Calcutta (now Kolkata) to Darjeeling used to take 5-6 days, using steam-engine-pulled trains, crossing the Ganga River by steam ferry at Sahebganj, and then using bullock carts or palanquins for destinations further north. In 1878, Siliguri was put on the railway map of India, cutting down the journey from Kolkata to two days. By 2007, the train travel time from Kolkata to New Jalpaiguri (a new railway station 6 km from Siliguri) was reduced to about 10 hours. The travel time by road from Siliguri to Darjeeling via Ghum now takes about 3–4 hours. By contrast, a journey by the Darjeeling Himalayan Railway takes about 6–7 hours to cover the same distance. Consequently the slow train has lost its advantage. However, tourists, both domestic and international, have always been found to seek a ride on this vintage train, especially because of the kaleidoscopic views of the Himalayan terrain and the local socio-cultural pattern they get from a slow-moving train. Therefore, the Indian Railways have decided to continue the train service, despite the problems of maintenance, viability, etc.

Ghum is also the meeting point of several roads. The road from Siliguri to Darjeeling, best known as the “Hill Cart Road” runs through the town. A road from here goes via Sonada to Kurseong, which is at a distance of 24 km. Kalimpong is about 45 km away from Ghum, and is reached via Lopchu. Another road goes to Mongpu and from there to the Kalimpong-Siliguri road. Sukhiapokhri, almost on the India-Nepal border, is 11 km away, on the road to Mirik.

Stop 2: Tiger Hill

Tiger Hill, at a height of 2590 m above mean sea level, is the summit part of Ghum, and is an important tourist destination, especially because it provides a panoramic view of the Mt. Evarest and the Mt. Kangchenjunga together on sunny days. At sunrise, as the slanting sun rays gradually brighten up the snowy peaks of Mt. Kangchenjunga in multitude of colours, while the lower parts still remain under dark shades, the observers get a unforgettable view of the majestic mountain, and a celestial experience *(Fig. 10)*. Mount Everest (8848 m), occurring further away, is faintly visible, especially on cloud-free sunny days. Mt. Makalu (8481 m), although at a lower height than Mt. Everest, looks higher due to the curvature of the Earth, as it is several kilometres closer than Mt. Everest. The distance in a straight line from Tiger Hill to Mt. Everest is 172 km.

On a clear day, Kurseong town is also visible at a distance in the south, as also the Tista River, Mahananda River, Balason River and Mechi River, all meandering down to the plains in the south. The Chumal Rhi mountain of Tibet, about 135 km away, is also visible over the Chola Range. Close to Tiger Hill is the Senchal Wildlife Sanctuary.

Fig. 10.
Panoramic view of the Kangchenjunga massif from Tiger Hill.

Stop 3: Old Monastery at Ghum
The actual name of the old Ghum Monastery is “Yiga Choeling”. The monastery belongs to the Gelukpa or the Yellow Hat sect of Buddhism, and is known for its 15 feet (4.6 m)-high statue of the Maitreya Buddha. The external structure of the building was constructed in 1850 by a Mongolian astrologer and monk, Sokpo Sherab Gyatso, who was head of the monastery until 1905. In 1909, Kyabje Domo Geshe Rinpoche Ngawang Kalsang, popularly known as Lama Domo Geshe Rinpoche, succeeded Sherab Gyatso as head. It was he who commissioned the statue of the Maitreya Buddha, and he remained head until 1952. During the Chinese occupation of Tibet in 1959 many high ranking abbots fled to India and took refuge in the Yiga Choeling monastery. In 1961, Dhardho Rinpoche became head of the Yiga Choeling monastery. Three years after his death in 1990, a boy named Tenzin Legshad Wangdi was recognised as his reincarnation. On 25 April 1996 he was enthroned at the Kalimpong Tibetan ITBCI school. The thirteenth in the line of Tulkus, Tenzin Legshad Wangdi, still goes by the name of Dhardo Tulku. He is studying Tibetan Philosophy at Drepung Loseling University in South India.

Under the supervision of Dhardo Rinpoche, a Managing Committee was set up in order to improve the monastery’s functioning. Presently the monastery is meeting its needs through donations and contributions from local devotees.

Stop 4: Bannockburn Tea Garden & Landslide

The Tea Estate at Bannockburn (N27º 03’, E88º 17’) is one of the oldest tea gardens in Darjeeling area *(Fig. 11)*. It is situated along the eastern valley side slope of the Rangnu Creek. The long, step-like slope of 10º-15º is dissected by tributary valleys that are up to 200 m deep. The slope is also characterised by several small depression-like features that actually are the scar marks left by landslides and shallow mudflows. The thickness of loose deposits varies from 4 to 10 m on gentler sloes, but bare rocky surfaces also exist. At least 60% of the area is occupied by terraced tea plantation, which accounts for more than 500 ha. Village settlements and small gardens occur on the steeper slopes. Discontinuous areas of untended forests (jungle) used to occupy an area of at least 20% of the whole garden area in 1968, but now the jungle area has shrunk considerably, and only a few remain with weeds and bushes yielding poor-quality fodder.

Froehlich and Starkel, (1987) & Froehlich, et al, (1989) carried out a detailed measurement of rainfall, infiltration rate and run-off on a spur in the Bannockburn Tea Estate. They concluded that the reasons for the formation of hundreds of shallow landslips, mudflows and debris flows in the Tea Garden after a high rainfall event in October 1968, was high permeability of the substratum. The rainfall event caused a very high seepage pressure, which led to the slips and damages in 20-25% of the garden’s area. They also estimated that individual rainfall events, causing downpours exceeding 200-300 mm, might result in recurrence of such slips on the steep slopes, as was noticed during 1983 and 1987. Based on the above study it may be concluded that the major land slips that occurred in this Tea Estate in 1950, 1968, 1980, 1983, 1987, 1990 and 1998, were all due to some high individual rainfall events, each exceeding 200 mm. Fig. 11 shows the location of some of the old and new landslides, while Table 6 enumerates the landslide area in each sector of the Estate.

Table 6. Tea and landslide areas in Bannockburn Tea Garden (Source: Bannockburn Tea Estate)

Sector No.	Total Tea area (Acres)	Total Landslide area (Acres)	Sector No.	Total Tea area(Acres)	Total Landslide area (Acres)
1.	39.23	–	8.	32.81	3.68
2.	44.30	0.40	9.	21.63	3.40
3.	25.58	1.54	10.	35.17	2.51
4.	32.63	0.85	11.	30.41	5.30
5.	9.75	0.33	12.	35.48	4.84
6.	26.55	1.85	13.	27.12	4.74
7.	12.88	0.80	14.	15.67	–
			Total	389.21	30.24

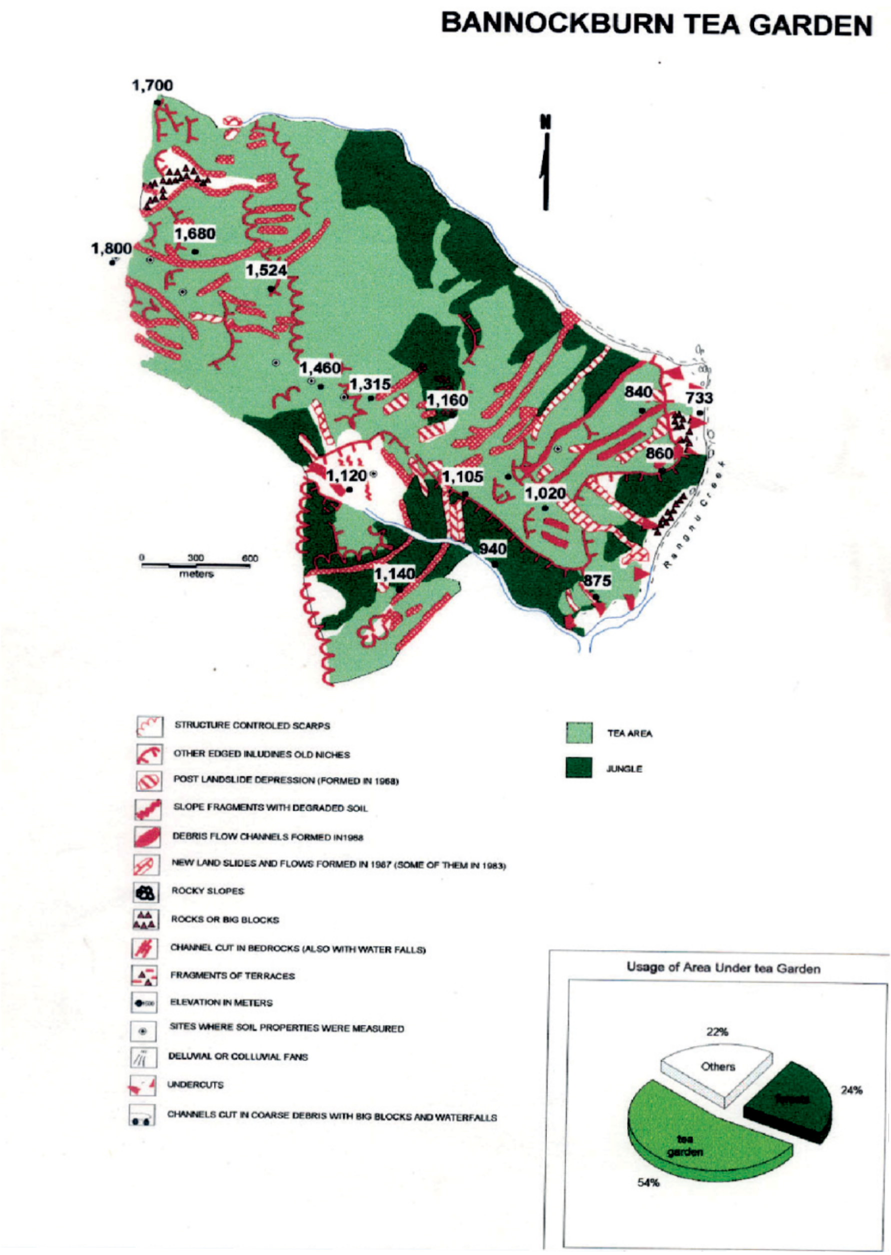

Fig. 11.
Landuse and landslide in Bannockburn Tea Estate.

Stop 5: Happy Valley Tea Estate

The Happy Valley Tea Estate, located 3 km to the north of Darjeeling town, was established in 1854, and is Darjeeling's second oldest tea estate (after the Steinthal Tea Estate that was established in 1852). Spread over 177 ha area (440 acres), it is situated at an elevation of 2100 m above mean sea level, and employs more than 1500 workers. This is also one of the highest tea factories in the world.

David Wilson, an Englishman, had originally named the garden Wilson Tea Estate and had started tea cultivation by 1860. In 1903, the Estate was taken over by an Indian, Tarapada Banerjee, who was an aristocrat from Hooghly (near Kolkata). By 1929, Banerjee also bought the Windsor Tea Estate nearby, and merged the two estates under the name of Happy Valley Tea Estate. Although the Estate worked fine for decades, and exported some of the finest quality tea to the world markets, the slump in tea industry at the beginning of this Century and old technologies being pursued for more than a century led to a major crisis, forcing closure of the Estate. In 2007 the Estate was bought by the owners of the Ambotia Tea Group, which established a new factory within the premises, and started modernization process, replanting and switching to organic farming. Finally, the estate reopened to public in 2008.

Stop 6: Tibetan Refugee Centre

Situated at Lebong, and locally known as the Hermitage, the Tibetan Refugee Self Help Centre (TRSHC) was started by Mr. Gyalo Thondup through local charity on 2 October 1959. Initially it provided emergency relief to Tibetan refugees who came over from Tibet during the period, following a difficult trek across the Himalayas. Tibetans considered the place auspicious because the Thirteenth Dalai Lama had spent his exile years here between 1910 and 1912. Presently the Centre provides shelter to several needy Tibetan families, runs pre-schools for small children, and a primary health care centre. It also provides technical training on handicrafts, etc.

Stop 7: Himalayan Mountaineering Institute and Tenzing Rock

The Himalayan Mountaineering Institute was founded on 4th November, 1954, after the first ascent of Mount Everest by Tenzing Norgay, an Indian and Edmund Hillary, a New Zealander, in 1953. Darjeeling being the home town of Tenzing Norgay, the Institute was established at Darjeeling, and Norgay was appointed its first director. It has now become a centre of excellence in the field of mountaineering. Originally the Institute was opened at Roy Villa on Lebong Cart Road, which was earlier the residence of a great Indian scientist, Jagadish Chandra Bose, and where Sister Nivedita, one of the greatest disciples of Swami Vivekananda, had spent her last days. In 1958 the Institute was shifted to its present location on Birch Hill, from where one can have majestic views of Mt. Kangchenjunga.

Near the Himalayan Mountaineering Institute lies the Tenzing Rock, a huge rock that has been named after Tenzing Norgay. Another giant rock nearby has been named as Gombu Rock to commemorate Nawang Gombu's ascent of the Mt. Everest twice (in 1963 and 1965). This was the first time a person climbed Mt. Everest twice. Nawang Gombu was a nephew of Tenzing Norgay, and became the director of Himalayan Mountaineering Institute after the retirement of Tenzing Norgay in 1976.

Day 4: 15/11/2017
Darjeeling to Siliguri (via Kurseong)
Stay at Siliguri.

The route from Darjeeling to Siliguri will be through Sonada where the headwater area of Balason River valley is cut in Darjeeling gneisses. Down the road one sees several tea gardens along the hill slopes, as well as some areas of land slips and debris flows with a very thin forest cover. The road passes through many gullies with large boulders. The cross sections of the road and the railway bridges are too small to accommodate the high discharge of debris moving frequently through them, and therefore cause damage to these infrastructures.

The route will also pass through Kurseong town, a trading and administrative centre. After passing through the imposing rocky wall of Eagle Craigs, Kurseong town is reached on the southern and eastern slopes of the first ridge at an elevation of 2000 m a.s.l, which is known as the Mahaldhiram Range, or the Dow Hills. This ridge is built of the more-resistant Darjeeling Gneisses. Yet, high deforestation on its southern margin and exposure to heavy monsoon rains exceeding 4500 mm per year makes the slopes vulnerable to landslides. During the rainstorm of October 2-5 1968, Kurseong received 1091 mm rainfall.

Stop 1: Ambootia Landslide
This is an interesting landslide zone in the Darjeeling Himalayas. On October 2–5, 1968, consequent upon an extreme rainfall event, hundreds of earth flows, debris flows, and large landslides scarred the mountain slopes in the area (Starkel, 1972). It has been estimated that between October 2 and 5, 1968, Darjeeling Himalayas experienced 600-1000 mm rainfall within a span of 50-60 hours. Ambootia recorded 890 mm rainfall, while an automatic rain gauge at Nagri Farm (6.5 km north of Ambootia) recorded a rainfall intensity in excess of 50 mm per hour (Starkel, 1972) during the last four hours of October 4. The largest of the landslides occurred along the left side of the Balasan River valley in the Ambootia Tea Estate, where the river cuts through an E-W marginal ridge rising to 1200–1800 m above sea level *(Fig. 12)*. The Polish researchers working on this landslide termed it as a "landslide valley" because the landslide not only has the shape of a valley, but its evolution is also the

product of gravitational slope processes acting in conjunction with linear down-cutting (Froehlich et al., 1991, 1992). The surrounding area is formed of the Darjeeling group of metamorphic rocks, comprising gneiss, mica-schists, and chlorite-schists of various resistance, inclined 30–50º NNW. The rocks are deeply weathered and the high density of fractures in the area is most likely indicative of a high degree of seismic activity.

During the 1968 event, thick saturated colluvia and the underlying weathered rocks in the shallow valley head slumped down and spread out like debris flow, carving out a channel 30–60 m deep and pushing out a mass of 10–15 million cubic m. Some of the material got deposited in the form of a fan in the Balasan River bed. The debris fan formed a dam. As a result, a lake several km long was also formed, storing about 10 million liters of water. The undercutting of the right side of the landslide in its middle part, featuring several hummocks, led to large rock falls. On the opposite side, shallow pene-structural earth flows and slips were triggered at the same time. We do not know the extent of the transformation that took place in October 1968, as the first photographs, drawings, and written records only became available in 1983 and 1984.

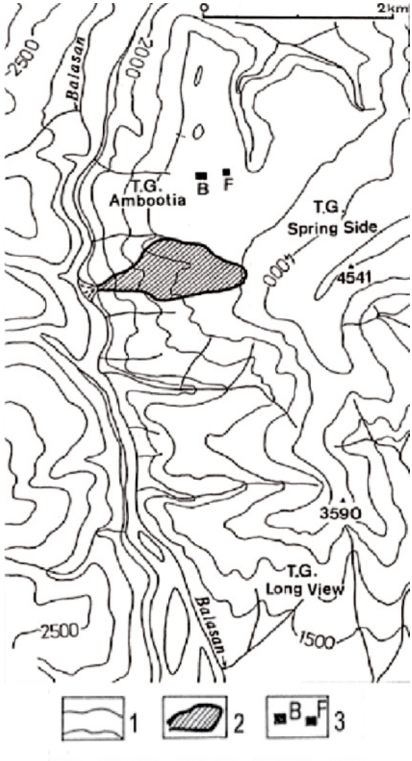

Fig. 12.
Location of Ambootia landslide valley in the Balasan River catchment.
1 - each 500 feet contour line;
2 - landslide valley;
3 - tea factory and bungalows.

Subsequent transformation included a continuous retreat of the right side niches, supplied by groundwater from a colluvial aquifer, as well as an extension of shallow slips and the formation of deeper cracks on the left slope. A simultaneous deepening of the main channel by debris flows led to the undermining of the upper part and the dissection of the lower part of the valley sides by new chutes and slips *(Fig. 13).*

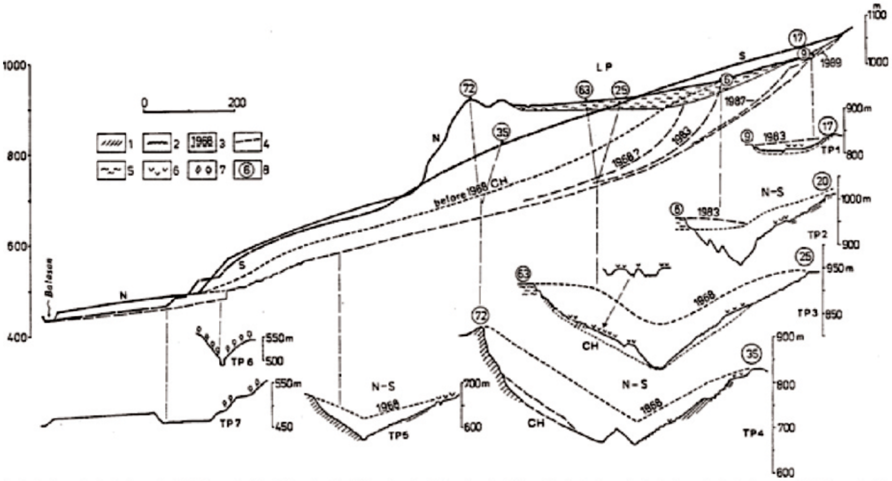

Fig. 13.
Longitudinal (LP) and transversal (TP) profiles of the Ambootia valley, showing gradual expansion prior to 1989 (Froehlich, Starkel & Kasza, 1991, 1992). 1- exposed bedrock, 2- blockfields, 3- calculated surface channel profile prior to the 1968 landslide, 4 - surface after October of 1968, 5 - thick colluvial series, 6 - revegetated slopes, 7 - jungle, 8 - control points. N and S - Northern and southern edges.

In March 1983, the main upper landslide niche resembled an amphitheatre, with its edge reaching probably no higher than 980 m above sea level. All area slopes had fresh features. At the outlet of the main valley, a large colluvial fan was found to be completely without vegetation. This suggested that at least prior to 1983-84 the landslide might have been very active *(Fig. 14)*. In 1988, this Ambootia landslide at the southern edge of the Tea Estate got reactivated again due to a

Fig. 14.
Ambootia landslide (1993).

high rainfall event. The landslide was very active from 1968 to 2003, when it continued to develop sequentially. However, since 2003 it is gradually becoming stabilized *(Fig. 15)*.

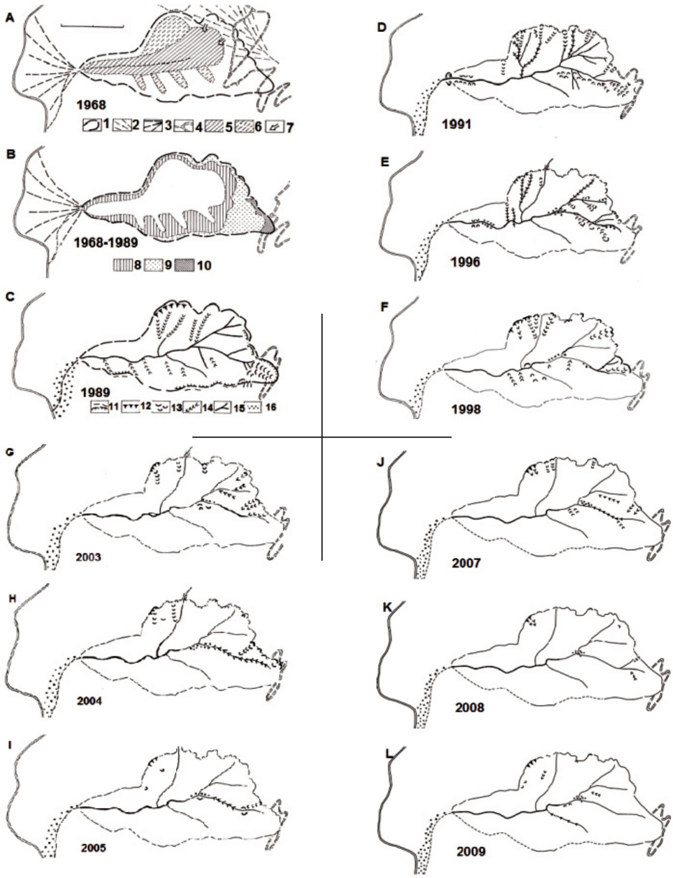

Fig. 15.

Changes in the Ambootia landslide valley, reconstructed for 1968 to 1989, then surveyed and analyzed for 1989-2009 (L. S t a r k e l). Legend: A. 1968, B. 1968-89, C. 1989, D. 1991, E. 1996, F. 1998, G. 2003, H. 2004, I. 2005, J. 2007, K. 2008, L. 2009. 1- main edge of landslide, 2 - old upper colluvial fan, 3 - Ambootia landslide fan, 4 - road, 5 - earth masses removed in 1968, early phase, 6 - 1968 late phase, 7 - subsurface drainage direction, 8 - extension in 1968–83, 9 - extension in 1983-87, 10 - extension in 1987-89, 11 - active niches and cracks, 12 - rock fall niche, 13 - sliding masses, 14 - block stream and debris flow, 15 - chutes and canyons experiencing downcutting, 16 - debris fans.

Stabilization of the landslide:

In March 1995, an "Eco-development Plan for the Ambootia Tea Estate for 1996–2000" was prepared. The plan included different types of watershed protection strategies such as the reforestation of the landslide and surrounding area using selected plant species, avulsion of water, check-damming, gully plugging (especially in the main "khola"), and grazing restrictions on landslide-prone slopes. The program went into effect in 1996. The upper section of the creek had already been re-routed in the 1980s. Hence the widest colluvial part had already ceased to retreat, as was estimated from photographs taken in different years. The years that followed were very wet once again. In 1998, 4229 mm rainfall was recorded, with highest monthly rainfall of 1505 mm and highest daily rainfall of 335 mm. The right bank of the upper part of the landslide slumped again and became dissected by a number of new gullies. The wetter years, combined with grazing restrictions, facilitated the re-vegetation of many parts of the bare slopes. The revegetation process could be easily observed across the area. Moreover, several debris dams were constructed along the main river channel in 1998-99. Following a wet 1999, the active parts resembled almost like in the year before. In 2002, an Organic Biodynamic Research Centre was established close to the landslide area, with a nursery of tea bushes and trees, which were continuously planted along the northern edge of the landslide. In February of 2003, following a relatively dry 2002, the number and area of slips decreased again. In March of 2004, while revegetation continued to make progress, several small parts of the landslide became reactivated, most likely due to higher rainfall in the summer of 2003. The annual rainfall was 3879 mm and July rainfall was 1219 mm. The following two rainy seasons (2004 and 2005) were characterized by very low precipitation (2447 mm and 2617 mm, respectively). Virtually the entire landslide area, except for small vertical slope sections, was covered by dense vegetation, young forest species, and a dense carpet of grass. Only the main gully, which collects water during rainstorms, transported coarse debris. Over the course of the next three years (2006 to 2008), annual rainfall increased to about 3000 mm, but with no major rainstorms. Re-vegetation continued to make progress and only small slumps could still be observed on a number of steep slopes. Presently most part of the landslide has been stabilized.

Stop 4: Paglajhora Slump Valley

Perhaps, the largest and the most complicated among the landslides in the Darjeeling Himalayas is the lower Paglajhora slump valley, which is active since the severe 1950 rainstorm. The morphological configuration of the Paglajhora slump valley is controlled by its geological structure and remodelled by the local hydro-geomorphic processes. The slope forms exhibit a combination of convex – concave – irregular profiles with highly variable inclination (10° to 35°). Overland flows, feeding the uppermost niche during heavy rains, get transformed into concentrated sub-surface flow over the permeable colluvium. The observed rills and cracks facilitate piping and deep drainage towards the slumped areas. The high intensity rainfall, as well as the high relative height and steep gradient, make efforts to stabilize the Paglajhora slumps difficult *(Fig. 16)*. At present, the slump's form has reached a quasi-unstable equilibrium. Each extreme rainfall (above 300 mm/day) causes substantial changes in its morphology (Sarkar, 2011).

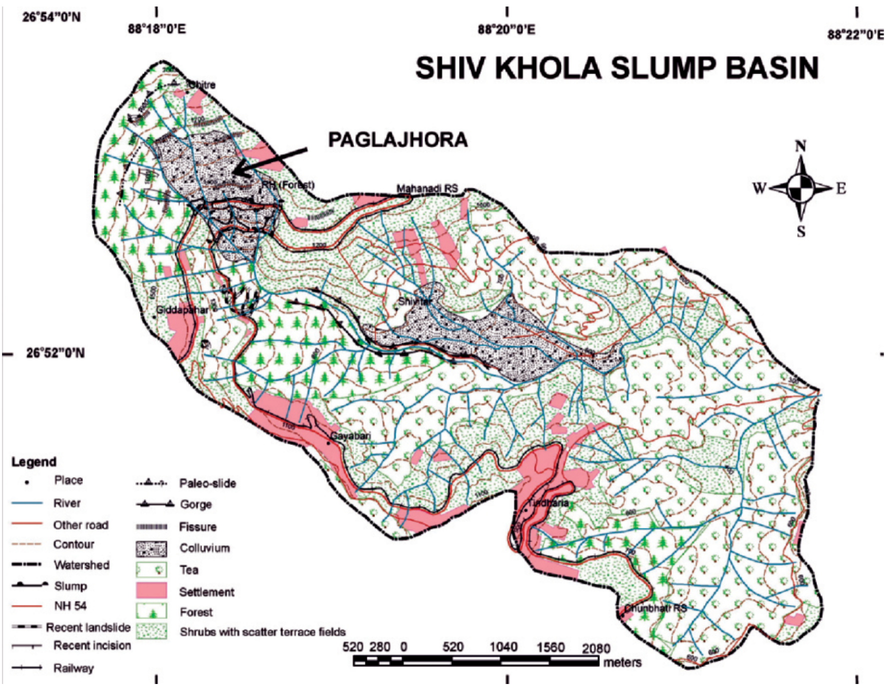

Fig. 16.

Shib Khola slump basin (after Sarkar, 2011).

Slope instability in Paglajhora is essentially a style of adjustment of the natural hydro-geomorphic processes operating on colluvial slopes and under the condition of unstable equilibrium. The extreme rainfall events hasten the transformation of slopes and river channels, and are followed by the formation of regoliths and armouring of channels. The catastrophic landslides tend to push the overburden down the slope, but need a relaxation and transformation time to move the sliding masses *(Fig. 17).*

Paglajhora slump in 1998. Paglajhora slump valley.

Fig. 17.

Panoramic view of the Paglajhora slump valley.

Stop 5: Tindharia Landslide (800 m a.s.l)

At Tindharia, as also at many other places, the hill slopes formed of Damuda Shales and Daling Phyllites with quartzite beds have become moderately undermined by the activities related to the construction and maintenance of the old railway tracks and the Hill Cart Road, even though efforts are made to stabilize the slopes mechanically. At places these unstable slopes are liable to various types of shallow mass movements *(Fig. 18),* often damaging the railway tracks and the roads. During the October 1968 rainstorm, the Hill Cart Road was blocked at more than 200 places. Basu and Sarkar (1985) described in details some such slides formed after the heavy rains of 1982 and 1984. All these slides on the undercut deforested slopes develop mainly after several consecutive heavy rains, and often at the end of the rainy season, when the crossing of the saturation and plasticity thresholds of the materials lead to slope failure.

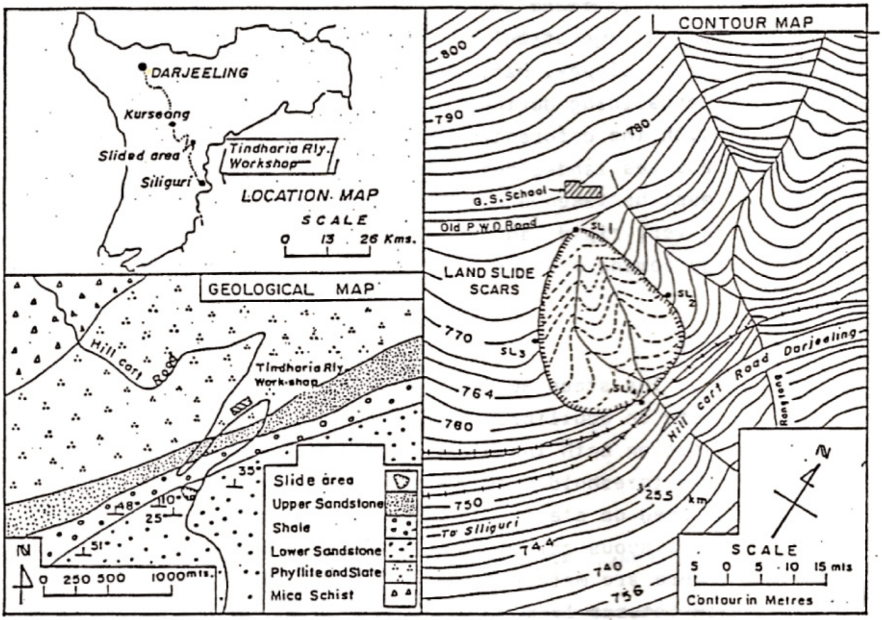

Fig. 18.
A landslide along the railway tracks and the road at Tindharia, which was formed in 1982 (after Basu & Sarkar, 1985).

Stop 6: Sukna (300 m a.s.l)

At Sukna two flat old terraces occur at about 300 m and 120-150 m above the active flood plains. Along the road crossing under the Sal (Shorea robusta) forest, deeply weathered gravels and boulders of metamorphic rocks are found exposed, with well-developed tropical red soil on the top. The higher surfaces belong to the tectonically-raised blocks situated between the Main Boundary Fault MBF) in the north and the Himalayan Front Tectonic Line (HFTL) in the south (Nakata, 1972).

Day 5: 16/11/2017
Siliguri to Kalimpong
Stay at Kalimpong.

Stop 1: Sevok – Tista Valley (170 m a.s.l)

Sevok is a small town and an important crossing point of the swift-flowing Tista River through a robust bridge. Here the river is 60-80 m wide, and flows through a deep rocky canyon, undermining both its valley sides. The channels are separated by a number of gravel bars with boulders of 1-2 m dia. Normally during floods the water level in the river rises by about 5 m, as marked by sandy over-bank deposits and lack of vegetation on the slopes. During the high-rainfall event of October 1968 the water level along the Tista River at Sevak rose by 25 m, which washed away the bridge. It is estimated that the river discharge at Sevak was approximately 18000 cumec. This exceptionally high discharge was accompanied by landslides along the hill slopes and consequent debris flows into the river channel, which caused temporary damming of the river at several places. Since then the bottom of Tista River was lowered by 1.5 m.

Stop 2: The Lish and the Gish Rivers

After crossing the bridge at Sevak, the road passes through the Lish River and the Gish River, which are two important tributaries of the Tista River. The morphology of the two rivers and geomorphic features of their surroundings will be observed near the road bridges on the two rivers.

Lish River catchment: Lish River is only 20 km long, and drains a total area of 64 sq. km, out of which 48 sq. km is under the hills with a peak of 1820 m. A dendritic network of deep valleys has cut into various geological units from the Siwaliks to the Darjeeling Gneisses. Between 1930 and late 1990s the area occupied by forest was reduced from 45% to 31% and at the same time the area occupied by agriculture and settlement increased from 16.75% to 45.5%. One important land use in the catchment area is coal mining. Data from 2004 reveals that the area covered by landslides has increased from 1.5 sq. km to 5 sq. km (Sarkar, 2012).

An alluvial fan, with a length of about 10 km and width of 3-5 km, can be noticed beside the bridge of the National Highway. Its surface descends from 200 m to 120 m. There are many records of floods and damages, during which the braided channel widened to 1.5 km in the upstream of the bridge, and to 1 km downstream *(Fig. 19a)*. In the 50-year period between 1930 and 1980 two large floods occurred in this catchment during 1954 and 1968. The first one considerably damaged the road bridge, while the second one washed away the bridge. Considerable damage took place in the Bagrakote and Washabari Tea Estates. In 1968, Bagrakote recorded 809 mm rainfall in 3 consecutive days, the highest being on 5th October when 499 mm was recorded.

Mapping of the channel features along the Lish River from satellite images of 1990 and 2004 showed extensive bar and shoal formation, but did not reveal any major changes in their spatial dimensions (Fig. 19b). However, a tendency towards aggradation and bank failure could be identified. Field work suggested that the channel floor of the river was elevated by 2.5 m between 1982 and 2004. Comparing features drawn from old and new maps and satellite images suggested that the total surface area covered by bars and shoals along the Lish River increased from 11.4 sq. km in 1930 to about 19 sq. km in 2004 (Sarkar, 2012). During the recent past three floods were recorded in 2002, 2005 and 2007.

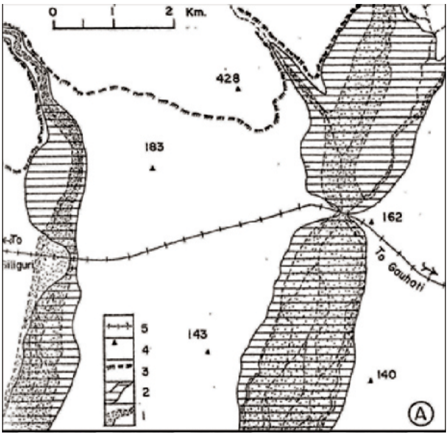

Fig. 19a.
Changes in alluvial fans of the Lish and the Gish rivers between 1935 and 1964; 1 - extent of braided channel in 1935; 2 - extent of braided channel in 1964; 3 - margin of the Himalaya; 4-elevation (m), & 5-railway line with bridge.

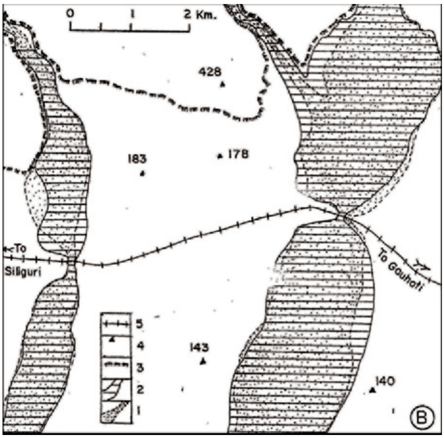

Fig.19b.
Changes in alluvial fans of the Lish and the Gish rivers between 1964 and 2004; 1- extent of braided channel in 1964; 2- extent of braided channel in 2004; 3- margin of the Himalaya; 4-elevation (m), & 5-railway line with bridge.

Gish River catchment: Gish River drains a larger catchment than the Lish River. Out of its 201 sq. km area, 160 sq. km is located in the hills. The river is 41 km long, out of which more than 30 km is in the hills. The dendritic drainage pattern has been formed on the same rocks described for the Lish River catchment. The highest ridge in the headwaters rises to 2370 m. Like in the Lish River catchment, this catchment area is also under coal mines, and is undergojng deforestation. Many large landslides are located especially in the marginal parts of the hills (Sarkar, 2012).

The area covered by forest between 1930 and late 1990s has decreased here from 49% to 37% of the total land use area, while agricultural land plus settlement area has increased from 22.6% to 33.6%. The extension of braided pattern followed between 1930 and 1980 when three creeks at the outlet from hills starting from 195 m have formed a fan of 3 km width. In 1954 a devastating flood occurred, when about 10 sq. km area of cultivated land was flooded and up to 1 m silt layer was deposited.

Satellite images of 2004 revealed that aggradation extended upstream and the area of non-vegetated bars and shoals was reduced. This was visible especially in the apex part of the fan where hundreds of trees got buried under sand and gravel bars. Between 1982 and 2004 the channel bottom rose by about 2 m, but many patches became re-vegetated, especially downstream of the two bridges and up to the junction with Tista River, due to gradual incision of several branches of the channels. The width of the lowest course of Gish River channel was reduced from 2 km to about 0.5 km (Sarkar, 2012).

Stop 3: Kalijhora – TLDP Stage IV
Stop 4: Rambhi – TLDP Stage III
Human role in shaping the hydromorphology of Tista River
Łukasz W., A. Bucała and S. Sarkar (2014) attempted to evaluate the hydromorphological state of Tista River and to determine the role of human activity in shaping the hydromorphology. The field research was carried out in selected channel sections with and without noticeable human interference. The assessment of the hydromorphological state was conducted on the basis of the River Habitat Survey method.

The analysed sections of the Tista River with noticeable human interference, i.e. river bank modifications, were found to be characterized by small or considerable modifications of the river habitat. The modifications that involve concrete walls or river bank re-profiling occur in the long channel sections, and their function is to protect the road infrastructure and buildings from river erosion. Despite a large human impact on river bank morphology, the studied channel sections of Tista River are characterized by considerably large diversification of natural morphological elements. As a result, the river habitat quality is not significantly different from the habitat quality in the sections without noticeable anthropogenic pressure, and can be categorized as low or sufficient. Additionally, exploitation of gravel during the dry season takes place at many places (Lukasz et.al, 2014).

Two reservoirs between Kalijhora and Tista Bazar, TLDP Stage III & TLDP Stage IV, which are under construction, will be another important factor leading to modification of the morphology in the mountain section of the Tista. The construction of reservoirs may cause the disappearance of some hydromorphological features of the valley that are characteristic of a river, and may result in the development of conditions typical of standing waters. The operation of reservoir complex will most likely have an influence on the natural hydrodynamics of the channel and on the fluvial processes. Below the reservoirs, it can be expected that erosion of the channel bottom caused by the outflow of water without river debris will increase. Intense accumulation of the material transported by Tista River will take place in the reservoirs. The local community that exploits the fluvial material in the area of the reservoir, having no access to the channel, as it is presently under standing water, has begun exploiting gravel in terraces located high above the channel. It should be assumed that, after some time, this will cause permanent changes in the morphology of the higher parts of the valley, and will also lead to other land-forming processes like landslides.

Stop 5: Tribeni Confluence at Pesoke (615 m a.s.l.)
At Pesoke, the view of the Rangit River meeting the Tista is an unforgettable treat for the nature lovers. The Rangit with its deep green and crystal clear water gushes in and meets the forceful mountain stream Tista at a point called Triveni. A closer look reveals that a fan is forming at the Tribeni confluence of the three rivers, the Tista, the Rangit and a small river, the Pesoke.

Day 6: 17/11/2017
Kalimpong to Bagdogra Airport
Bagdogra Airport to New Delhi
Stay at New Delhi.

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