KNOWLEDGE
A Multidisciplinary e-Journal
Journal Website:
https://www.vivekanandacollegeforwomen.org/ejournal

The Slope Instability Along Transport Arteries – A Major Environmental Hazard, Case Study: Road Running from Labha to Paparkheti, District: Darjeeling,West Bengal

Dr. Soma Bhattacharya, *Principal, Department of Geography*
Vivekananda College for Women, Kolkata, West Bengal, India

Abstract- *Slop instability in the form of landslides and subsidence are common environmental hazard in the Darjeeling Himalayas as all the natural phenomena in the region are in favour of slope instability. The highly weathered steep slopes in such a rainy climate are further disturbed by anthropogenic activity and earthquake. Therefore slope failures along transport arteries are common, particularly during rains, frequently disturbing vehicular flow.*

Key words: *Slope instability, foliation, cleavage, bio-chemical weathering, deep weathering, slope undercut.*

Introduction : Slope instability in the form of landslides and subsidence are common environmental hazard. But it becomes particularly intensive in areas of disturbed slopes. Slope disturbance occurs both due to natural and anthropogenic causes. Deep weathering under tropical rainy climate makes slopes susceptible to fall with loss of stability due to such natural reasons as earthquake or heavy shower or due to unscientific use of slope for the construction of roads, railways lines, settlements, dams so on and so forth.

Area of study : - To study the natural and anthropogenic causes of slope disturbances, the researcher has selected a part of road running from Kalimpong to Gorubathan. A 20 km. stretch of this road between Labha to Paparkheti has been studied in detail. (Fig 1)

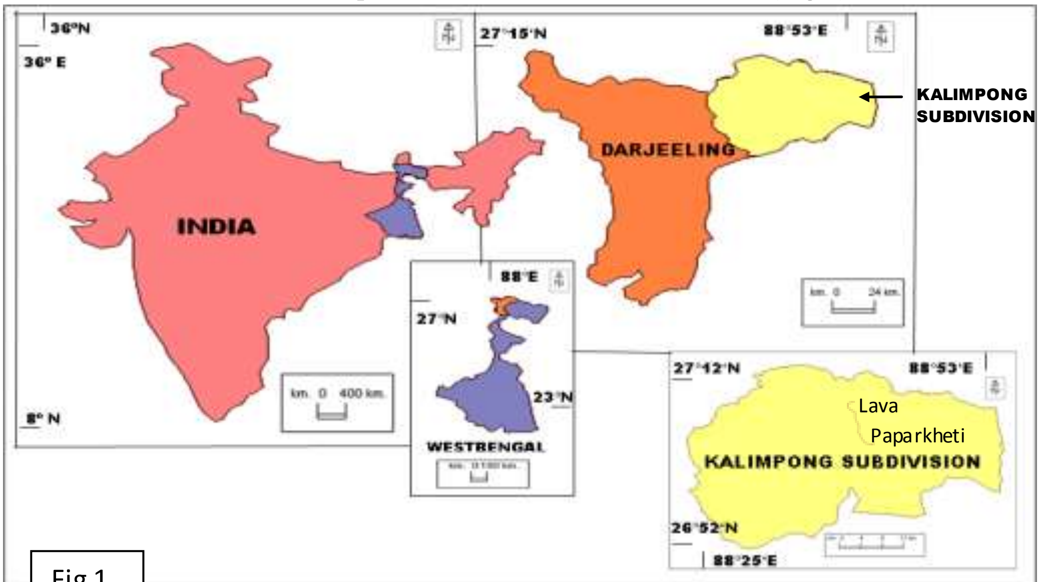


Fig 1

Objectives :- The objectives of this study can be summarized as follows –

1. To study and measure the subsidence and landslides along the road between Lava and Paparkheti.
2. To analyze the reasons behind this through study of relief, drainage, lithology, climate, weathering, vegetation, deforestation and different types of manmade construction.

Previous Work

One of the first attempts of study in Darjeeling Himalaya was made by J.D. Hooker, (1854)[1] who gave a systematic report for the first time on landslides. After that, F.R. Mallet (1874)[2] did geological investigation and classified the metamorphic rocks into Daling Series and Darjeeling Gneiss.

After that H.H. Hayden (1912)[3] and R.C. Burton (1914)[4] visited Darjeeling to advice, the Bengal Government with regard to the protective measures necessary in Happy Valley tea garden. Then A. Heim and A. Gansser (1939)[5] visited the area, studied the structural characteristics of the area, and made the first geological map of Darjeeling.

In 1899 the then Government of West Bengal made a committee to enquire into the causes of landslips and to suggest preventive measures. T.H. Holland[6] the head of the committee concluded that the immediate cause of the catastrophe was aggravated by the cutting of slopes for artificial needs.

Then S.P. Nautiyal & K.K. Dutta (1951)[7] studied the landslips of Darjeeling on behalf of Geological Survey.

After that S.Roy and S.B. Sen Sharma(1965-66)[8] carried out detailed study of the slope pattern around Darjeeling.

L.Starkel and A polish team from Polish Academy of Science (1984)[9] started detailed investigation on the role of extreme and normal rains in the evolution of slopes and river of Darjeeling.

After that, S.R.Basu & S.Sarkar (1985,1987)[10,11] carried out detailed case studies of the causes and consequences of landslide at the 27 km bustee and Tindheria along Hill-Cart Road and Pankhabari Road. Another valuable work, was done by L. Starkel, and S.R.Basu, (2000)[12] in course of the scientific exchange programme between the Indian Science Academy and the Polish Academy of Science, which studied some specific landslides in Darjeeling Himalaya in detail and also mapped the slide faces as published in the monograph titled "Rains, Landslides and Floods in the Darjeeling Himalaya". After that S.R. Basu, (2001)[13] analyzed the process of urbanization and rise of population with decline of forest area and associated environmental changes in his paper titled "Urbanization and Environmental catastrophe in the Darjeeling Himalaya".

Materials & Methods: - To fulfill the above mentioned objectives the following methodology were followed-

- Measuring and surveying of the landslides and subsidence through extensive field survey with general survey instruments
- Analysis of rock types and pattern, type and depth of weathering
- Survey of previous literature and maps including Survey of India Topographical Sheet No. 78A/12

Discussions:-

Causes of slope instability :- Any kind of slope instability arises when stress factors working on a slope are more powerful compared to the factors of strength. R.D. Cooke and J.C. Doornkamp[14] mentioned in their book 'Geomorphology in the Environmental Management' that Fs, an indication of slope stability. According to them

$$Fs = SStt/SSt$$

Where, Fs is factor of safety, SStt is shear strength and SSt is shear stress.

Shear strength is the sum of forces resisting slope failure and shear stress is the sum of disturbing forces,

When Fs = >1 stability occurs.

Fs = <1 instability occurs.

The calculation of Fs depends upon the onsite measurement of the geotechnical properties of the slope materials or the analysis of rock or soil samples in the laboratory (Petley, 1984) [15]

Factors leading to decrease in shear strength and increase in shear stress can be summarized as follows:-

1) High relative relief
2) Degree of Slope and its form
3) Drainage density
4) Climate
5) Natural Vegetation and Deforestation
6) Lithology of the area
7) Weathering
8) Manmade constructions
9) Earthquake

High relative relief:– The steeper a slope the more liable it is to failure. The difference between the highest and lowest relief gives in general an idea of steepness of relief, as it gives a difference of the height between

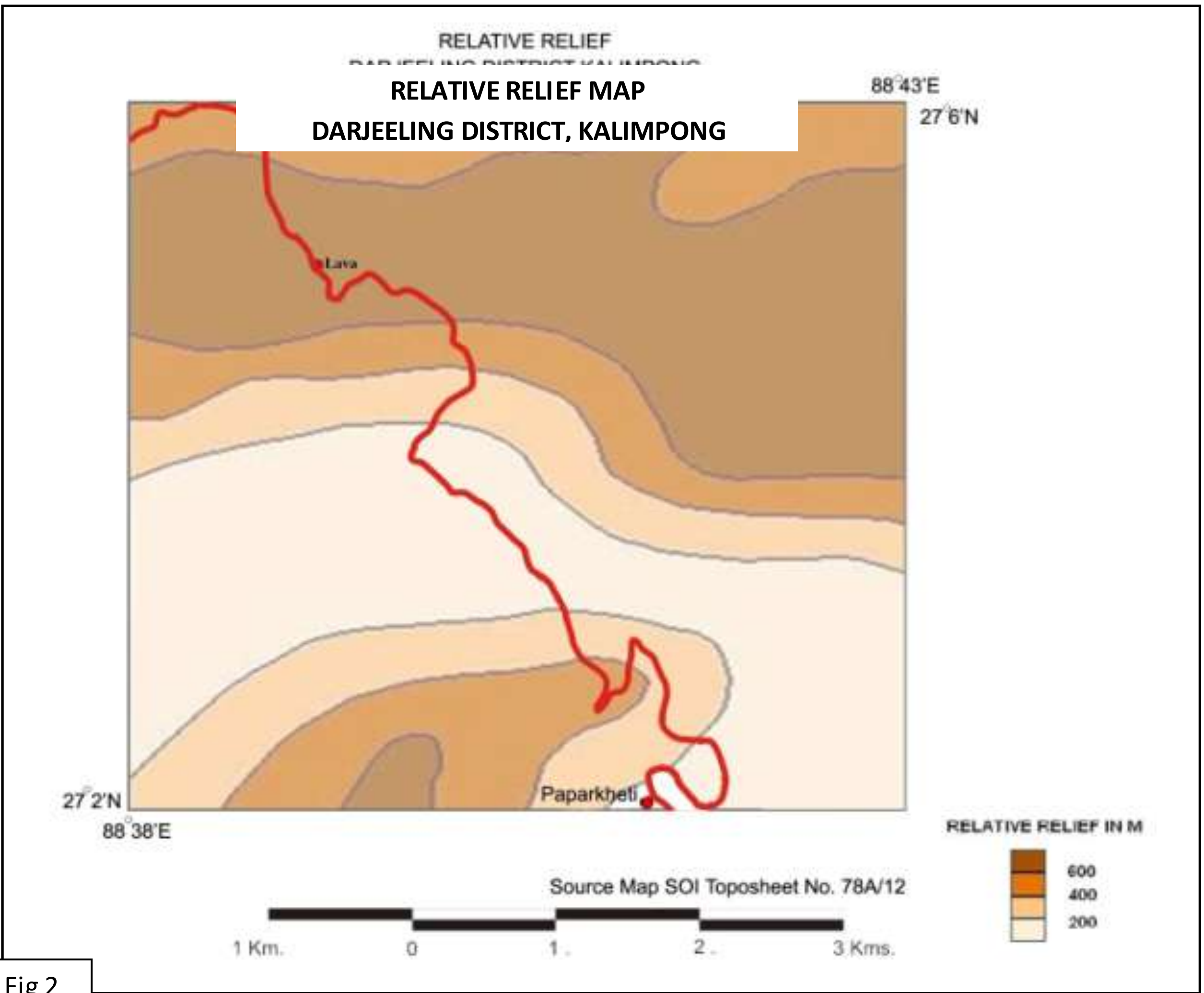


Fig 2

the topmost part of a valley side slope and the lowest depth of the valley. The steepness of the relief of the area has been assessed by Relative Relief Analysis (Highest elevation in a grid – lowest elevation of that grid) with the help of topographical map. Though such assessment gives a very generalized view, even then the relative relief indicates the steepness of the area with more than 80% of the area showing relative relief above 400 meter and more than 40% of that showing a relative relief of more than 600 meter. High relative relief undoubtedly indicates a high steepness and a huge fall from the hill top to the adjacent valley floor, a factor responsible for slope instability. (Fig 2)

1) ***Degree of slope and form:*** - After relative relief the second relief factor which is most important for slope instability is the slope amount and form. Slope amount has been determined by Wentworth's method. Again more than 80% of the area shows more than 4^0 slope angle and about 40% shows more

than 6^0 slope angle. Obviously the area which shows high relative relief shows high slope angle. (Fig 3) Slope form is also another important factor for slope instability, as we know the convex slope is one of unstable kind, while rectilinear slope is relatively stable. Due to river under-cut convex slope is very common in the area causing instability. Construction of roads is another important cause for deliberate change in slope form and thus resulting instability which will be discussed later.

AVERAGE SLOPE MAP
DARJEELING DISTRICT, KALIMPONG

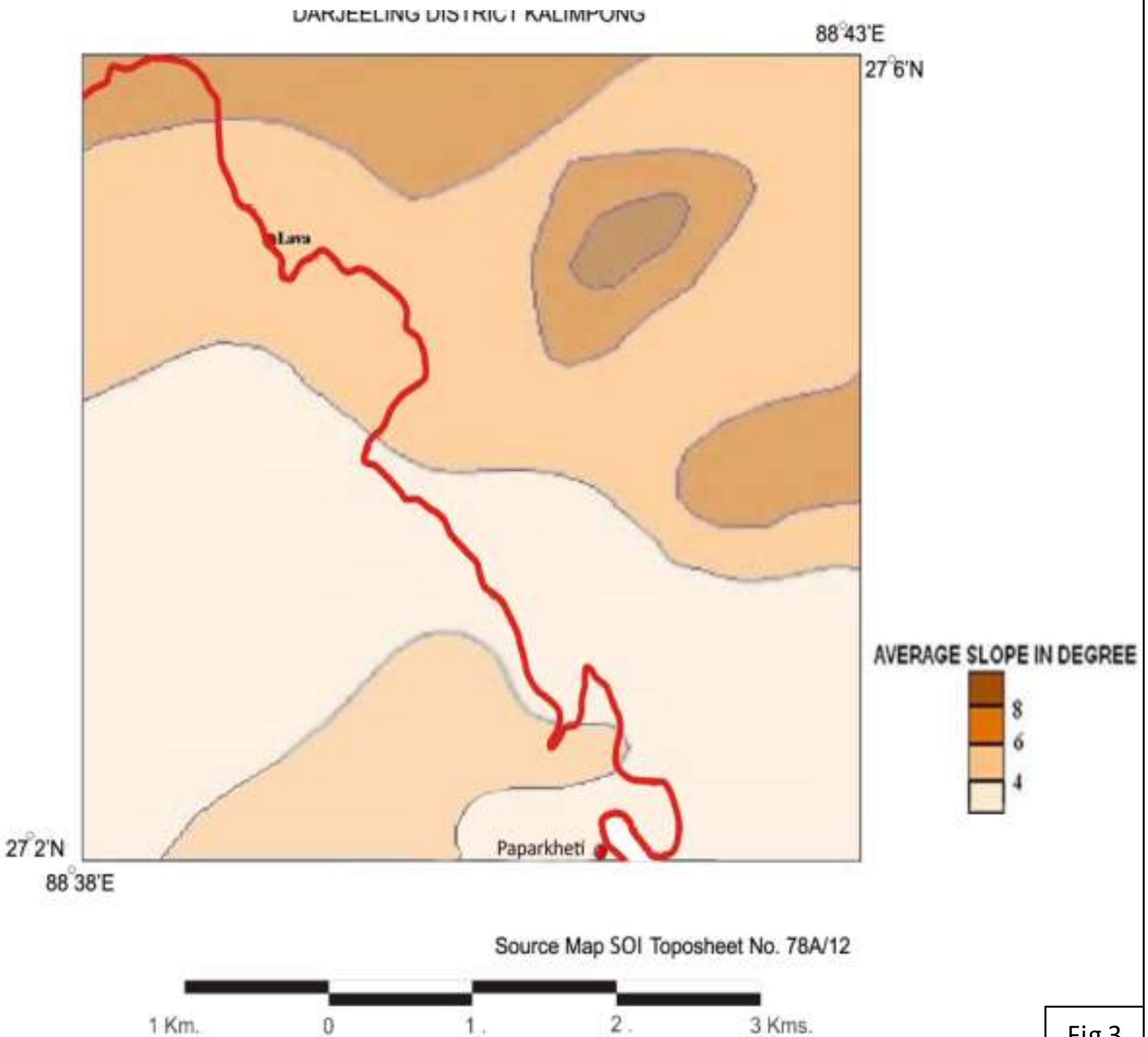


Fig 3

2) ***<u>Drainage Density</u>*:-** According to R.D. Cooke and J.C. Doornkamp high drainage densities are a sign of such things as impervious strata, high rainfall, little vegetation and active stream incision all of which may tend to increase the likelihood of man movement. The study area shows a very high drainage density, most of the area having of more than 2km length of river per square km. An abundance of first order stream indicates presence of high velocity, high rate of erodibility and the youthfulness of

drainage, which undoubtedly increases the probability of slope instability. Moreover high rainfall allows seepage of fine clay and silt by a drag effect due to seepage pressure of water thus loosening the entire slope material. (Fig 4)

DRAINAGE MAP

DARJEELING DISTRICT, KALIMPONG

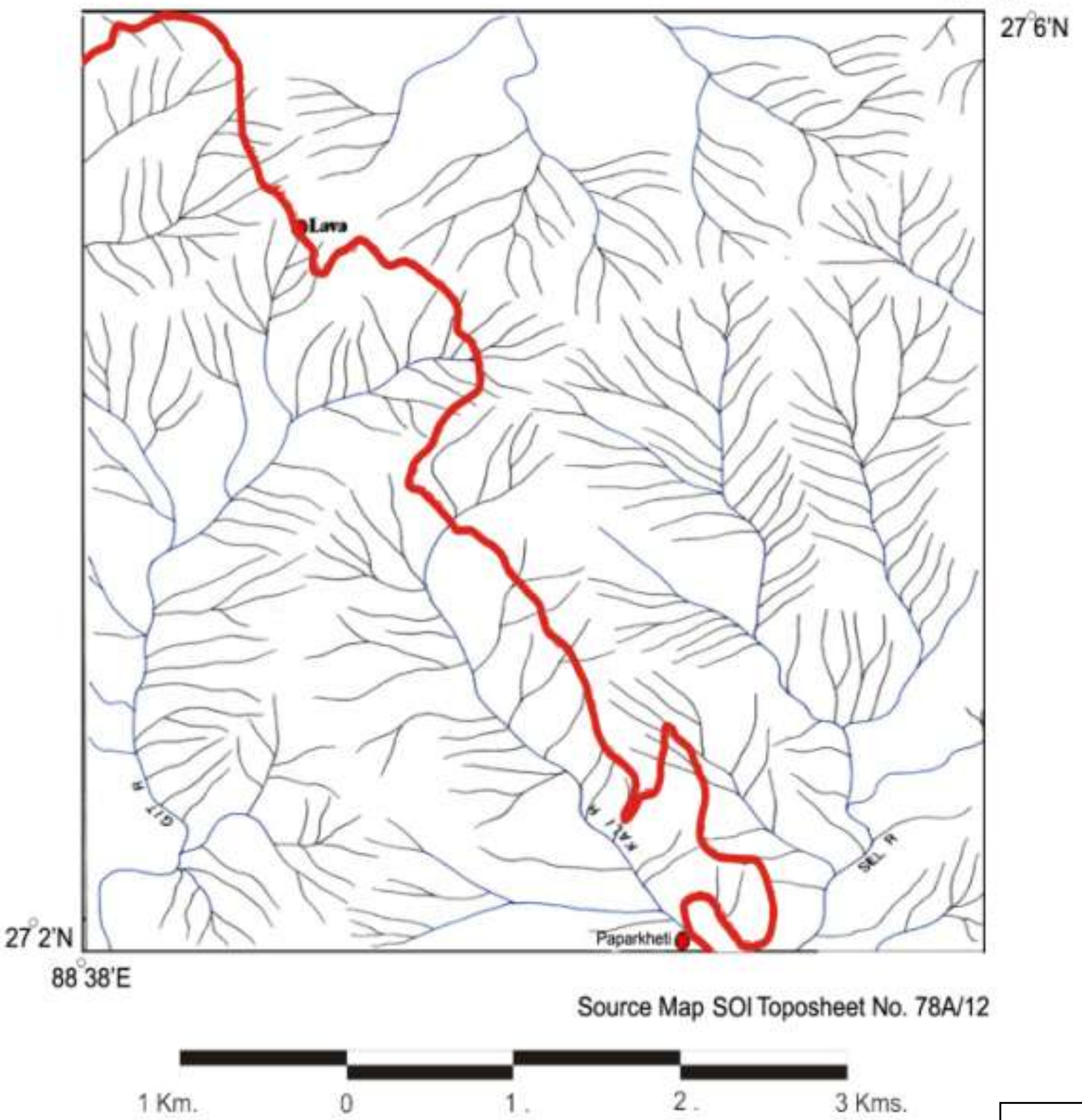
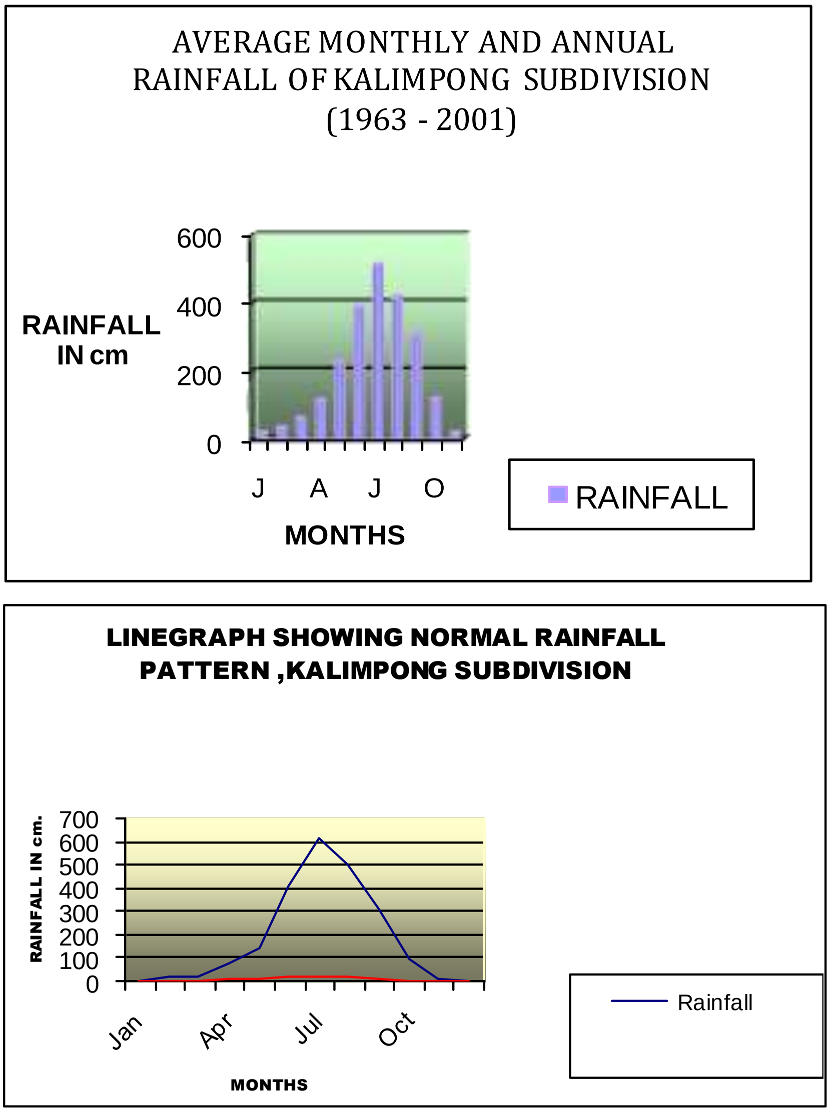


Fig 4

***Climate*:-** Climate of the study area is tropical monsoonal in nature being characterized by a very high temperature ranging from 7^0 C - 10^0 C winter temperature to 17^0C - 22 ^{0}C summer temperature. The second important characteristic of climate is huge rainfall and its intensity and seasonal distribution. The mountain front is subjected to huge precipitation. The Kalimpong hills receive annual rainfall ranging from 200 cm. to above 600 cm. The seasonal distribution of precipitation (Fig 5) and its concentration during one half of the year creates immense problems leaving practically no slope stable due to deep weathering and huge pore water pressure. The maximum concentration of landslide incidences occurs between 2100mm to 4100mm isohyets. The road sector running between Lava and Paparkheti falls into the zone receiving quite high rainfall (410 cm. – 460 cm.) (Fig 6) Naturally the region is highly susceptible to deep weathering and landslides.



RAINFALL DISTRIBUTION MAP OF KALIMPONG

Fig 5

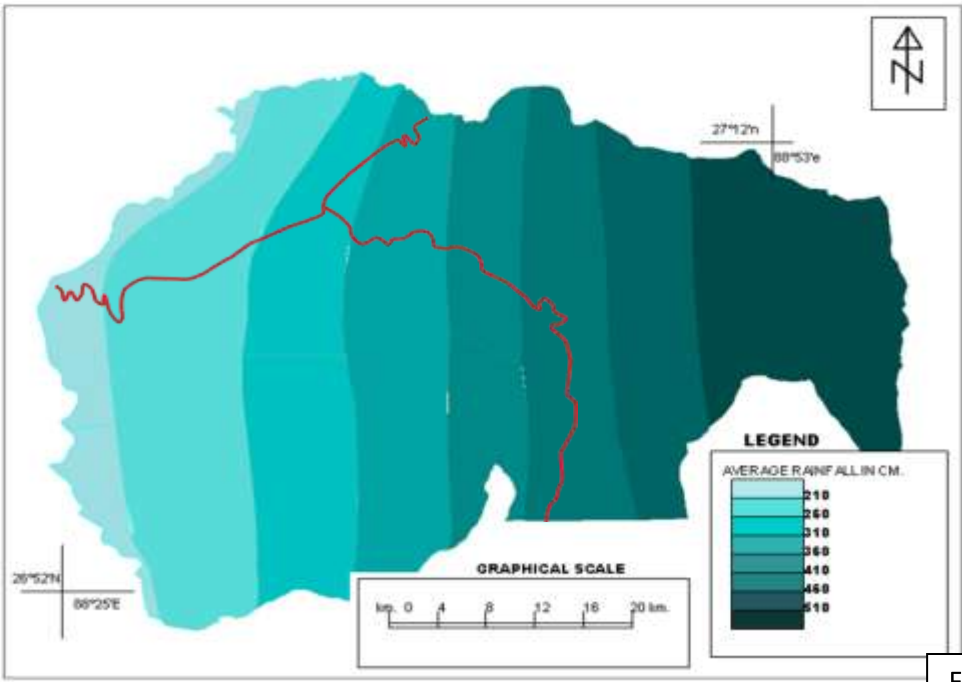


Fig 6

Natural Vegitation :- Climate of the area is as such that it helps growth of dense vegetation. In 1830 Captain Herbert[16], then Deputy Surveyor General stated that the mountains are completely clothed with forest from the very top to the bottom General Lloyd in 1837[16] similarly described it as ‘clothed

SATELLITE IMAGERY SHOWING SPARSENESS OF NATURAL VEGETATION ALONG LAVA PAPARKHETI ROAD

Fig 7

from the top of the hills to the very bottom of the valleys with a dense forest.’ Now forests stand below 1000metre and above 2000 meter (Fig 7).

The settlements, agriculture, roads all anthropogenic activities are highly concentrated within this level. The climate and natural vegetation of the area have a profound influence on rock material of the area through intense chemical and biological weathering a point to be discussed later.

3) ***Lithology of the area :-*** The predominating rock of this area is Darjeeling gneiss, phyllite and schist. The gneisses are coarse grained with alternating dark and light bands. The light band is necessarily white indicating the presence of plagioclase feldspars which is weak in composition than orthoclase feldspars. Another rock phyllite, a regionally metamorphosed rock with chemical composition of shale having foliation and cleavage, is also susceptible to weathering. So also the case of schistose rocks having very distinct cleavage and foliation is highly susceptible to weathering.

The rock foliation strike is N 25^0W-S25^0E and dip at 45^0 towards N65^0E. The dip and strike of rock foliation are indicative to slope failures and it is strikingly observable that almost all the subsidence and slides are confined to the east dipping rock, that is, the dip slope of the Paparkheti – Kuapani ridge. Slope failures are rare or almost absent on west and south facing slopes. Thus the road sectors which are along anti dip slopes are almost free from slope failures.

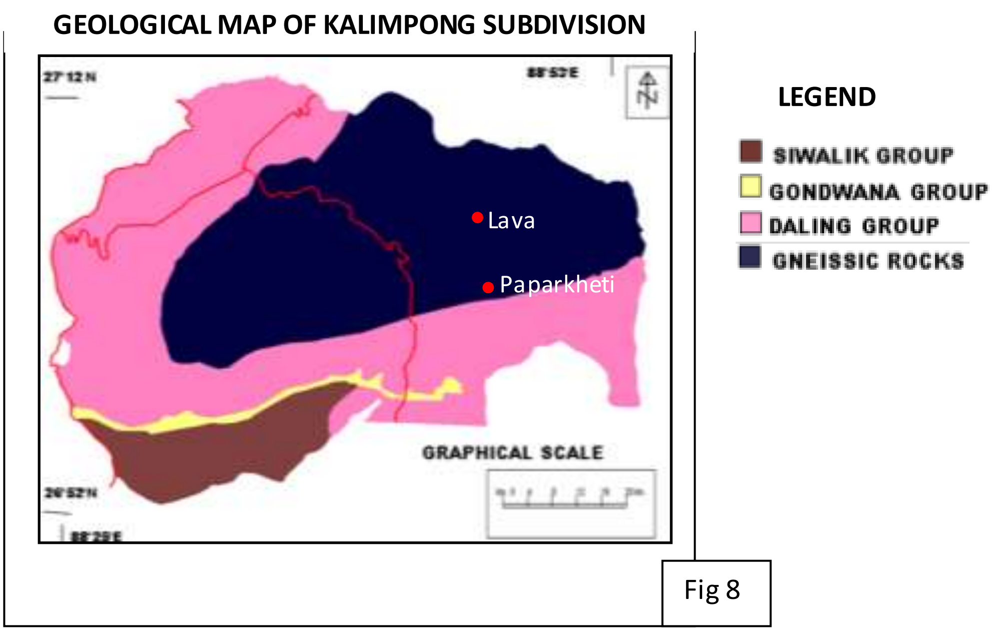


Fig 8

4) ***Weathering*:-** Deep weathering under tropical monsoonal climate is probably the foremost reason of slope failure in the eastern part of the Himalayas. Ollier[17] in his book Weathering mentioned “Water is the most important reactant in almost all kind of weathering”. We all know water is an universal solvent and practically most elements are soluble in water. Amount, style and type of weathering depend on total rainfall. Leaching of some cations and weathering of less stable minerals depend on annual rainfall as well as precipitation-evaporation ratio. There is a tendency for the rate of chemical reaction to

increase as temperature increases. Chemical weathering in the form of hydration (addition of water to mineral) and hydrolyses (chemical reaction between mineral and water) are very common in high temperature and high rainfall region.

High rainfall along with high temperature results in huge vegetation cover including growth of dense undergrowth creepers etc. which results in both physical and chemical weathering related to vegetation. Bio-physical weathering occurs by the extension of roots (upto 10m) and rhizomes (upto 20mm) resulting in increased pressure along cracks or foliation plane, thus breaking the rock into parts. Thick vegetation cover also helps chemical weathering normally termed as bio-chemical weathering. Chelation is a kind of chemical weathering that occurs in the presence of vegetation. Plant utilise chelating agents (can extract ions from otherwise insoluable solids and enable the transfer of ions in chemical environment where they would normally be precipitated – Olier[18]) to extract ions (nutrients) and thus enable mineral weathering to take place at a much greater rate.

Deep weathering converting rocks into regolith

Photo 1

Gneiss, phyllite and micaschist being the most common rocks the predominating minerals are quartz, plagioclase feldspars (as the light band is predominantly white), mica and other clay minerals. Penetration of water along cleavage enabling rapid alteration of feldspars into kaolin with formation of secondary mica and a host of other secondary minerals can form. Mica is soft and easily attacked by water because of cleavage. Mica alters into chlorite and other clay minerals. In case of phyllite and mica schist schistosity is very important for weathering of the composing clay minerals.

Therefore the rocks of the area upto a depth of 10m (approximately) is highly weathered and form regolith through deep weathering (Photo 1). This regolith under pore water pressure during rainfall becomes unable to remain stable on slopes.

5) ***Man-made constructions***:- Construction, that deteriorate slope stability are of many types like the bridges, barrages, dams, brick houses with two to three storied floor all disturb slope and put pressure on it but construction of road (which is otherwise important for communication and development of hill area) disturbs slope maximum particularly when the slope is itself vulnerable due to the factors mentioned above. Normally we know convex slope is unstable due to its own form. So leaving the question of convex slope we can see how construction of roads at different levels makes slope unstable, as the upper part of the slope above the road remains hanging without any balance (Fig 9). There are thirteen road benches existing (Fig 10) on one slope along the Paparkheti – Lava road. This means the normal slope angle is disturbed at thirteen levels by the road, as a result of which almost every upper level suffers subsidence and slides due to under-cut by the construction of the lower level. Such subsidence and slides are common even in the areas with guard wall.

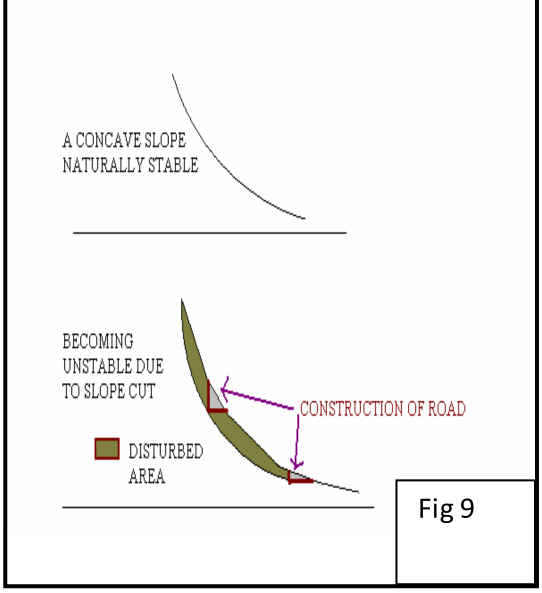


Fig 9

ROAD ALIGNMENT FROM LAVA TO PAPARKHETI

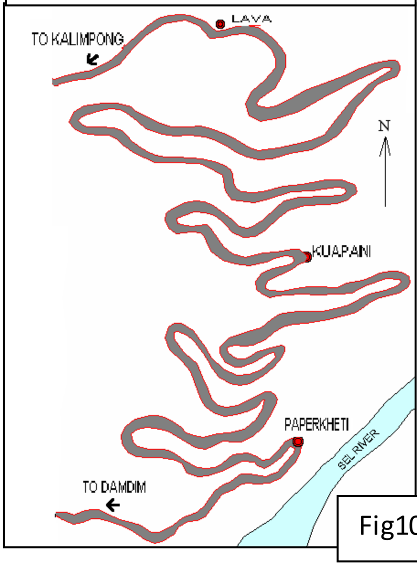


Fig10

NOT TO SCALE

6) ***Earthquake*** :-Neotectonic jerks play a very important role to move the already unstable material, which are in a state to fall at any simple reason. The earthquake at Sikkim and North Bengal on 17th September 2011 did damages to road.

Slides and subsidence studied :- The subsidence (Table 1, Fig 11, Photo 2) and landslides (Table 2, Photo 3) studied have been listed with all their characteristics which reflect the influence of the causes discussed above.

List of major subsidence (Table 1)

SL.NO.	LOCATION	LENGTH	SUBSIDENCE	SLOPE ANGLE
1	1 km from Paparkheti	24m	45cm	100
2	2 km Paparkheti	16m	55cm	200
3	2.5 km Paparkheti	14m	60cm	250
4	4.5 km Paparkheti	25m	60cm	150
5	8 km Paparkheti	24m, 10m	45cm, 20cm	100

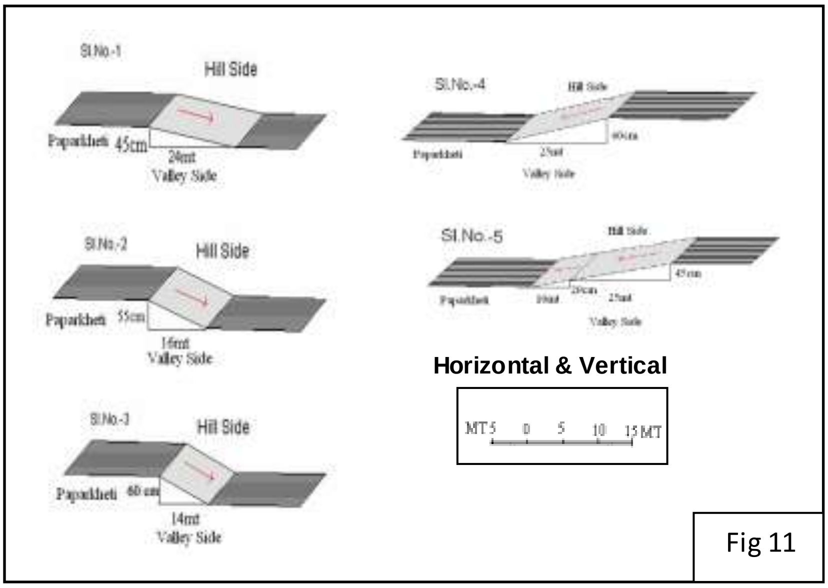


Fig 11

Major Subsidence

Photo 2

Subsidence in an area with guard wall

List of major landslides (Table 2)

SL.NO.	DISTANCE	LENGTH	WIDTH	SLOPE ANGLE	SLOPE FORM	TYPE	MATERIAL
1	200m from Paparkheti (old scar)	50m	35m	50^0	Convex	Rotational	**Unconsolidated clay, micaceous, lightly weathered, loose phyllite and gneissic boulders**
2	500m from Paparkheti (on old scar)	70m	22m	40^0	Convex	Rotational	**Unconsolidated clay, micaceous, highly weathered boulders of highly foliated schist predominantly**

3	1km from Paparkheti (a smalled scar active)	8m	7m	65^0	Convex	Rotational	**Loose unconsolidated highly weathered gneissic, phyllitic boulders**
4	1.5km from Paparkheti	50m	17m	45^0	Rectilinear	Translational	**Loose unconsolidated highly weathered gneissic, phyllitic boulders**
5	2km from Paparkheti (active)	150m	100m	40^0	Convex	Rotational	**Loose clay, highly weathered phyllite, mica -schist**
6	2.5km from Paparkheti (active)without vegetation	30m	10m	50^0	Rectilinear	Translational	**Highly block disintegrated gneissic and phyllitic material**
7	5km from Paparkheti (active)without vegetation	40m	30m	40^0	Convex	Rotation-al	**Highly block disintegrated gneissic and phyllitic material**
8	5.5km from Paparkheti (active)without vegetation	40m	23m	45^0	Rectilinear	Compound	**Both weathered clay and rocky surface**
9	13.7 Km from Paparkheti (A scar of recent past with spars vegetation)	95.5 m	35 m	45º	Convex	Elongated	**Gneiss rich in mica**
10	16 Km from Paparkheti (A scar of recent past with spars vegetation)	30 m	29 m	29º	Concave	Rotational	**Gneiss**
11	17.5 km from Paparkheti (active without vegetation)	35 m	50.4 m	28º	Convex	Rotational	**Gneiss**
12.	**18 km from Paparkheti (active without vegetation)**	**34.4 m**	**47.3 m**	**36º**	**Convex**	**Rotational**	**Gneiss**

Landslides No. 9, 10, 11, 12 (as per Table No. 2) have been studied in detail for the purpose of mapping as well as to mark out the micro geomorphological features that have grown on the slide surface.

<u>Description of landslide no. 9</u>:- This landslide is an example of elongated slide. This is located at 6.3 km from Lava. Total length of the landslide is 95.5 m. and the highest height of the landslide is 35 m. The landslide material is highly weathered, foliated, gneissic rocks and mica-schist. In high rainfall areas

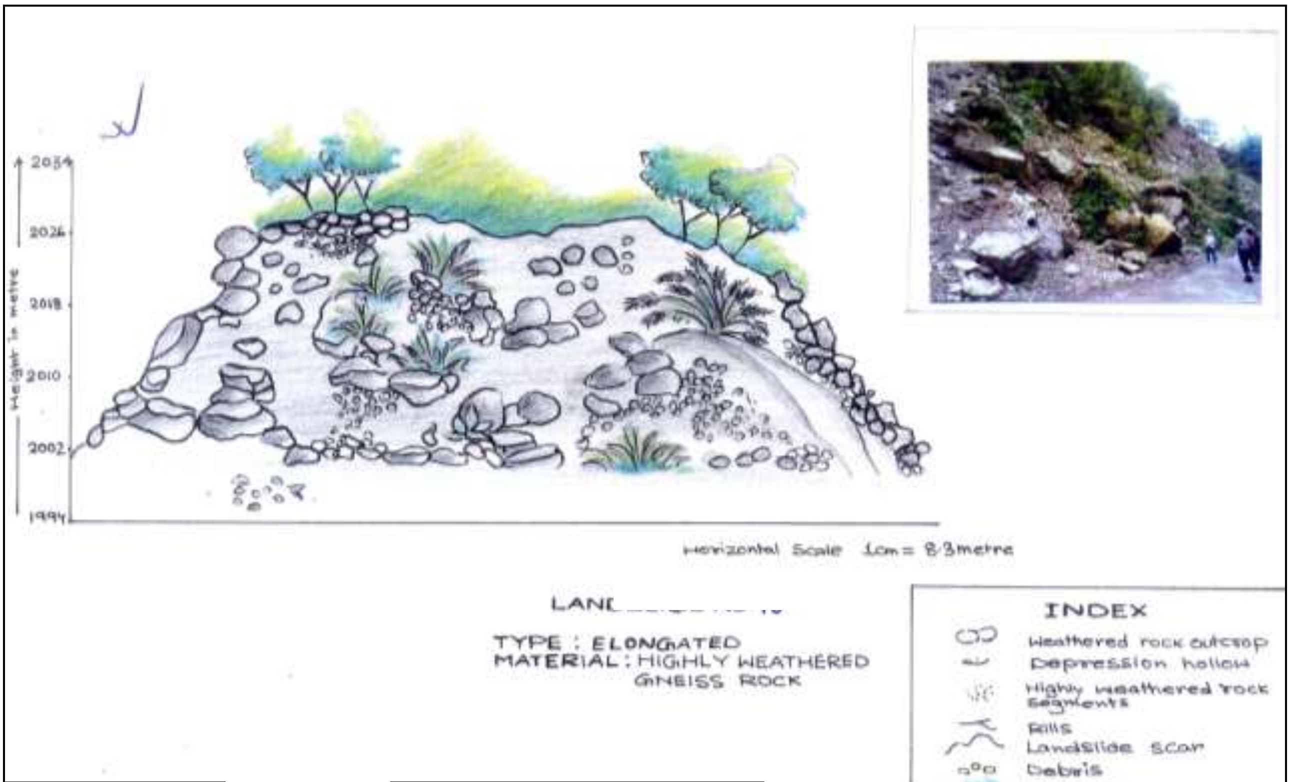


Fig No. 12

LANDSLIDE NO.: 9

gneissic rocks are deeply weathered and susceptible to slope failure. Slope angle of the landslide is 45°. The blocks of rocks in the slide are separated and fall along bedding plane. However the growth of bushes indicates that the slides is not active at present but the sparseness of vegetation indicates a scar of recent past and may become active at any time if any of the immediate reasons like high rainfall, tectonic jerks, increase in pore water pressure etc. occurs.

<u>Description of landslide no. 10</u>:- This landslide is an example of rotational slide (Fig 13). This is located near 4 km from Lava. Total length of the landslide is 29.6 m. and the highest height of the landslide is 30 m. The landslide material is highly weathered gneissic rock. In high rainfall areas gneissic rocks are deeply weathered and susceptible to slope failure. Slope angle of the landslide is 29°. The slope form of the slide is concave. It means that the sliding actively has stopped. The growth of vegetation though sparse indicates that the stability of slope.

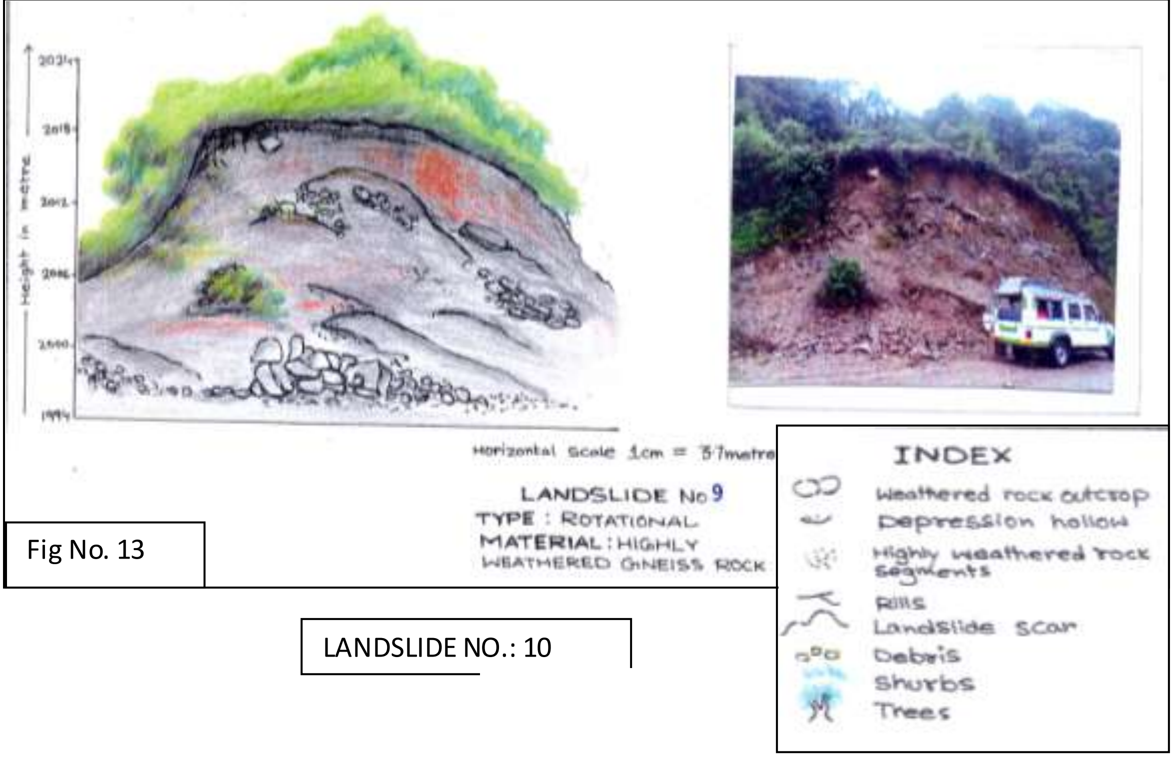


Fig No. 13

LANDSLIDE NO.: 10

Description of landslide no. 11:- This landslide is rotational and located at 2.5 km from Lava. Total length of the landslide is 50.4 m. and the maximum height of the landslide is 35 m. The landslide material is highly

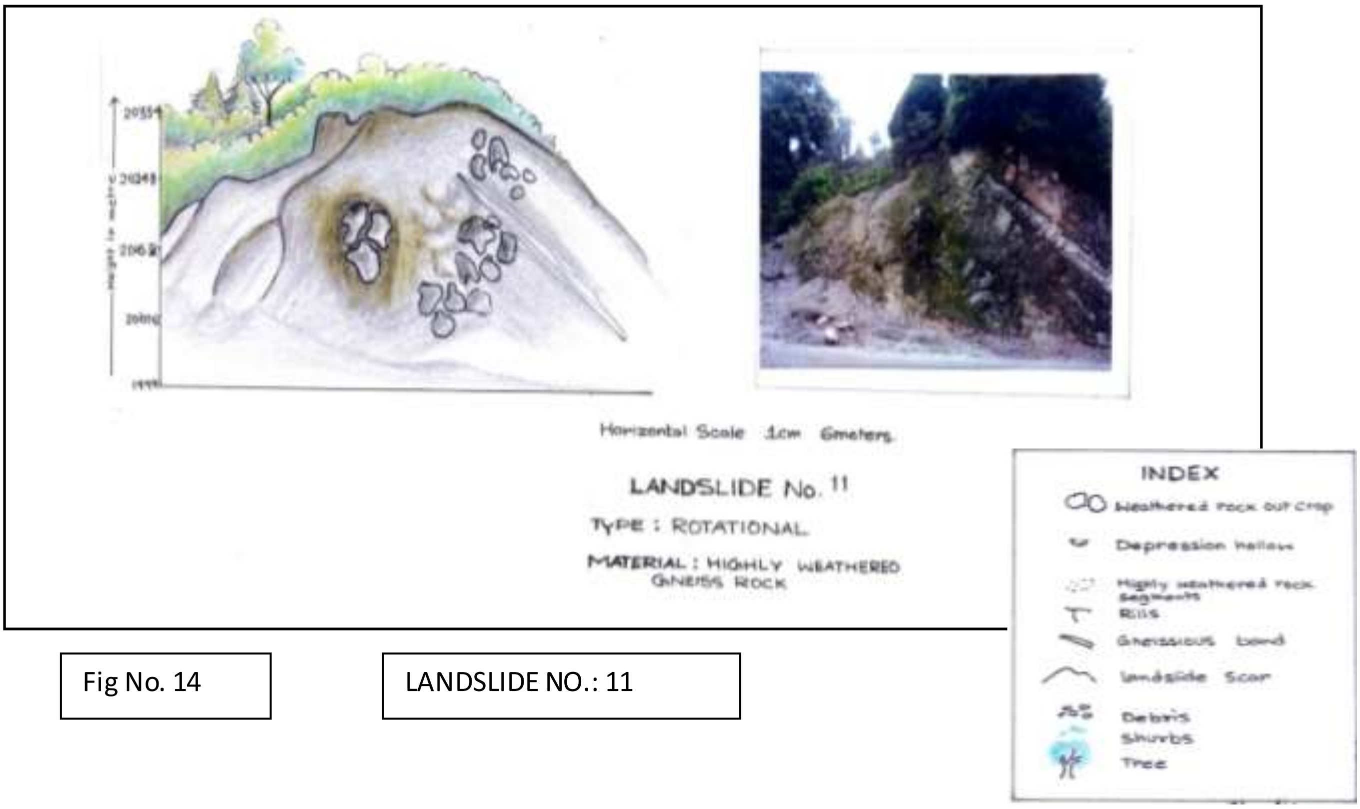


Fig No. 14

LANDSLIDE NO.: 11

weathered gneissic rock. In high rainfall areas gneissic rocks are deeply weathered and susceptible to slope failure. Slope angle of the landslide is 28°. The slope form of the landslide is convex it means that the slope of the landslide is unstable and it is easily susceptible to another failure. In lower part of the landslide many small rills are formed due to water action. Some boulders and debris are found in the bottom of the slide.

<u>Description of landslide no. 12</u>:- This landslide is an example of rotational slide. This is located at 2 km from Lava. Total length of the landslide is 47.3 m. and the maximum height of the landslide is 34.4 m. The landslide material is highly weathered gneissic rock. In high rainfall areas gneissic rocks are deeply weathered and susceptible to slope failure. Slope angle of the landslide is 36°. The slope form of the landslide is rectilinear, it means that the slope of the landslide is not stable and the chance of further failure is fifty fifty. The lower part of the landslide is active and this part is also a bit convex. Many small rills are formed due to water action. Some gneissic boulders are found on the slope and weathered rocks of different size are present in the bottom of the slide.

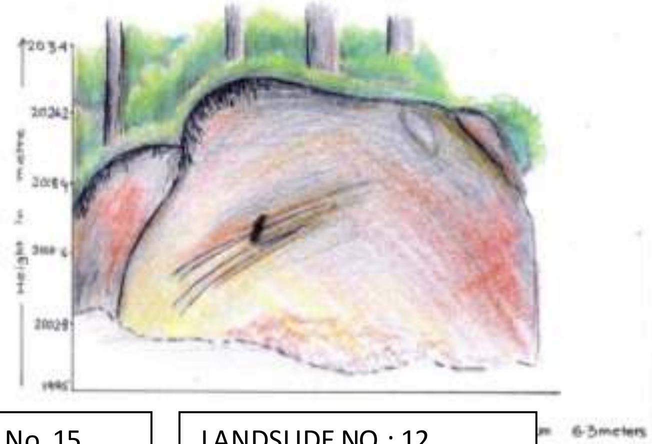
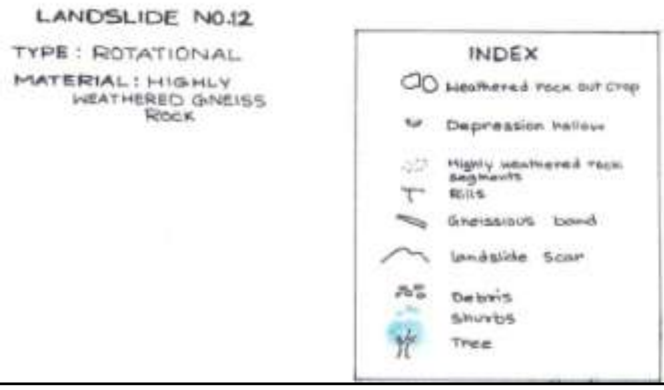


Fig No. 15

LANDSLIDE NO.: 12



Landslide on highly weathered Gneiss and Phyllite

Photo 3

Conclusion :-

In the concluding remarks it can be said that the entire area is naturally quite vulnerable to landslides and subsidence. This natural vulnerability increases when anthropogenic disturbances occur. All the transport arteris along this part of the study region are highly subjected to subsidences and sliding excepting the antidip slopes of the hill and the areas of massive hard rock- preventing weathering till date. Traffic flows along the roads cause loading and jerking (particularly the pressure created by highly loaded goods vehicles) which is also risky for the highly unstable slope surface (though it is difficult to measure the actual amount of effect). The deforestation required for construction of roads left the loose regolith unprotected and ready to fall.

Many kind of preventive measures have taken by PWD Roads including such as construction of surface drainage structures, subsurface drainage works, construction of drainage well and drainage tunnel, retaining walls of different kind, grouting, hardening of soil so on and so forth but the result is very temporary. Long term prevention of roads susceptible to sliding in such a physical environment is practically impossible, unless and until the slope angle is reduced in highly weathered areas.

Reference :-

1. Basu S.R. and Sarkar S. 1885. Some considerations on recent landslides at Tindharia and their control. Indian Journal of Power and River Vally Development, Vol. XXXV, Nos. 10 & 11, 188-194
2. Basu S.R. and Sarkar S. 1987. Eco-system vis-à-vis landslides – a case study in Darjeeling Himalayas. Proceedings of the national Conference on Impact of Development on Environment, Geographical Society of India, Calcutta, Vol. II, 45-50
3. Chatterjee B., 1984. A Geological Approach to the Landslide Hazard Zonation in Darjeeling Himalaya, West Bengal, unpub report, Geological Survey of India
4. Cooke, R.D. and Doornkamp, J.C.1990. Geomorphology in the Environmental Management.Oxford University press, Oxford, 113
5. Griesbach G.L. 1899-1900. General Report, GSI
6. Hayden H.H. 1912. General Report for 1911 and 1912. Rec. Geol. Survey of India, Vol. 42 and 43, part 1 and 2, .70
7. Heim, A. and Gansser, A.1939. Central Himalayan. Geological observation of the Swiss Expedition 1936, Hem.Soc.Sci.Nat.73,1 ,. 245.
8. Hooker J.D. 1854. Himalayan Journals. London, John Murray
9. Mallet F.R. 1874 on the geology and mineral resources of Darjeeling District and the Western Duars. Memoir, G.S.I.
10. Malley L.S.S.O, 19072 Bengal District Gazetteers Darjeeling, Government of West Bengal 124
11. Middlemiss C.S. 1916. General Report for 1914. Rec. Geol. Surv. India, Vol. 45, 2, .119.

12. Nautiyal S.P. 1966. On the stability of certain hillsides in and around Darjeeling, W.B. Bull. Of the Geol. Survey of India, Series B, 15, 1, 31-48.
13. Ollier C.D.,1961 Longman Group Ltd. Weathering, 34
14. Petley, D.J., 1984 'Ground investigation, sampling and testing for studies of slope instability', in D. Brunsden and D.B. Prior (eds.), Slope Instability (Wiley, Chichester), 67-101.
15. Ray S. and Sen Sharma S.B. 1967. Geological report on the stability of hill slopes in and around Darjeeling town, Darjeeling district, W.B. GSI Report, unpub.
16. Starkel L. and Basu S. 2000.History of Research and Method, (in) S.R. Basu and L.Starkel (ed.), Rains, Landslides and Floods in the Darjeeling Himalaya, Indian National Science Academy, New Delhi, 6-11
17. Starkel. L.1970. Causes and effects of a heavy rainfall in Darjeeling and in the Sikkim Himalayas. Journal of Botany Nat. Hist. Soc. 97,1,45-50.
18. Urbanization and Environmental Catastrophe in the Darjeeling Himalayas, (in) L.R. Singh (ed.)-Impact on Man on Environment: Some Cases of Concern, Prof. R.N.Dubey Foundation, Allahabad, pp. 1-21