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Some aspects of snow cover development and avalanche formation in the Indian Himalaya

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ABSTRACT Vast areas of the Western Himalaya receive heavy snowfall and witness avalanche activity. As one proceeds west to east or south to north in the Himalayan region, significant variations are noticed in the snow - properties and its stability. Avalanche activity is also severe in the Himalaya. Both dry and wet snow avalanchesare common. The high altitudes, large catchment areas, steep slopes add to the problems. The paper attempts to bring out some of the characteristics of seasonal snow cover and its development and also to discuss some aspects of avalanche formation and occurrence with special reference to terrain features.

QUELQUES ASPECTS DU DEVELOPPMENT DE LA COUVERTURE DE NEIGE ET DE LA FORMATION DES AVALANCHES DANS LES HIMALAYAS INDIENS

RESUME De Vastes terrains dans les Himalayas occidentaux reçoivent des chutes de neige abondantes et sont soumis à de fréquentes avalanches. En allant de l'ouest à l'est ou du sud au nord dans la région Himalayenne, des variations significatives sont remarquables dans les propriétés de la neige and dans sa stabilité. L'amplitude des avalanches est aussi sévère dans les Himalayas. Des avalanches de neige seche et humide, sont également communes. De hautes altitudes, des captations des eaux très larges, ainsi que des pentes raides augmentent le problème. Ce document essaie de mettre en relief quelques caracteristiques de la couverture de neige saisonniere et son developpement. ll essaie aussi de discuter quelques aspects de la formation et l'occurrence des avalanches avec référence particuliere aux reliefs du terrain.

INTRODUCTION

The Western Himalaya, presents an intricate mosaic of mountain ranges; the alignment, altitude and interiorness of which have a profound influence on the weather and climatic conditions. Extending NW - SE, with altitudes ranging from 450m to 7500m, the ranges are interspersed by longitudinal valleys (Fig 1). Vast areas of this region receive heavy snowfall and witness avalanche activity. As one proceeds west to east or south to north in the Himalayan region, significant variations are noticed in the physical and mechanical properties of fresh snow, its depth, duration, metamorphic process and stability.

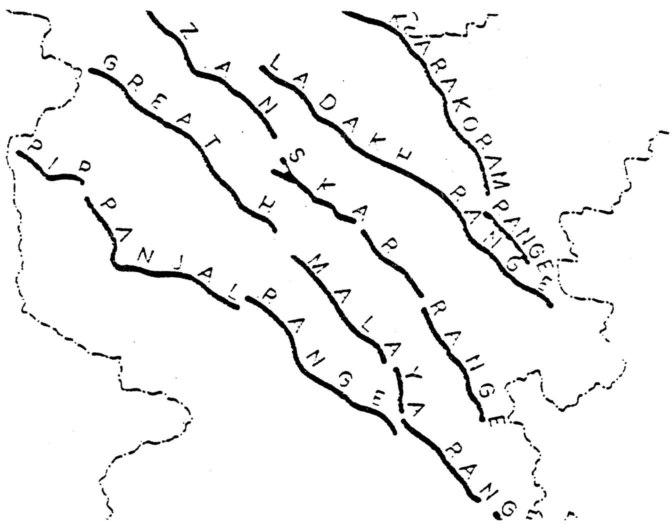

FIG 1. Himalayan Ranges extending NW-SE.

The large accumulation of snow coupled with rugged and steep terrain and high altitudes results in severe avalanche activity. The avalanches of Himalaya though massive in character have not been viewed as a hazard till lately because of the limited interaction between man and mountains. The situation has changed significantly in India in the last decade with the opening of road communications to high altitude snow bound areas and with new strides in hill development and winter tourism.

Based on the studies conducted in the field over the last ten years by the Snow & Avalanche Study Establishment an attempt is made in the paper to bring out some of the characteristics of seasonal snow cover and its development and also to discuss some aspects of avalanche occurrence and avalanche formation with special reference to the terrain.

SNOWFALL PATTERN

The total yearly snowfall in the Himalaya has shown a variation of 400 cms to 1500 cms in the last decade and is spread out in about 15 spells. There are occasions when the snow storm lasts for several days, sometimes as long as 7 to 8 days, with intensities reaching a peak value of 9 to 12 cms/hour. Major snow storms

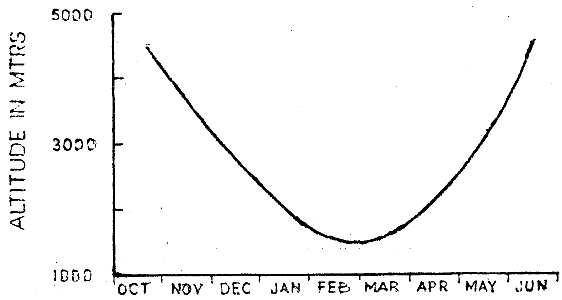

FIG 2. Descent of snow line due to seasonal snow.

bring 100 - 200 cm of snow in one spell. In peak winters the seasonal snow line in Western Himalaya descends from altitude of about 4500 m (permanent snow line) to 1500 m. (Fig 2). Mohan Rao (1983).

The snowfall period depending on altitudes extends from 3 months to 8 months in a year. While in the lower ranges (Pirpanjals) the snow exhibits 'Wet Snow' characteristics, the snow in the higher reaches of Great Himalaya is primarily 'Dry Powdery Snow'.

Data on weather and snowfall have been collected at different locations across the mountain ranges of Western Himalaya in Himachal Pradesh (SW-NE) at altitudes ranging from 2200 m to 4900 m. The lowest minimum temperatures vary from -6 °C to -30 °C. The surface air temperatures at any given altitude are lower and the duration when the minimum temperatures remain below 0 °C higher, to the north of Pirpanjals compared to the South of this range. This feature influences the duration of seasonal snow cover, rate of settlement and type of metamorphism resulting in variation in snow cover characteristics on either side of this range.

Observations on fresh snowfall densities and intensities to the south of Pirpanjals and to its north as we approach the Great Himalaya are presented in Table 1. As one approaches the Pirpanjal range from south, there is a general increase in the average fresh snow density as well as snowfall intensity with increasing altitude. To the north of Pirpanjals and towards the Great Himalaya, the same trend is observed for the average fresh snow density values. It is interesting to note that the highest densities and intensities decrease with increasing altitudes to the north of Pirpanjals and towards

Table 1 Observations on fresh snow fall densities and intensities in the Himalaya

Station & Altitude m	1 2200	2 2500	3 3500		4 3100	5 3100	6 3300	7 3800	8 4900	
Fresh Snow Density in Kg/m³				Pirpanjal Range						Great Himalaya Range
Highest	280	250	280		200	180	160	140	130	
Average	89	98	124		80	87	103	106	94	
Lowest	40	40	60		60	60	50	60	40	
Fresh Snowfall Intensity cm/hr										
Peak	4.6	8.3	12.0		8.0	7.7	4.0	4.3	3.3	
Average	1.8	2.3	2.4		2.2	1.7	1.3	1.3	1.2	

Great Himalaya. The highest density of 280 kg/m^3 recorded at station 3 appears to be the result of wind blown snow and the value of 280 kg/m^3 at station 1 at an altitude of 2200 m appears to be due to wetness.

PROPERTIES OF SEASONAL SNOW COVER

Standing snow profiles at different altitudes in the Pirpanjals and Great Himalaya for 1984-85 are presented in Fig 3. The snowfall was however below average during this year. The duration of seasonal snow cover, settlement rates and ablation rates are also given in Table 2.

Table 2 Variation in duration, settlement and ablation rates of seasonal snow cover in Himalaya

Station	Altitude (m)	Duration of Seasonal Snow Cover	Settlement Rate(%)		Ablation	
			Period I 10–15 Jan	Period II 10–16 Feb	Period	Rate (cm/day)
1	2200	30 Dec – 10 Feb	4.4	-	30 Jan–10 Feb	8
2	2500	12 Dec – 25 Feb	3.6	-	05 Feb–25 Feb	8
5	3100	12 Dec – 16 Mar	2.1	0.8	20 Feb–13 Mar	10
6	3300	12 Dec – 11 Mar	1.1	0.6	23 Feb–11 Mar	10
7	3600	12 Dec – 30 Apr	1.7	0.7	24 Feb–30 Apr	7

It will be observed that-

(a) The duration of seasonal snow cover is more as we go towards the Great Himalaya.

(b) Significant decrease in settlement rates are observed towards the Great Himalaya because of prevalent low temperature and high altitude.

(c) The ablation rates are almost the same at all stations. For station in the Great Himalayan belt (Stations 5,6&7) the snow cover ablation rate is apparently more because the ablation and settlement take place simultaneously.

Altitude variation of precipitation

Based on the precipitation data at different altitudes recorded during the last seven winters (1 Nov to 30 Apr) in the Kullu Valley of Himachal Pradesh, an altitude factor has been worked out to show the effect of altitude on precipitation. The results are plotted in Fig 4. It is seen that the total winter precipitation increases exponentially with altitude.

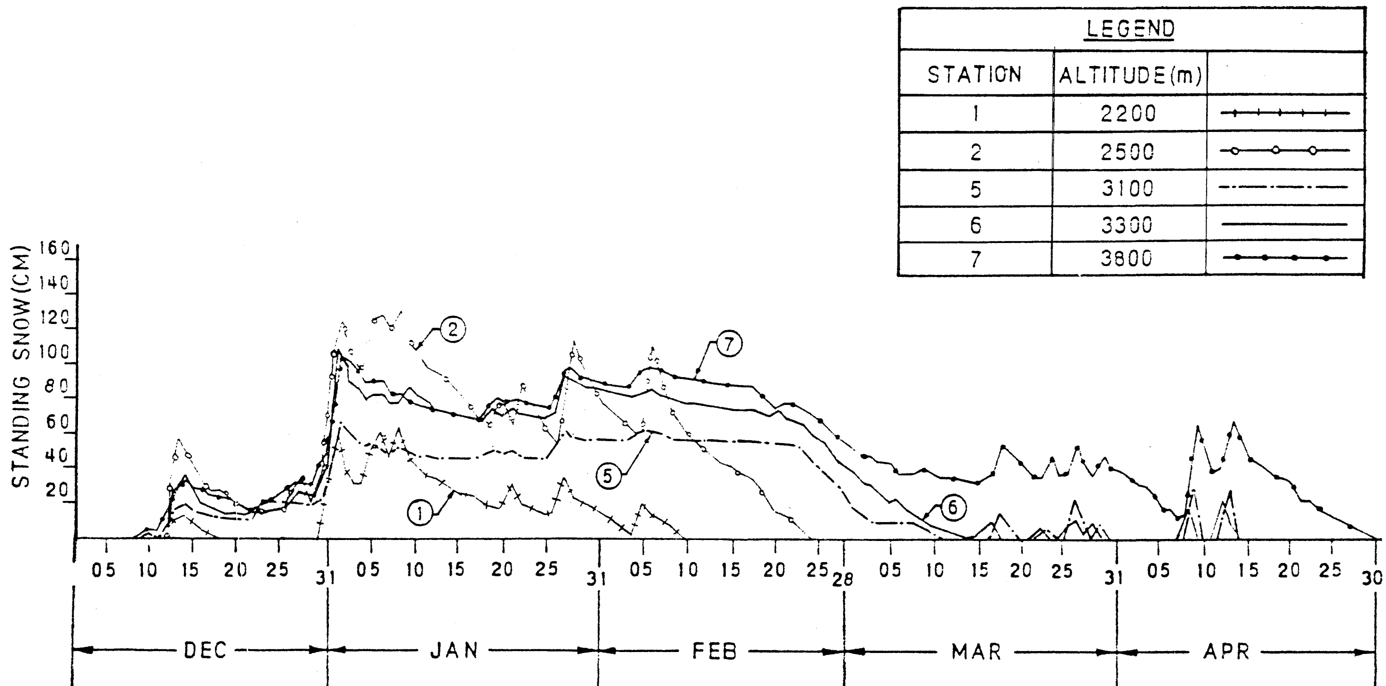

FIG. 3. Standing snow profiles at different altitudes in the Himalaya.

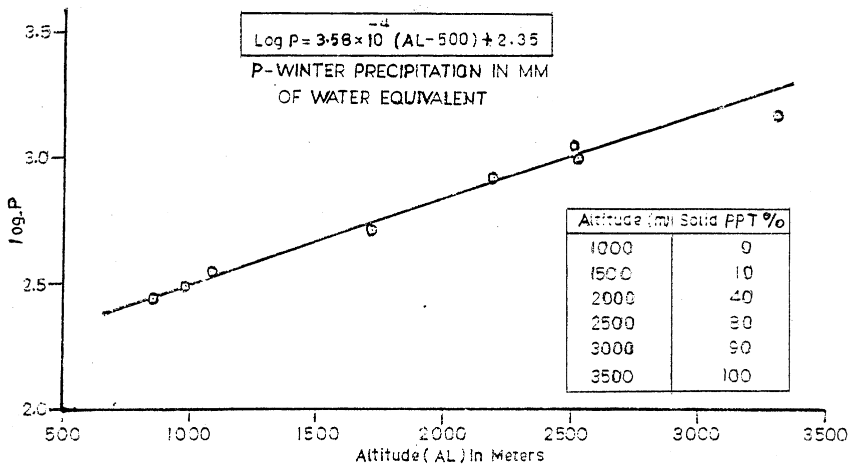

FIG 4. Effect of altitude on precipitation.

AVALANCHE PROBLEMS

Many villages, famous pilgrim centres and mountain roads in the Himalayan region are affected by the avalanche phenomena. The avalanche activity is most pronounced in the months of January, February, March. Avalanches have also been taking a heavy toll of human and animal life. In the year 1979 nearly 230 persons died in one district of Himachal Pradesh due to avalanches that came down in March that year. (Return period about 100 years). A high density of avalanche concentration on hill roads results in a heavy deposition of avalanche snow over great road lengths.

In the Indian Himalaya both dry snow and wet snow avalanches are common. Soft slab avalanches are more frequent. T.G. metamorphism also plays a major role in the release of the avalanches in the upper reaches. Powder avalanches are not uncommon.

Terrain Characteristics

In most of the avalanche slopes the formation zones are above timber line and are therefore exposed to snow deposition due to wind action. A large number of starting zones are at altitudes of about 3500m to 4500m. The starting zones are extensive (20-40 hectares) and are generally bowl shaped with steep confined gullies (30^{o} to 45^{o}), Mohan Rao, Rangachary (1983). Out of 195 avalanche sites studied in the Himalaya the following terrain characteristics for formation zones are significant.

Forested	3
Above tree line	192
Rocky with outcrop	128
Loose boulders	26
Shrubs and long grass	30
Shrubs with scattered trees	8

The avalanche activity at 15 avalanche slopes in the Pirpanjals has been under observation for the last 10 years to understand the

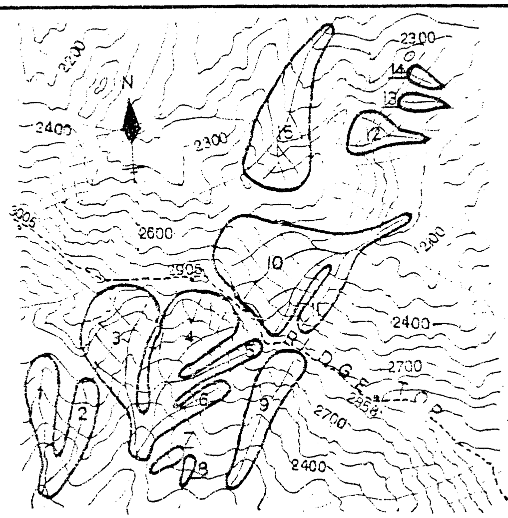

FIG 5. Map showing a group of avalanches in the Pirpanjal.

mechanism of formation and occurrence of avalanches in relation to snowfall, terrain characteristics and wind activity, (Fig 5). The terrain characteristics of these avalanches and their occurrences are given in Table 3.

It will be seen that the avalanche frequency is higher for No 10 and 11 avalanche slopes (34 and 21 respectively) in 10 years as compared to avalanche No. 4 and 9 (13 and 14 respectively). The avalanches from these slopes during the last ten years generally triggered when the standing snow at the observatory site (altitude 2200 m) was about 100 to 120 cms. It was difficult to attribute this difference mainly due to wind action as the wind direction at the ridge line was quite fluctuating from NNE to SSW. Since the wind was NNE for longer periods, the avalanche slopes 10 and 11 could not be classified as leeward slopes. The height of formation zones, the climate and snowfall conditions being almost the same for this group of avalanches, it appears that more than any other factor, aspect is playing an important role in relation to avalanche frequency. The southern slopes receive good amount of solar radiation whereby they are getting stabilised faster before the release of avalanches, whereas the northern slopes being in shade (Nos 10 and 11) are releasing avalanches frequently. This and the steeper slope angles appear to be influencing the pattern of avalanche release in this stretch. Data on avalanche occurrence in relation to aspect is presented in Table 4. Details for this group of avalanches under discussion are given under Group I. Avalanche occurrences with formation zones in the altitude range of 3500 - 4500 m are shown under Group II.

From this data it is broadly inferred that

(a) In the lower range where formation zones are around 3000 m, aspect has a significant influence on the avalanche frequency, which is appreciably higher on northern slopes than southern slopes. The southern slopes get stabilised due to solar radiation.

Table 3 Terrain Characteristics of a group of avalanches

Ava No	FZ Area $10^{-2} Km^2$	Mean Alt of FZ (m)	Ave Slope FZ (degrees)	Aspect	Ave Slope Track (degrees)	Ava Occurrences in 10 yrs	Terrain Characteristics FZ	Terrain Characteristics Track
1.	8.0	2740	36	SE	24	4	Loose boulders,small grass.	Loose boulders,grass.
2.	3.0	2560	28	SE	25	2	Small grass.	Small grass.
3.	11.4	2845	34 to 35	S	27	6	Loose boulders,rock outcrop,grass.	Loose boulders and gravel.
4.	19.5	2842	35	SW	28	13	-ditto-	-ditto-
5.	5.0	2450	30	SW	27	8	Rocky with grass, loose soil & grass.	Rocky with loose soil & grass.
6.	5.0	2430	32	SW	26	9	Loose boulders and scattered trees.	Loose boulders and small grass.
7.	3.0	2285	31	SW	28	5	Grassy.	-ditto-
8.	4.0	2380	33	SE	28	9	-ditto-	-ditto-
9.	12.0	2800	35	SW	25	14	Rocky with loose soil and grass.	Scattered trees and loose boulders.
10.	13.7	2840	42	NE	26	34	Rocky with loose boulders & grass.	Loose boulders and scattered trees.
11.	5.5	2650	36	NE	26	21	-ditto-	-ditto-
12.	6.0	2460	35	E	25	9	Loose soil with grass & loose boulders.	Loose soil with grass.
13.	5.0	2330	37	E	27	4	-ditto-	-ditto-
14.	6.0	2320	33	SE	28	3	-ditto-	-ditto-
15.	14.0	2640	35	N	26	4*	Loose boulders and partly forested.	Loose boulders with grass.

*All occurrences not recorded as they do not affect the road.

Table 4 Avalanche occurrences in relation to aspect for two groups of avalanches

Aspect	Group No 1(145 occurrences in 10 yrs)		
	No of avalanche slopes	Avalanche frequency	Avalanche index
North	3	59	19.7
East	2	13	6.5
West	-	-	-
South	10	73	7.3
	Group No 2(399 occurrences in 10 yrs)		
North	39	75	1.9
East	58	111	1.9
West	26	62	2.38
South	96	151	1.57

This is in contrast to the conclusions of Schaerer that aspect had no influence on the average frequency of avalanches, Schaerer (1977).

(b) At higher altitude, with formation zones above 3500 m, aspect has no significant effect on avalanche release.

(c) In both the cases, slope of the avalanche path is also a significant variable.

Avalanche formation and movement

Our knowledge on the formation and movement of avalanches in Himalaya is still limited. Of great interest, in the context of avalanche control measures being undertaken in Indian Himalaya, are the determination of the friction co-efficients μ & ξ. The values recommended by EISLF of μ = 0.16 and ξ = 1360 m/sec^2, Buser and Fruitger (1980), appear to give runout distances far greater than what is observed in the field; may be because in the few observations made the mass and speed of the avalanches were relatively low. On many slopes it is observed that the deposition starts on slopes of 18° to 15°. Values of μ = 0.25 to 0.30 and ξ = 800 m/sec^2 in the track yield more accurate results for runout zone distances in some instances. Further studies are being planned to study the aspects of avalanche formation and movement in the lower and higher Himalaya.

Another interesting aspect of avalanche formation in the Himalaya is the occurrence of powder avalanches. Powder avalanches are to be expected in the higher reaches of Himalaya where very low temperatures, dry snow conditions and steep terrain exist. Very occasionally powder avalanches also come down in the lower valleys.

One such rare instance is the avalanche that triggered on 6th March 1979 from the slopes of the Guskiar village in Keylong district taking a heavy toll of human lives, forest wealth and properties. The avalanche which has a formation zone area of about 34 ha, triggered from an altitude of 4500 m. The average slope of avalanche path in the formation zone is 36^{o} . The length of the track was nearly 3.5 km with an average slope of 24^{o}. In one of the village houses (stepped construction) that was destroyed, were about 10 persons who were all buried under the debris except for one young girl who could be rescued alive after being deposited about 50 m away (horizonal distance) with a fall of 30 m. Based on the case study on accident details the speed of the avalanche was estimated to be 33 m/sec.

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