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Progressive development and risk analysis of rock avalanches: a case study in Higher Himalayan Crystallines of the Langtang National Park, central Nepal

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ABSTRACT

Basic research work on the rare phenomenon of the Tsergo Ri mass movement in the Upper Langtang valley (Nepal Himalaya) during 1990-1996 has helped to identify the most important causes of this extraordinary event (Weidinger et al., 1996). Further investigations all along the valley revealed the preexisting structures in the crystalline rocks of the Higher Himalayan sequence that are also responsible for smaller but frequent landslides and/or rockavalanches (Weidinger, 1997).

Dynamic geomorphological changes are the result of weak rock behaviour due to mechanical conditions of different lithology and seismotectonic structures. Rejuvenations of landslides and rockfalls are frequent as well. They often show a progressive development and/or continuous activity.

Keeping in mind the preexisting structures of the Tsergo Ri landslide, which have been described as brittle reacting leucogranite dykes, metamorphites with deformational fabrics, sulphide ore and neotectonic structures, four recently occurred rockavalanches (typical for the Langtang Valley) were investigated: one in the right side of the recent Langtang valley glacier (Langtang Tsang), about 2 km north of the Alp Pangri Goldum, one in the area of the broken crest of the Tsergo Ri mass movement, west of the glacier named Kyimoshung Tsang (both in the Upper Langtang Valley) and two more in the Lower Langtang valley, south of the "Landslide Lodge" and north of the "Lama Lodge".

Studying these phenomena from the geological and tectonical point of view, geomorphologic changes, morphodynamic development and triggering factors during a period of six years, made it possible to analyse future-risk for some parts of the area.

GEOTECTONICS OF LANGTANG AREA AND POSITION OF LANDSLIDES

All landslides are located in the Langtang valley (Fig. 1),which is situated at about 50-70 km north of Kathmandu. In the lower parts of the valley, near the "Landslide lodge" (1760 m), a rockavalanche originated near the footwall of the Higher Himalayan Crystallines composed of the Gosainkund gneiss, which borders the Syabru gneiss separated by the Main Central Thrust (MCT). A second landslide occurred between the "Lama Lodge" (2470 m) and "Chumna" (2800 m). The NNE to SSW striking valley is a part of a narrow gorge, cutting through the Ghora Tabela gneiss, a fine grained sillimanite and garnet gneiss of the Higher Himalayan Sequence (Macfarlane, 1993).

Occurrence of huge boulders and accummulation of debris along the densly forested bottom of the valley indicate that torrents along erosional rills, gullies and oversteepened flanks often give rise to rockfalls and debris flows during heavy rainfalls, specially during the monsoon.

With the deposit of the Tsergo Ri mass movement, which filled up an area of 24 km^2 from the Alp of "Kyangjin Kharka" (3920 m) further up

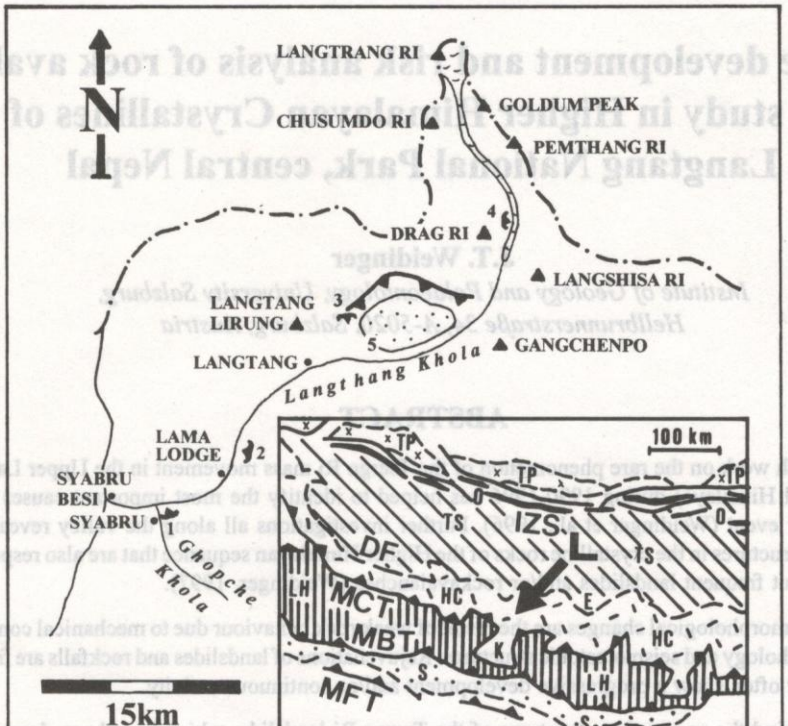

Fig. 1: Langtang area in central north Nepal: Geotectonic position (after Tapponnier et al., 1986): L - Langtang valley, K- Kathmandu, E- Mt. Everest, IZS- Indus-Zangbo-Sutur, DF- South Tibetan Detachment System, MCT- Main Central Thrust, MBT- Main Boundary Thrust, MFT- Main Frontal Thrust, S- Siwaliks, LH- Lesser Himalaya, HC- High Himalayan Crystalline, TS- Tibetan Sediments, O-Ophiolithes, TP- Trans Himalayan Plutons. Peaks, Rivers and Settlements with Position of the Landslides: 1- Landslide Lodge, 2- Lama Lodge, 3- Kyimoshung Tsang and 4- Pangri Goldum-Rockavalanches as well as 5- Tsergo Ri- mass movement.

the valley, one reaches the hanging wall of the Higher Himalayan Gneiss Zone. The Kyangjin and Langshisa Units of the local Langtang Migmatite Zone dominates this area, where gneisses, migmatites and partly discordant leucogranitic dykes are exposed. The general dip of rocks is towardsNE at moderate angles (Reddy et al., 1992; Searle et al., 1997). Besides the giant Tsergo Ri landslide, two more rockavalanches typical for these lithologies, the "Kyimoshung Tsang slide" (5000-5400 m) and the "Pangri Goldum slide" (4885 m), occured in this area.

In the study area, almost all the different exposed lithological units show silent witnesses of seismotectonic events, such as horizons of mylonites and slickensides, related to overthrusting along the MCT and/or within the Higher Himalayan Crystallines, and pseudotachylites, related to frequent earthquakes due to ancient tectonic movements. These horizons, especially exposed in rigid reacting leucogranites, have made the rocks susceptible to sliding (Weidinger et al., 1996).

CHRONOLOGY OF SLIDING EVENTS

Landslide Lodge-Rock Avalanche

Although of low altitude, the part around the confluence of the Ghopche Khola (originating near Gosainkund in the south) with the Langtang Khola, just east of the Syabru village, is one of the most hazardous parts in the investigated area. It is endangered by oversteepened flanks from both sides of the main valley (Fig. 2).

In the monsoon of 1984, the corner part of this flank between the two rivers collapsed creating a huge cone of debris, which fades into a blocky stream (diameter of boulders up to 10 m). Both still reach from the broken crest – at an altitude of 2160 m – down to the main river at 1620 m.

At that time, the path along the Langtang valley and up to the Syabru village was seriously damaged. This situation claimed one victim, a tourist, who could not find his way up to Syabru and was lost in the landslide area. The path was again under construction, while drainage waters from the

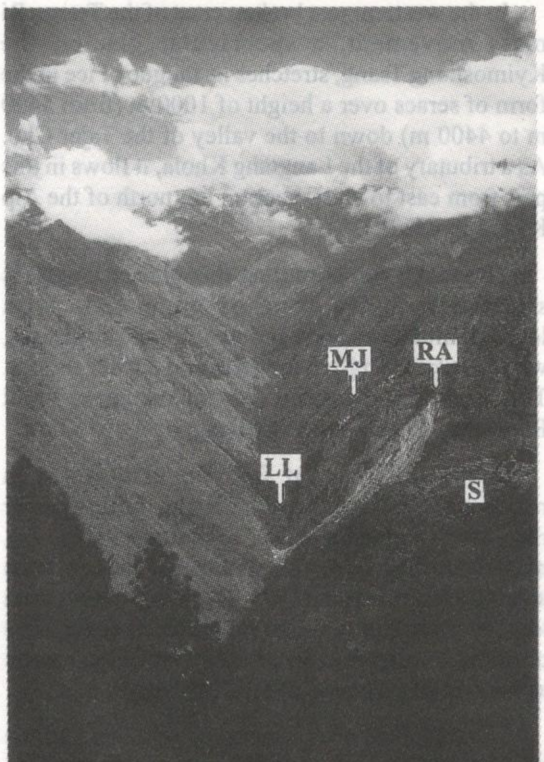

Fig. 2: Landslide Lodge-Rockavalanche: View towards E into the Lower Langtang valley, Landslide Lodge (LL) upwards. Dimensions of the rockavalanche (RA) and potential rockflank- material susceptible to sliding, seperated by open mega-joints (MJ). Terraces of the Syabru village (S). Standpoint: 1 km E of Gompagaon (2300 m), view towards E.

landslide area saturated an older cone of debris at its foot and triggered a small slide in the monsson of 1987. This one was named as the "Landslide Lodge", which is situated just 650 m east of the main slide, from where one has a good view to the younger slide.

Although stable condition has not yet reached, there is no further progressive sliding after 1987. Due to the tectonic position (close to the MCT), open release structures, mega-joints (pore-water pressure during monsoon as well as ice-cracking during winter and spring) and oversteepened flanks, this is still a high-risk-area, which is most susceptible to sliding and averlanching.

Lama Lodge Rock Avalanche

First Stage

Except the extraordinary large Tsergo Ri massmovement, the landslide is one of the biggest (size of affected area and volume) of the investigated rockaverlanches (Fig. 3a). It occurred during the monsoon of 1985.

Field investigations five years later (Weidinger, 1997) revealed that in the area of the broken crest at an altitude of 3600 m, in the east flank of the Langtang Khola - only a small part of the hard rock was affected. Three small peaks in the vicinity of the broken crest were not tangent by the event (P1, P2, P3), although they have shown signs of movement on active joint systems (Fig. 7a).

Further downslopes, an almost 900 m long gully was formed on the collapsing masses due to rock-erosion, where blocks and debris were first collected in the funnel-shaped upper part and later channalised in the narrow middle part of the gully (two small peaks, P4 and P5, south of it were still visible). At last, in the lower parts of the gully, the material of the rockavalanche has spreaded and formed a wide cone of debris towards south, into the Langtang Khola (2700 m).

The diameter of blocks among the debris of this fan was relatively small (up to 2 m). According to the dimensions of the fan, the displaced volume of the slide was estimated at 900,000 m^3, but the neighboring forested zone towards north was nearly unaffected.

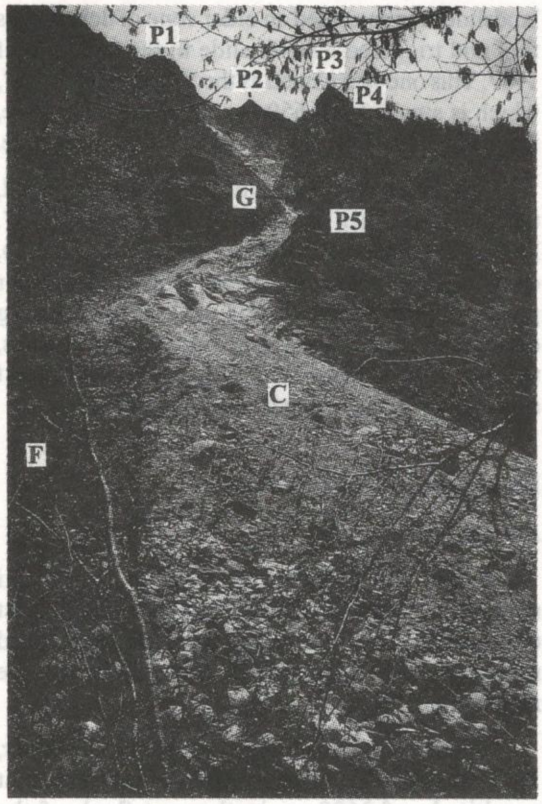

Fig. 3a: Lama Lodge - Rockavalanche - first stage: Unaffected peaks (P1, P2, P3) in the vicinity of the broken crest; 900 m long narrow gully (G) of rock-erosion with peaks P4 and P5; wide cone of debris (C) towards the river Langtang Khola; unaffected forrested zone (F) towards north. Standpoint: 0.75 km S of Chumna Lodge (2760 m), view towards E.

Rejuvenation

One or both of the monsoon seasons of 1994 and 1995 must have had a heavy influence on the development of the slide. Fig. 3b from spring 1996 shows a serious rejuvenation of rockfall and debris avalanche in the area. The new collapse, originated near and enlarged the old parent lodge to northern, eastern and southern direction, causing geomorphological changes all over the sliding area.

Four of the above-mentioned five peaks around the scarp and the gully were damaged seriously: P1 lost its western flank, P2 disappeared almost completely and lost height of several tens of metres, P4 collapsed in situ (perhaps due to a collision with bouncing boulders) triggering erosion on the southern flank above the cone of debris, and P5 lost the northern edge obviously due to a bouncing "rock-bullet" having crashed against it. P3 still poses a potential hazard.

In consequence of this rockfall, the cone of the dislocated material below the sliding area is enlarged to almost double the size of 1990 (estimated total volume = 1.8 million m^3), mainly upstream to the north (huge boulders with diameter of 10 m and more) destroying the former vegetation and the forest.

Kyimoshung Tsang- Rockavalanche

In the westernmost broken crest of the Tsergo Ri mass movement, a spectacular glacier, the Kyimoshung Tsang, stretches its tongue of ice in the form of seracs over a height of 1000 m (from 5400 m to 4400 m) down to the valley of the Tajar Chu. As a tributary of the Langtang Khola, it flows in this part from east to west, about 3 km north of the Alp Kyangjin Kharka.

The rocky rim bordering this glacier tongue is situated within a zone of migmatites with leucogranitic intrusions and neotectonic structures, which strike from ENE to WSW and dip 80° to SSE. They form the mountain crest of the peaks Phrul Rangtshan Ri (6940 m) and Dragpoche (6562 m).

Based on frequent field investigations, a rockavalanche from the western side of the glacier rim, which formed a small "rock tower" (Fig. 4a), must have had occurred within the period from autumn 1993 to autumn 1995. There is no report from local eyewitnesses to fix the exact date. It might have occurred during or short after the monsoon season as well as near the end of a winter season.

The collapsed peak reached an absolute altitude of 5400 m, wereas its foot was at 5000 m. Two million m^3 of rockfall material crashed down to a small western branch of the Kyimoshung glacier, which covered and pushed out some of the ice and were mixed up with local deposited moraine material. Further down the flank and to the valley, the rockslide material formed a wide cone of debris, which can be found as far as down to 4400 m altitude (Fig. 4b). Some blocks even reached and damaged

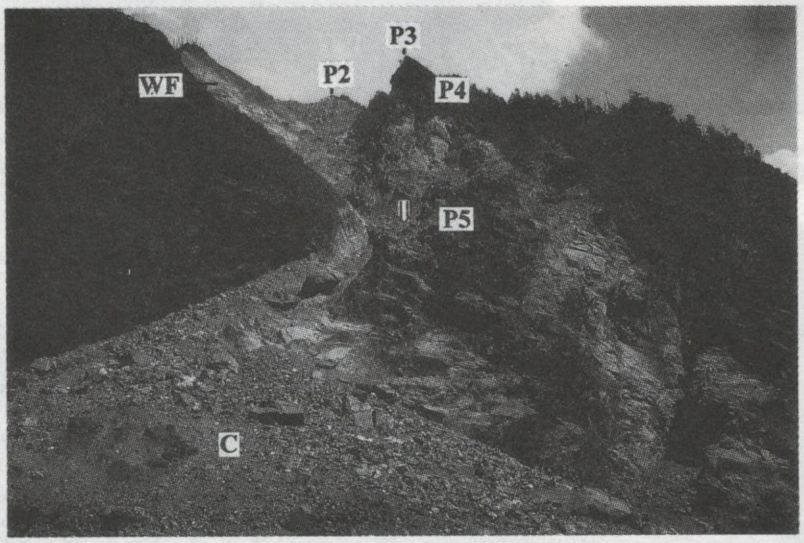

Fig. 3b: Lama Lodge-Rockavalanche - second stage and rejuvenation: Seriously damaged peaks within the enlarged broken crest area as seen in W-flank (WF) of P1, almost disappearance of P2, insitu collapse of P4 causing second erosion channel on the flank above the cone of debris, and lost northern edge of P5 (arrow); debris accummulation (C) enlarged to almost double the size destroying the forrest. Standpoint: 0.75 km S of Chumna Lodge, alt. 2760 m, view towards E.

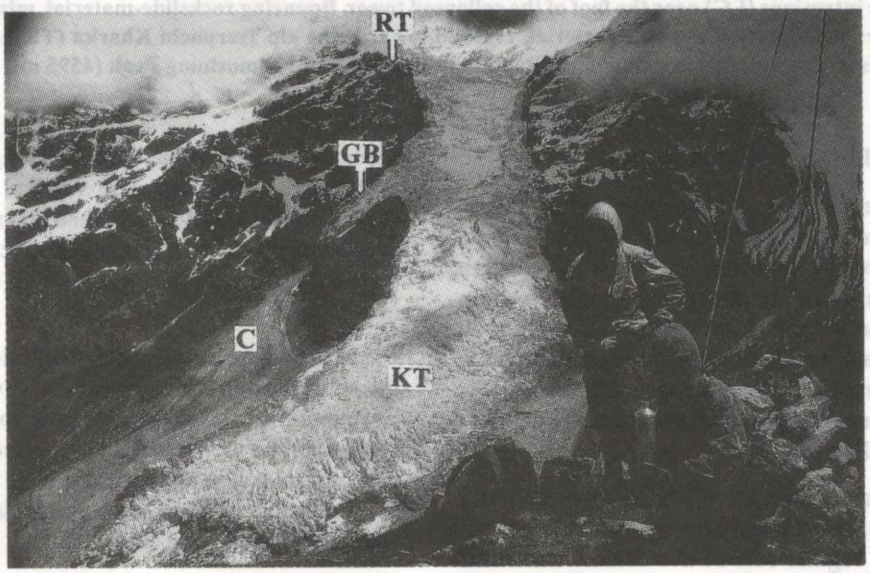

Fig. 4a: Kyimoshung Tsang-Rockavalanche - before the event: The "rock tower" (RT) in the upper left (oro. right) part of the glacier Kyimoshung Tsang (KT) with no signs of disintegrated material. Behind the glacier and its moraine a cone of debris (C) originating from a small branch of the glacier (GB) below has accummulated due to outwashed, fine grained moraine material. Standpoint: Kyimoshung Peak, (4645 m), view towards N.

the Alp huts of Tserpochi Kharka (4240 m). The whole flank, which fortunately is just partly used as an agricultural land, is still a risky place for hazardous rockfall events.

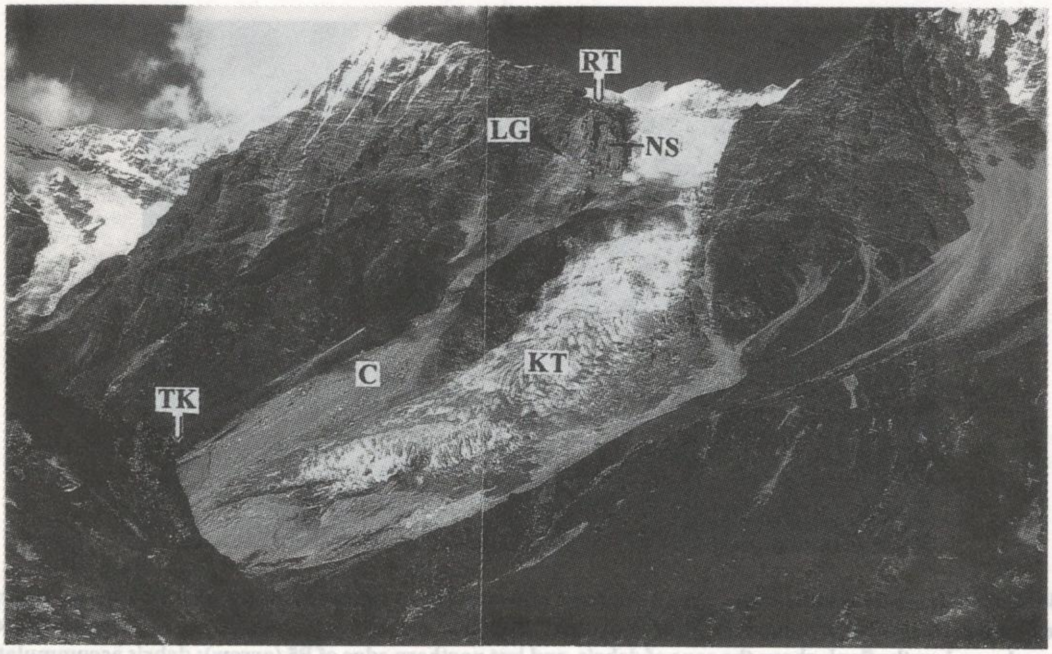

Fig. 4b: Kyimoshung Tsang-Rockavalanche - after the event: Collapsed "rock tower" (RT) with mountain failure along vertical fault-planes of neotectonic structures (NS), crosscutting this peak parallel to the flank. Destabilicing leucogranitic intrusions (LG) near the foot of the collapsed tower. Bouncing rockslide-material, mixed with ice of the glacial branch and local moraine material, crashed towards the alp Tserpochi Kharka (TK), enlarging the cone of debris (C) with gravel and boulders. Standpoint: 0.5 km E of Kyimoshung Peak (4595 m), view towards NNW.

Pangri Goldum Rockavalanche

This big rockfall was first recognised in autumn 1993. The area named after an Alp (4720 m), which is situated about 2 km south, is close to the western lateral moraine of the Langtang Tsang (= main glacier of the valley). Although not situated in an part of the valley with the possibility of an effect to cultivated land and lives of people, this landslide is a typical example for rock failures in the uppermost Langtang valley (Fig. 5).

It occured along sulphide ore bearing leucogranitic intrusions within migmatites, which are fractured by regular sets of neotectonic structures (Fig. 6 and 7e). In addition, due to regression of the active glacier body, the flank lost its static foot of ice and morainic material.

The area behind the lateral moraine and the cones of debris originating from the steep flanks of the valley are filled up with huge granitic boulders (diameter >10 m). Disseminated and weathered sulphide ores give a destabilising input for mechanical properties. The vertical distance of dislocation was slightly more than 300 m of altitude. Because of this, the rolling and bouncing boulders could not jump over or crash through the morainic barrier.

Studies at the broken crest revealed an actual age of the rockslide of just a few years. A rejuvenation of the slide with new rockfalls even bigger than the mentioned are expected not only at this point, but also all along the way on the right lateral moraine of the Langtang glacier, up to the base camp of Langtang Ri (7205 m).

PREPERATORY CAUSAL STRUCTURES OF LANDSLIDES IN THE LANGTANG VALLEY

The preperatory causal factors, which lead to the mountain- failure of the Yala Peak (5220 m) and

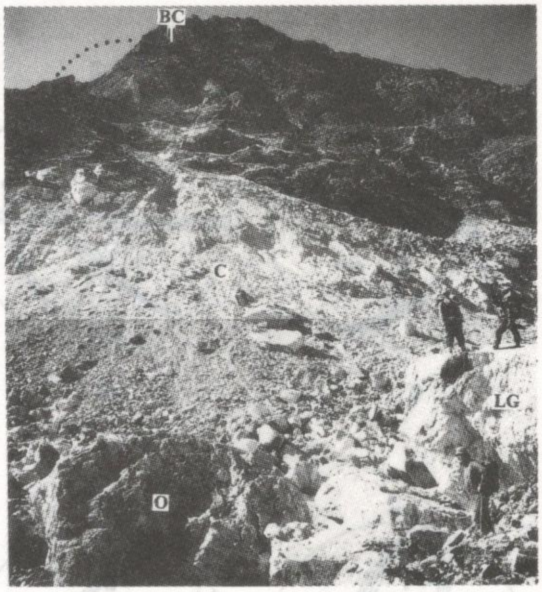

Fig. 5: Pangri Goldum-Rockavalanche: Ore containing (O) leucogranitic boulders (LG) with diameters up to 10m behind the lateral moraine of the glacier Langtang Tsang. Scarp of the broken crest (BC) and cone of sliding-material (C) in the background. Standpoint: 2 km N of the alp Pangri Goldum (alt. 4885m), view towards W.

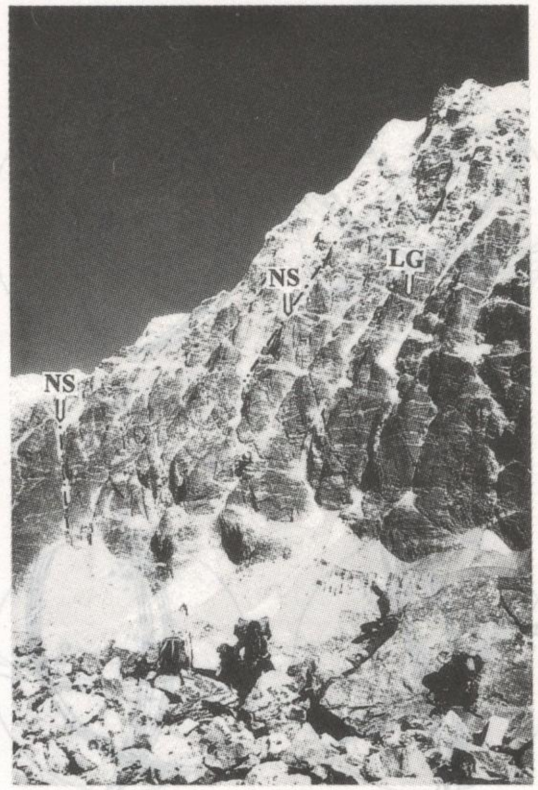

Fig. 6: SW-flank of Pemthang Ri (6758 m): Extraordinary regular sets of parallel neotectonic structures (NS) as outlined in Fig. 7e and leucogranitic intrusions (LG) discordante to primary foliation, which both give rise to erosional processes (cones of debris near bottom) and rockfalls. Standpoint: 2.5 km N of the Alp Pangri Goldum (4890 m), view towards NNE.

Dragpoche Peak (6562 m) crest creating the Tsergo Ri massmovement, have been outlined as: i) weak rock quality due to disseminated ore-mineralisation, ii) brittle and rigid mechanic reaction of leucogranites, iii) seismic and tectonic triggered brittle reacting pseudotachylites, mylonites and slickensides, and iv) neotectonic structures and release joints (Weidinger and Schramm, 1995; Weidinger et al., 1996).

Almost all over the Langtang valley some (no leucogranites in the lower parts!) or all of these factors are at present relevant for sliding events. Statistic analysis and studies of fabric data at the peaks of Lama Lodge Rockavalanche, Gangchenpo, Langshisa Ri, Drag Ri, Pemthang Ri, Goldum, Langtang Ri and Chusumdo Ri (Fig. 7a and 7h) underline these results. This means that besides Tsergo Ri massmovement, the focused rock avalanches show one or more of these factors as preexisting structures (preperatory causal factors), which are conducive to landsliding (Table 1).

The rock-loosening and mountain-failure of Lama Lodge- Rockavalanche was recognised along extensive neotectonic faults and release-joint-sets (Fig. 7a) striking partly parallel or subparallel to metamorphites with a deformational fabric (slickensides, mylonites and pseudotachylites), which support the destabilisation of the crystalline rocks. The same situation prevailed in the area of the Landslide Lodge- rockavalanche. In this part of the Lower Langtang valley, rigid reacting leucogranitic intrusions and associated ore mineralisations are missing.

Destabilising effects of the Kyimoshung Tsang- Rockavalanche were mainly recognised along neotectonic structures and partly due to

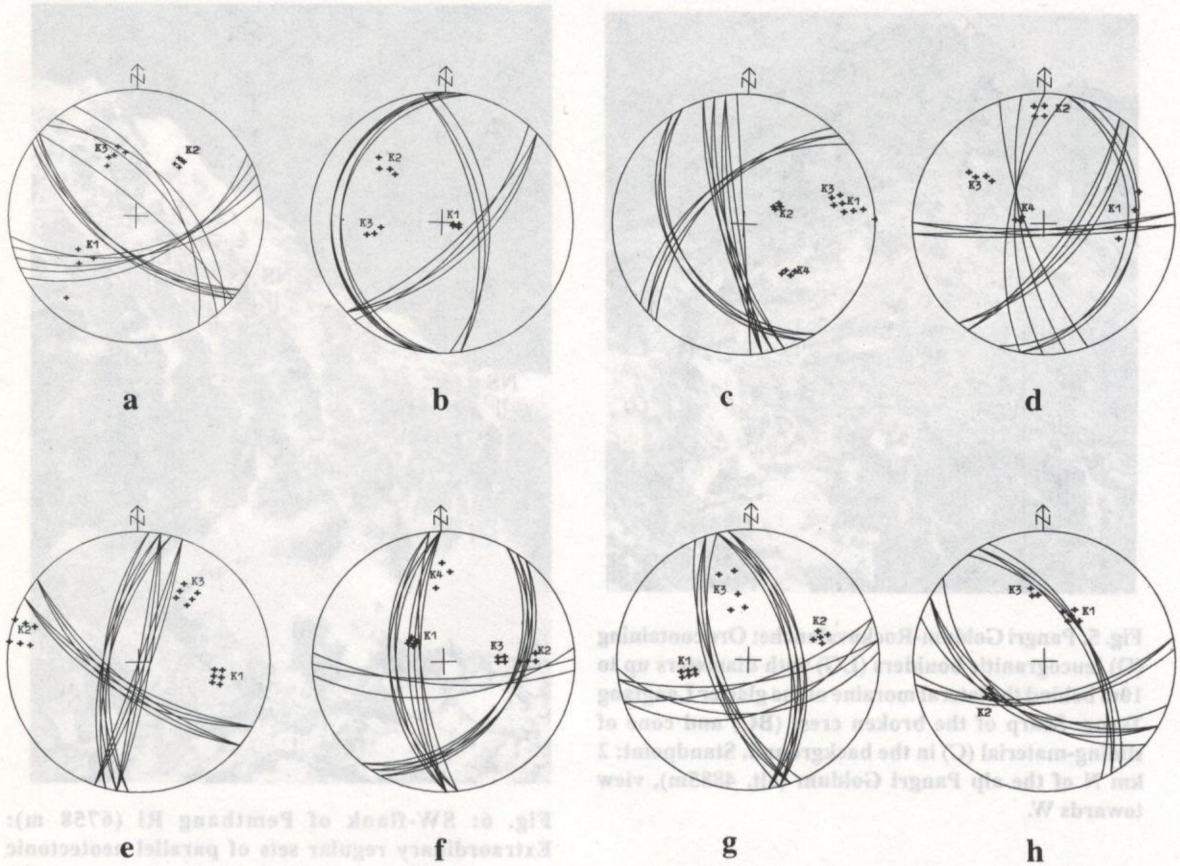

Fig. 7: Stereographic representation (lower hemisphere) of active joints and related structures in the Langtang valley (listed according to their importance). a) Broken crest of Lama Lodge - Rockavalanche (3600 m). 15 data points: main foliation with parallel set of joints (K1). Two open sets of joints (K2, K3) causing the rockfailure and dominating the broken crest of the sliding area. K2 parallel or subparallel to mylonites and pseudotachylites. b) NE-flank of Gangchenpo (6387 m). 12 data points: Fault along a mighty discordante leucogranitic intrusion (K1) crosscutting the whole peak. Set of joints crosscutting the N-crest of the peak (K2) and causing displacement and disorientation of blocks and parts of the crest. Set of joints (K3). c) SW-flank of Langshisa Ri-SE-peak (6145 m). 16 data points: Three sets of joints (K1, K2, K3) creating dislocation and disintegrated rock-bodies like "rock-towers". Open set of joints (K4). d) SE-flank of Drag Ri (5700 m) near the alp Pangri Goldum (4725 m). 15 data points: Spreading set of joints (K1) along parallel mylonitic horizons within a leucogranitic body. Set of joints (K2) without signs of ancient overthrusting tectonics. Neotectonic set of joints, close and parallel to the valley (K3). Set of joints parallel to the main foliation of the outcropping migmatites (K4). e) SW-flank of Pemthang Ri (6758 m) with similar structures as near Pangri Goldum Rockavalanche. 18 data points: two sets of joints (K1, K3) with regular distances of 70-100 m inbetween forming the wall and causing gully-like erosion (hudge cones of debris on the foot of the flank) in and along their crosscuts. Set of joints, partly responsible for the failure of Pangri Goldum - Rockavalanche (K2). f) SW-flank of Goldum Peak (6700 m). 17 data points: four sets of active joints and related structures (K1, K2, K3, K4). g) SSW-crest of Langtrang Ri (7205 m). 16 data points: Extraordinary regular set of joints (K1). Set of joints along discordant leucogranitic intrusions below the summit (K2). Set of sulfidic ore-mineralised joints (K3). h) E-flank of Chusumdo Ri (6602 m) at an altitude of 6325 m. 12 data points: Two sets of joints (K1, K2). Set of sulfidic ore-mineralised joints, parallel or subparallel to the flank (K3) with pinnate fractures as sulfidic mineralised veins to different directions.

Table 1: Rockavalanches and Tsergo Ri- mass movement of Langtang valley: Basic data and distribution of preperatory causal factors (preexisting structures): A= year of the event, V= volume of the dislocated masses in cubicmeters, H= vertical distance from broken crest to deposit in meters, M= metamorphites with a deformational fabric (mylonites, slickensides, pseudotachylites), G= leucogranitic intrusions (dykes) within migmatites, O= disseminated sulfidic-ore-structure(s) within leucogranites, N= neotectonic structures and release joints, + = occurring, - = not occurring.

Rockavalanches of Langtang valley	Basic Data			P.C. Factors			
	A	V	H	M	G	O	N
Landslide Lodge	1984	50,000	540	+	-	-	+
Lama Lodge	1985, 1994/95	1.8 million	900	+	-	-	+
Kyimoshung Tsang	1993 - 1995	2 million	1000	+	+	-	+
Pangri Goldum	≈ 1983	15,000	300	+	+	+	+
Tsergo Ri	≈ 40.000a	> 10 billion	> 1600	+	+	+	+

mylonite-containing, leucogranitic dykes, whereas the Pangri Goldum Rockavalanche, as a typical example for rockslides and falls in the Upper Langtang valley, shows a mixture of leucogranites, ore mineralisation, neotectonics and release structures (Fig. 7e).

TRIGGERING FACTORS

Extraordinary large landslides, such as the Tsergo Ri- massmovement, might have been triggered by seismic events due to progressive seismo-tectonic activity in the Himalayas towards the south (Weidinger et al., 1996). This means that both, the lithotectonic preexisting structures and the seismic exposition, are responsible for this rare catastrophies.

On contrary to this, the smaller but more frequent events present a causal mixture, where lithotectonic conditions build the preperatory causal factores and the climatic circumstances, mostly heavy rainfalls during monsoon season and/or frost, play the role of initial triggering effects for the events.

The precipitation in the Langtang valley tends to decrease from SW to NE with increasing aridity and elevation. Heavy snowfalls due to disturbances of the western wind system occur only in some years, whereas heavy monsoonal rainfalls are more frequent, in August 1992 with 221.8 mm precipitation per month (Ibetsberger, 1996).

Beyond an altitude of 5400 m snow dominates over the precipitation. Due to this, landslides in the upper part of the valley tend to be triggered and rejuvenated by ice-cracking, whereas those in the lower parts are primary initiated by rainfalls.

CONCLUSIONS AND RECOMMENDATIONS

The landslide and rockavalanche investigations all over the whole Langtang valley give evidence that even much smaller and recent massmovements support the theories of preperatory causal factors as the main reasons for the collapse of the instable Yala Peak and Dragpoche Peak crest (Tsergo Ri- mass movement) some 40,000 years ago.

The study also shows that the outlined factors are not only responsible for ancient sliding but also for mountain-hazards, because some of the still active landslides have occured recently and have still not reached stable conditions.

The Upper Langtang valley is not encroached much by human beings. Hence, the investigations overthere are useful for basic landslide research.

Applied geology for hazard mapping can be practised in research of the landslides in the Lower Langtang valley. Especially the narrow gorge in this area with rockmass susceptible to sliding (e.g. "Lama Lodge" and "Landslide Lodge rockavalanches and affected areas in between) confirm unstable conditions of the tectonised crystalline rocks.

This situation in the area is dangerous for cultivated land as well as for human beings. "Lama Lodge Rockavalanche", e.g. show that parts of the peaks P1 and P2 as well as the whole peak P3 are still active and act as potential hazards for the trekking route along the Langtang Valley. One more serious problem is that the area around the "Landslide Lodge", east of the Syabru village, is dangerous because of the above-mentioned rockslide and also due to wide open neotectonic structures and release joints on both flank of the valley. They were also mapped below the alp meadows of Sherpagaon, towards the northern flank of the valley.

Apart from this, a rockavalanche, which was partly triggered by surface-weathering of the gneissic rocks, is also noteworthy: 1.5 km west of the Landslide Lodge rockavalanche, the Langtang Khola down to the Syabru Besi village, a cone of rockslide material has once reached the bank of the river. It originated just in the right flank of the valley, where a surface parallel to the flank of the valley (depth = 20-30 m) is created by weathering and became unstable and endangered the trekking-path.

The path all along the valley is not very frequently visited by tourists and locals during the monsoon season. The small tourist-village of Lama Hotel and the two lodges of Chumna are the most affected area. The Landslide Lodge and adjacent area further up the valley are also located in a highly endangered part.

Hence, it is recommended that the present work on hazard mapping should be continued and the hazard zonation should be carried out in order to make safe use of land development and cultivation.

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