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Landslide dams of Tal, Latamrang, Ghatta Khola, Ringmo, and Darbang in the Nepal Himalayas and related hazards

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ABSTRACT

This study deals with five landslide dams in the Nepal Himalayas. Two of them (i.e. Tal and Latamrang) are situated within the Higher Himalayan Crystallines of the Annapurna region, one (i.e. Ringmo) lies within the Tibetan-Tethys Zone of Dolpa, and remaining two (i.e. Ghatta Khola and Darbang) are located within the Lesser Himalayan rocks. All of them formed a more-or-less stable lake upstream by damming the main river.

In this paper, an attempt has been made to work out the stability conditions of these dams and their risk of failure. Generally, the stability of such dams is attributed to their morphology, volume of debris as well as its composition and size of clasts. Based on the study of these five cases and another well-known example from the Himalayas (i.e. Ghona Tal), it can be shown that there are other following important factors affecting the stability of landslide dams:– type of movement (sliding, avalanching, in situ collapse);

- grain size distribution of the landslide debris (boulders, not disintegrated and interlocked blocks, shattered and crushed material);
- possibility of mixing of the landslide debris with the glacial deposits;
- possibility of secondary cementation of the landslide debris (by seepage water, transported sediments, mineralised thermal waters);
- climatic conditions; and
- rate of sedimentation in the lake.

INTRODUCTION

Many workers (Gansser 1987; Uhlir 1997; Weidinger 1998a, b; Weidinger and Ibetsberger 1997a, 1997b; Yagi, 1992, 1997; Yagi et al. 1990) have reported landslide dams of various dimensions and ages from the Himalayas. In most of the cases, the landslide debris and lake sediments– the sole silent witnesses of such events–are washed away forever due to erosion and outbreak of the dam. Therefore, it is important to know the reasons behind the dam failure: a) when it takes place within the first few days, and b) when it remains stable for a very long period (Costa and Schuster 1988; Schuster 1986). It is equally important to know how the lake is filled up with sediments before the dam breaches.

To elaborate on the so far known results, five landslide dams were investigated for their stability conditions. These dams differ in their age, shape, and size as well as in the composition of landslide debris and size of the lake.

The study was carried out in the gneisses and quartzites of the Higher Himalayan Crystallines of the Annapurna region (central Nepal), and the results are compared with previous studies on other landslide dams in the carbonate rocks of the Tibetan Sediments of Dolpa and the Lesser Himalayan rocks of Galwa and Darbang (all three situated in western Nepal).

LANDSLIDE DAMS

Gigantic mass movements are common in the Marsyangdi Valley of the Annapurna Range. They are attributed to the overprinting of the last two main glaciations as well as the Late- and Post-Glacial geomorphological changes affecting mainly the carbonate rocks (Hagen 1969).

Two new examples of mass movements and rock avalanches from the Higher Himalayan Crystallines (in one case, bordering the Tibetan Sediments) are presented (Fig. 1 and Table 1). One more mass movement featuring the focussed problem is situated within the Lesser Himalaya. The latter lies in the Ghatta Khola, a tributary of the Nyor Gad, which again is a tributary of the river Karnali – the largest river of Western Nepal.

In the Shey Phoksundo National Park, which is positioned in the area of Dolpo (east of the Kanjiroba Himal in Western Nepal), the landslide of Ringmo is one of the largest in the Himalayas. The Darbang landslide in the valley of the Myagdi Khola south of the Dhaulagiri Himal, which occurred in 1926 as well as in 1988 represents a recent example of this problem. A short description of the five landslides is given below.

Landslide of Tal

One of the most important landslides of the Marsyangdi Valley is the rock avalanche near the village of Tal (altitude: 1,600 m), which is situated 7 km south of the confluence of the Dudh Khola (Fig. 1) and the Marsyangdi River. The avalanche took place on the sillimanite-grade gneisses of the Higher Himalaya (Colchen et al. 1986). It had an estimated displaced volume of 4.5 million cubic metres and occurred along the direction perpendicular to the N–S tending valley (i.e. from E to W). The landslide debris dammed the river and

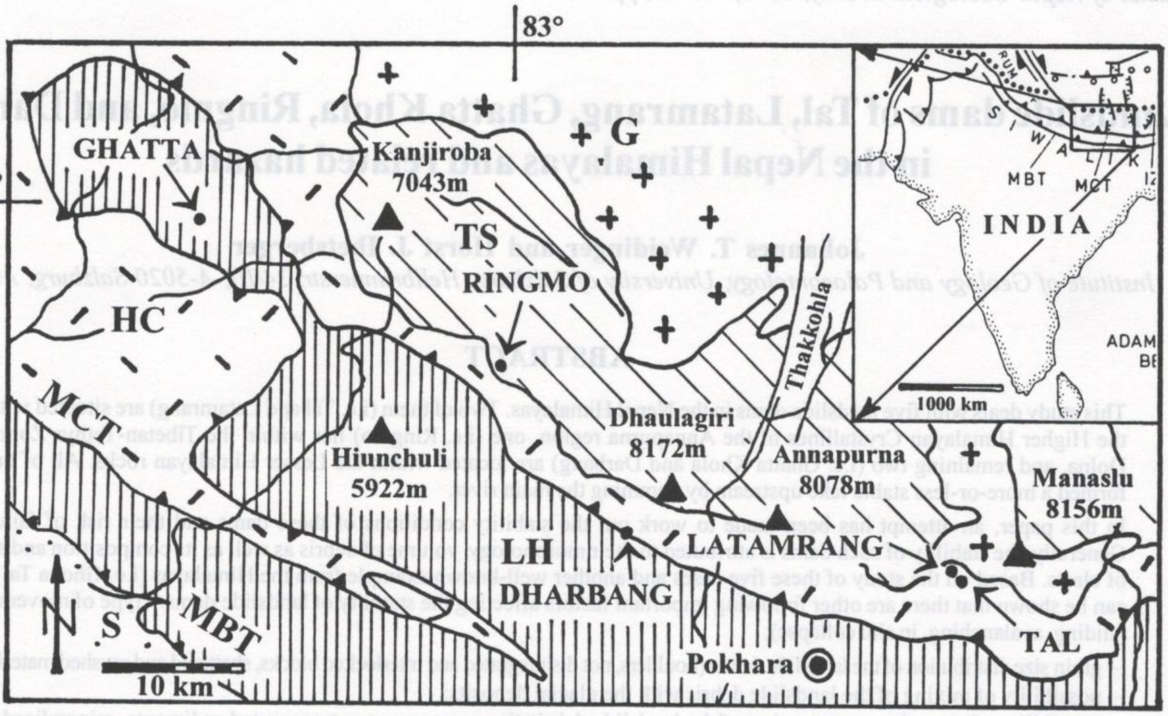

Fig. 1: Geotectonic position of the investigated landslides: S – Siwaliks, MBT – Main Boundary Thrust, LH –Lesser Himalaya with the Ghatta Khola landslide within the tectonic window of Galwa, MCT – Main Central Thrust, HC– Himalayan Crystallines with the landslides of Tal and Latamrang, TS – Tibetan Sediments with the landslide of Ringmo within the Dhaulagiri Limestones, G – Alpine granites and granodiorites. Base Map by G. Fuchs 1980: Geologic-tectonic Map of the Himalaya, scale 1:2,000,000, Vienna; drawings by J. T. Weidinger 1998.

Table 1: Characteristics of five landslide dams in the Nepal Himalayas

S. N.	Name/location	Age	Type	Lithology	Volume	Composition of material
1	**Tal** Marsyandi Valley	<1000 years	Rock avalanche	Gneisses of the HHC	4.5 million m^3	Boulders with diameters between 0.2 and 10 m
2	**Latamrang** Marsyandi Valley	?30,000 years inter, late or Post Glacial	Sledge-like sliding	Gneiss and quartzites of the HHC	Remaining 0.2 form Estimated 1.5 billion m^3	Disintegrated and mixed up cataclastic masses
3	**Ghatta Khola** Galwa	Post Glacial	Rock avalanche	Dolomites of the LH	4.8 million m^3	Boulders with diameters up to 5 m, the rest smaller
4	**Ringmo** Dolpo	30,000–40,000 years	In situ collapse	Limestones of the TS	1.5 billion m^3	Partly disintegrated rock fragments
5	**Dharbang** Myagdi Khola	Occurred in 1926 and rejuvenation in 1988	In situ collapse	Shists, phyllites quartzite	5 million m^3 in 1988	Disintegrated "pulverized" and cataclastic rock

formed a lake of more than 1,000 m in length, around 300 m in width, and about 100 m in depth holding 10– 15 million cubic metres of water.

Today, the former basin is filled up with sediments of the lake and river (Plate 1), but the name of the village (*Tal* means lake) still reminds of the past event. A successive decrease in the level of hazard due to the natural lowering of water level by stepwise erosion of the landslide dam or rapid outbreaks, as reported from the Garhwal Himalayas (Weidinger 1998a; Weidinger and Ibetsberger 1997a, 1997b), is not seen in the area of Tal. No signs of failure of the major dam can be detected. The lake was gradually filled up with sediments within an estimated period of less than 200 years.

Landslide of Latamrang

Some indications of the giant mass movement forming a landslide dam are found between the villages of Latamrang and Thanchauk at an altitude of about 2,400 m. The areas is situated further upstream of Tal along the Marsyangdi Valley where the river changes its course from N–S to E–W. Similar situation is also seen about 15 km upstream of Tal near the village of Chame, at the proximity of the confluence of the Marsyangdi River and the Dudh Khola (Fig. 1).

The mass movement involved the Higher Himalayan Gneisses of the F II and F III Formations and quartzites of the Annapurna Formation belonging to the Tibetan Sediments (Colchen et al. 1986), and Late- to Post-Glacial morainic deposits. It dammed the Marsyangdi River and

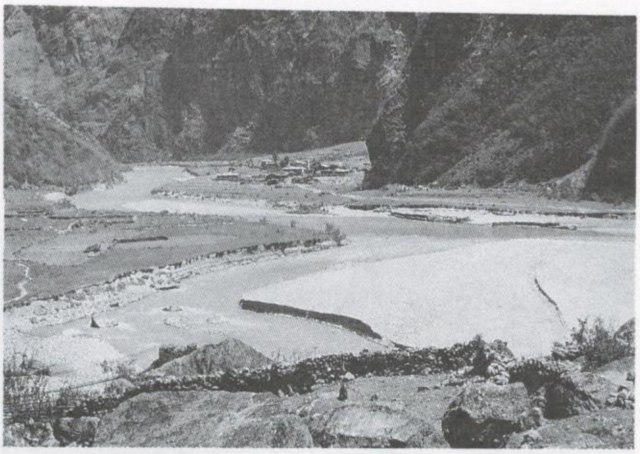

Plate 1: Former basin of the lake in the Marsyangdi Valley near the village of Tal (upper centre), which was dammed by a rock avalanche (boulders in the foreground), today filled up with lacustrine and alluvial sediments visible on both sides of the meandering river (Photo: J. T. Weidinger 1993).

formed a long but narrow lake. There are at least the following three evidences pointing out that some kind of mass movement from SW to NE must have occurred in this area.

- Extensive occurrence of disintegrated and shattered rock fragments mixed up with morainic deposits that are discordantly overlying the bedrock, indicating an unusual mechanism of accumulation, partly in the form of "schlieren" (Plate 2). This material is highly susceptible to erosion (Plate 3) and can be interpreted as a product of rapid movement along the sliding surface and within the landslide mass (Weidinger and Schramm 1995a, 1995b). The landslide reworked the ground morainic deposits generated by syngenetic melting out of glacier ice. In other words, the landslide triggered a rapid movement within the morainic material.
- A wide range of heavily shattered and brecciated rock fragments making up a thickness of about 30 m along the base of the landslide (Plate 4). Probably they were generated due to mechanical stress during the movement, and contain not only clasts of gneisses from the surrounding area but also huge (tens of metres in diameter) dislocated quartzite boulders from the Annapurna Formation.
- Lake sediments upstream of the debris deposits (Plate 5).

Although the area lies in the gneissic material of the Higher Himalayan Crystallines, the geological and morphological features around the two villages are anomalous over a distance of 4 km. Most of the heavily shattered debris (which is mixed up or overlain by the ground morainic deposits) is eroded away, but the morphology clearly shows the rudiments of a huge barrier at the bottom of the valley. The volume of the remaining material is about 0.2 billion cubic metres, and covers an area of 1,000 m in length and 800 m in width. It has a relative elevation of 500 m from the bottom of the valley and occupies the left bank of the Marsyangdi River around the bend northeast of the village Latamrang.

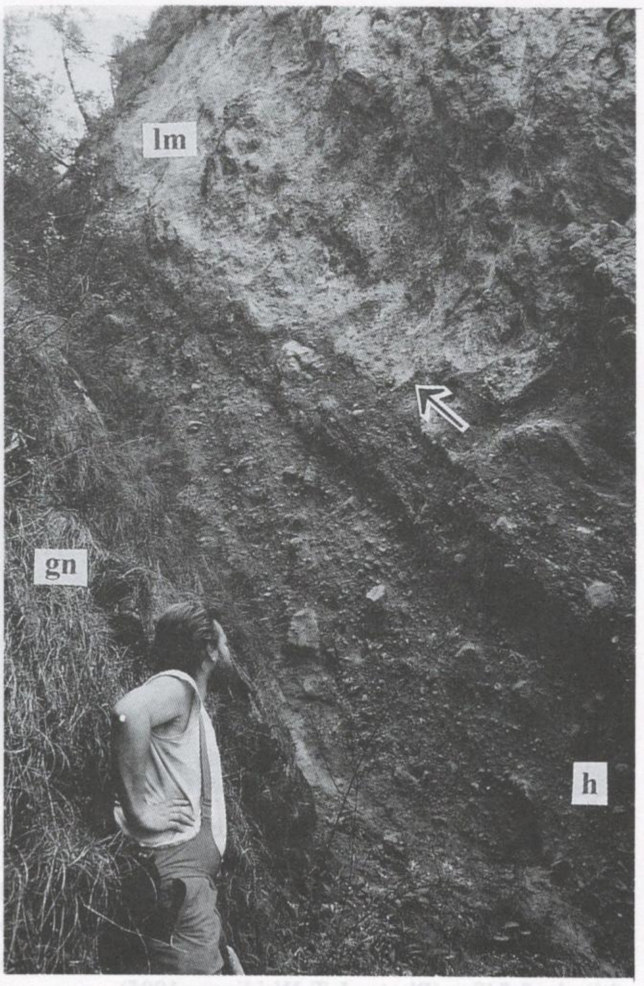

Plate 2: Contact of the heavily eroded landslide material mixed up with "schlieren" of ground moraine (lm) of Latamrang, deposited discordantly on a layer of compacted hiatus and moraine (h) followed by blocks of gneisses from the Himalayan Crystallines (gn): Note the heavily shattered, disintegrated, and deformed material, showing cataclastic rock-fragments (partly in the form of "schlieren") mixed with sediments on the sliding plane, closer to the sediment layer below. This unusual deposition was a consequence of the landslide as follows: Due to sledge-like sliding the rock fragments were generated by rapid movement along the basement and within the mass of the landslide. Reaching the bottom of the valley (altitude: 2,400 m) from SW to NE, the mass first collided with the ground moraine, and then was mixed up with it rapidly "climbing" up the opposite flank of the valley as high as 500 m (altitude: 2,819 m) crashing over bedrock. At this special point, the direction of movement of the landslide was upwards, from right to left. Location: left bank (northern side) of the Marsyangdi River, opposite the village Latamrang, altitude: 2,610 m (Photo: J. T. Weidinger 1995).

Plate 3: Heavily shattered and brecciated rock, partly mixed up with "schlieren" of the ground moraine along the base of the landslide deposit of Latamrang, generated by mechanical stress during the rapid movement. It is very susceptibility to erosion. Location: a gully NE of the village Latamrang, altitude: 2,540 m (Photo: J. T. Weidinger 1995)

As this was the zone of collision, the material must have come from an altitude of about 5 times this height (Heim 1932) – that means from somewhere southwest, about 2,500 m up the recent riverbed. In this area, a huge scarp (crown) of the landslide is seen on the ENE-facing slope of an unnamed 4980 m high peak (Fig. 2).

According to the field data, the original volume of the landslide material was 1–1.5 billion cubic metres. The former lake must have covered the valley for a distance of 5 km beyond the village Chame (Fig. 2). The volume of this first unstable lake is estimated between 500 and 800 million cubic metres. The highest level of lake sediments gives evidence that a smaller but stable lake of just 2 km in length must have existed in the valley (perhaps after the first outbreak) for a period from 300 to 1,000 years.

Landslide of Ghatta Khola

This landslide is situated within the tectonic half-window of Galwa in the Lesser Himalaya of Western Nepal (Fig. 1). The anticlinorium is represented mainly by dolomites with intercalations of schists (Fuchs and Frank 1970; Fuchs 1967, 1974, 1977, 1980). Originating from the mountain pass of Ghurchi Lagna (south of Lake Rara), the Ghatta Khola drains an area of about 25 to 30 sq km with the highest precipitation in summer monsoon. The valley trends due NNW-SSE, whereas the direction of the mass movement (i.e. a rock avalanche) that dammed the Ghatta Khola at an altitude of 3,010 m was at a right angle to the course of the river (i.e. from WSW to ENE). The previous valley bottom might have had the depth comparable to that of the southernmost course of today's valley, which is about 200 m below the level of lake sedimentation. That means the volume of the displaced masses was about 4.8 million cubic metres (Plate 6).

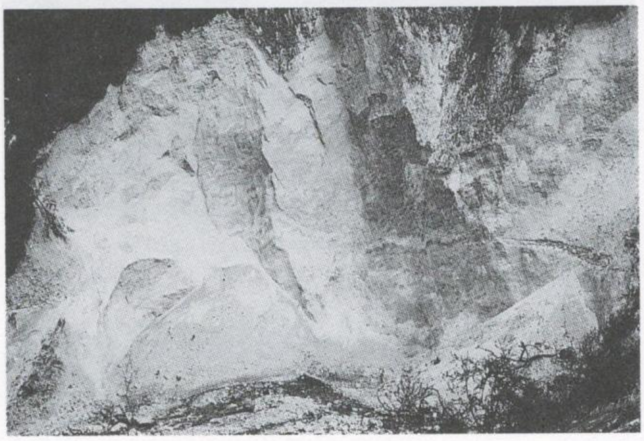

Plate 4: Heavily shattered and brecciated rocks - quartzites of the Annapurna Formation - with a thickness of several tens of metres, originated from the crown of the landslide of Latamrang, generated due to mechanical stress during the movement. Location: right bank (southern side) of the Marsyangdi River, about 3 km W of the village Latamrang, altitude: 2,500 m (Photo: J. T. Weidinger 1993)

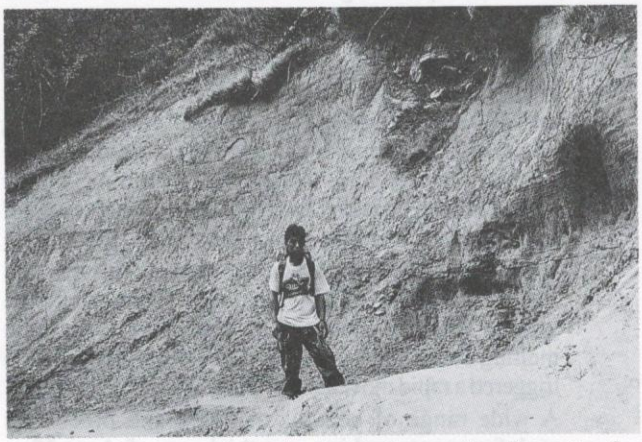

Plate 5: Outcrop of rhythmically layered sediments of a former lake, formed by the landslide dam of Latamrang. The visible thickness of it is 6 m (about 300 years of sedimentation) and the total thickness is 20 m, indicating that the lake existed over a period of at 1,000 years. Location: right bank of the Marsyangdi River NW of the village Thanchauk, altitude: 2,495 m (Photo: J. T. Weidinger 1993)

The landslide debris is exposed asymmetrically. Its southwestern part is low and relatively flat, and seems to be the debris cone that is gently dipping towards the

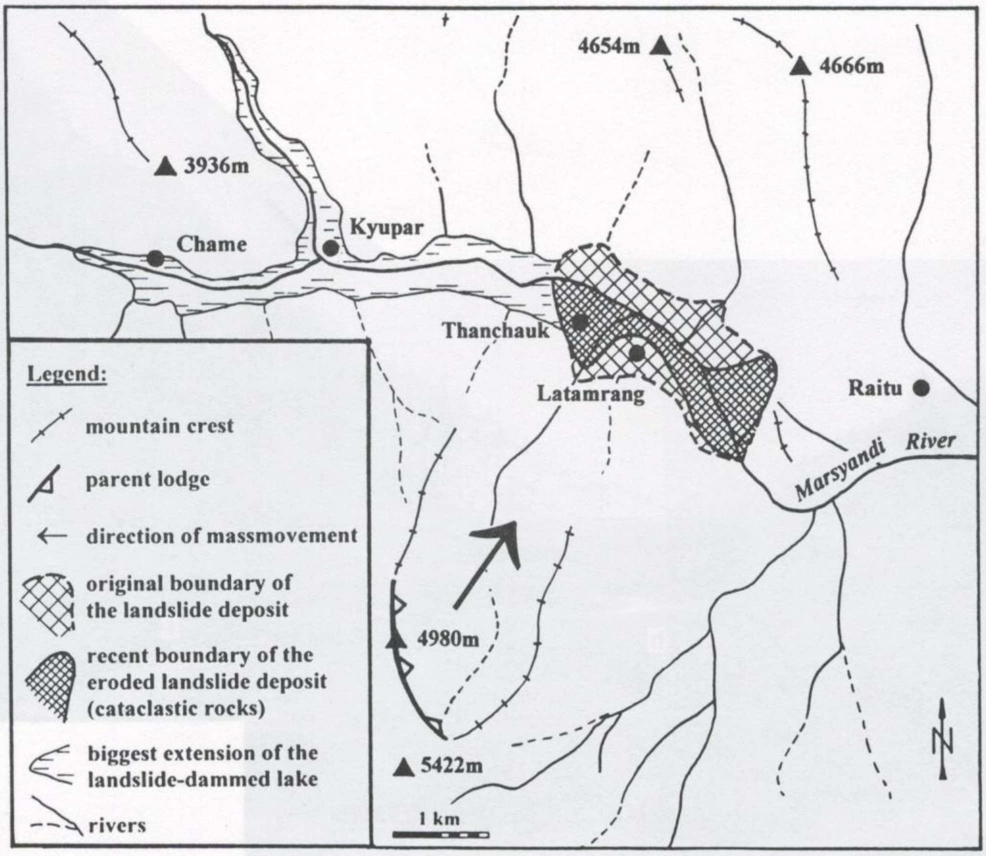

Fig. 2: Sketch map of the landslide area of Latamrang with the former dammed lake

mountainside. In contrast, the area of collision in the northeastern part has the shape of an isometric and rounded hill. In the centre of this hill, the thickness of the debris above the present valley bottom (last level of the lake) is not more than 40 m along a width of about 200 m. The lake resulting from the landslide dam was about 300 m long, 100 m wide, and 100 m deep with 1.5 million cubic metres of water. The exposed lake sediments on the flanks give evidence that an older lake with higher level was simply filled up with sediments without any catastrophic outbreak.

Landslide of Ringmo

In the upper course of the river Suli Gad (about 25–30 km north of the town Dunai in Western Nepal), which is also called the Phoksundo Khola or Bauli Gad, the shattered and fractured carbonate masses of this landslide deposit dammed the river and formed the more than 200 m deep holy lake of Phoksundo. This lake, the second largest in Nepal, covers an area of 4.5 sq km at an altitude of about 3,700 m (Fig. 1).

It is situated within a metamorphic transition zone between the Higher Himalayan Crystallines, the so-called Upper Crystallines, and the Cambro-Ordovician Dhaulagiri Limestones of the southwestern Dolpo Synclinorium of the Tibetan Sediments (Gansser 1964; Hashimoto 1973; Frank and Fuchs 1970; Fuchs 1964, 1967, 1974, 1977, 1980; Fuchs and Frank 1970).

The landslide debris forms a 2.5 km long and 1.5 km wide barrier at the NW facing mountain flank, SE of Lake Phoksundo. It has an estimated volume of about 1.5 billion cubic metres (Fig. 3).

A number of discontinuous tension cracks are developed on the gentle slopes of the left mound of the deposit, parallel to its contours. The rills on top of the still stable barrier near the recent outlet of the lake, south of the little village of Ringmo, show that the original level of the lake was somewhat higher and catastrophic outbreaks must have occurred in its early days.

The recent basin of the lake is 5,000 m long, 800 m wide, and up to 200 m deep, still containing 350 – 400 million cubic metres of water.

Landslide of Darbang

About 40 km west of the district capital Baglung, this landslide lies on the right bank of the Myagdi Khola (which is a western tributary of the Kali Gandaki), on the opposite side of today's village, short after the river changes its course from N–S to E–W (Fig. 1).

Geotectonic position and climatic conditions were the factors triggering the mass movement (Ibetsberger and Weidinger 2000). On the one hand, the landslide zone (especially the crown) lies exactly at the geological contact between the Chails (in the north) and the Jaunsar Formation

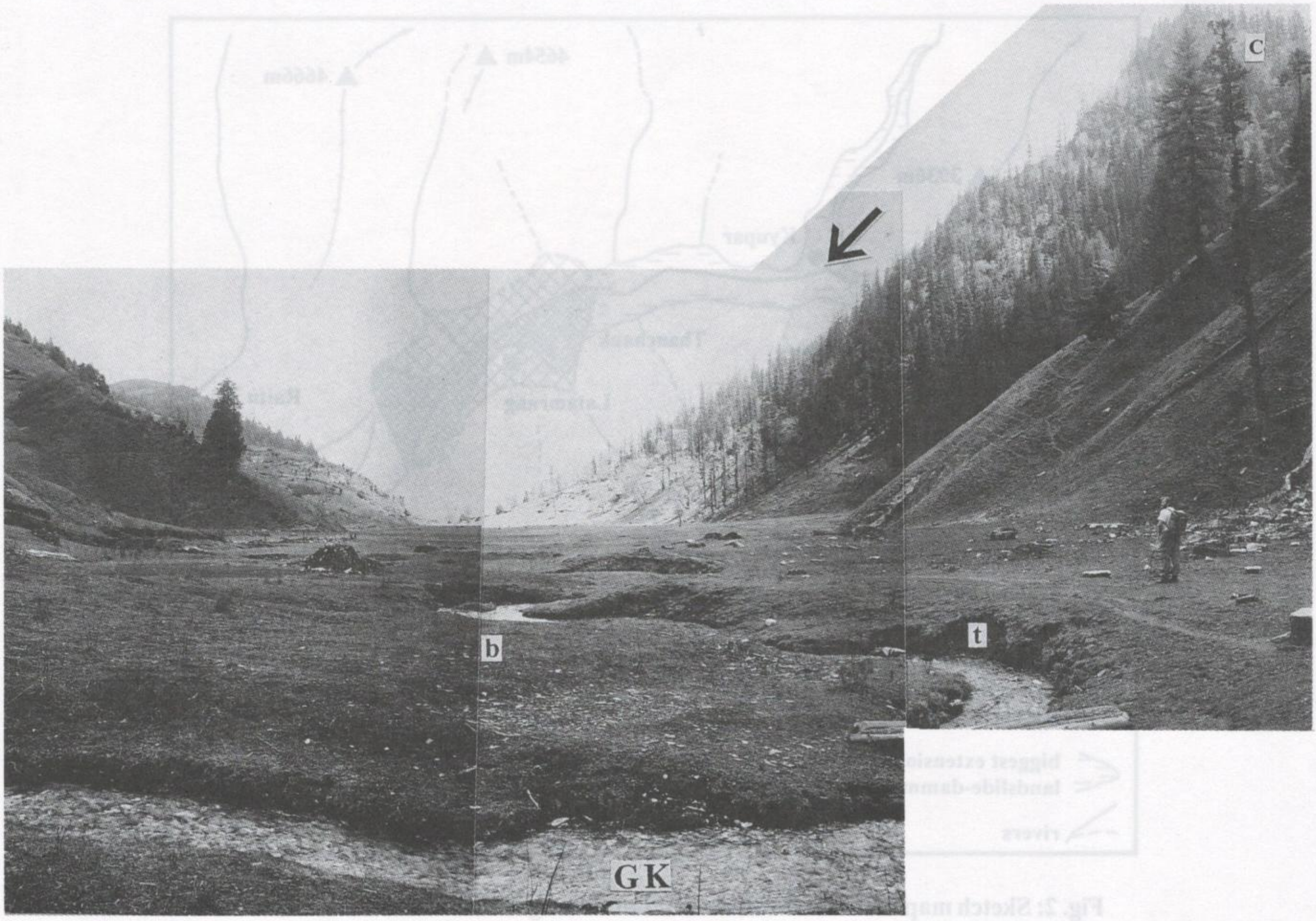

Plate 6: Former basin of the lake, dammed by the landslide of Ghatta Khola. The landslide (rock avalanche) occurred in a direction from W to E. This view towards S shows the crown (c) in the right upper corner and the partly eroded deposit of the landslide material (d) in the background. The basin (b) was filled up with the alluvial deposits of the Ghatta Khola (GK), today covered by thick turf (t) (Photo: J. T. Weidinger 1994).

(in the south) of the Lesser Himalaya (Fuchs and Frank 1970). These horizontally-lying meta-sedimentary rocks, consisting of quartzites, phyllites, and slates, are highly susceptible to failure (Yagi 1992). On the other hand, the Main Central Thrust lies at a short distance towards the north of the landslide (Yagi et al. 1990).

The crown of the 1988 landslide is situated at an altitude of 1,870 m. It is reported that the one of an earlier event was situated some 300 m below. It is now almost invisible due to the newer failure. The direction of movement of the two events was from south to north, and the masses reached the bottom of the valley at an altitude of about 1,100 m, destroying the former villages on the right bank of the river twice, killing more than 500 people in 1926 and around 100 in 1988 (Plate 7).

Heavy rains during late September of 1988 led to the quick overtopping of the landslide dam, which reached an estimated size of 700 m in length, 100 m in width, and about 50 m in depth before it broke out after less than 6 hours of existence. The flood destroyed the dam and caused serious damage to the valley downstream.

AGE OF LANDSLIDE DAM

The fact that the name of the village Tal means "lake" shows that this lake still existed when people started to settle on the shore of it. This happened about 300–500 years ago (early Tibetan settlers in this valley). The slide must have been of Post-Glacial age, maybe not older than 500 years and the lake could have dried out after less than 200 years (Table 2). This is supported by studies from Ghona Tal in North India (Weidinger and Ibetsberger 1997a, 1997b; Weidinger 1998a), where a much bigger basin of a landslide-dammed lake with similar climatic conditions and size of the watershed was filled up within a period of not more than 78 years.

It is still not clear whether the giant landslide of Latamrang occurred after the last high glaciation or even within the last interglacial time. Although the seepage of the waters and the outbreaks of the lake could have done a good job in eroding the landslide material, the extreme morphological overprint of the deposits – just leaving rudiments behind – supports the age of around 30,000 years. Therefore, the event of Latamrang could be of the same age as that of the giant landslide between Pisang and Manang in the upper Marsyangdi Valley (Hagen 1969), whose material fills up the bottom of the valley, being overridden by moraines of the last main glaciation. On the other hand, the landslide could have triggered movements in the Late- to Post-Glacial ground morainic material. If so, the age of the event is to be dated within these times.

The depth of weathering (from a few cm to 2 cm across the foliation and up to 4 cm across the joint) in the form of "Kaaren" at the landslide area of Ghatta Khola, dense forest as well as thick "Braunerde" on top of the landslide material and the lake sediments give evidence for its Post-Glacial age of some thousand years. The dammed lake must have had a short life of just a few decades.

The light brown loess covers the landslide debris of Ringmo, which dammed the valley of Phoksundo Khola. Inside the loess horizon, some intercalations of reddish brown soil layers were observed. Such red soils have often been found in Nepal with ages of about 30,000 – 40,000 years (Yamanaka and Yagi 1984). If it is the case, then the age of the landslide and Lake Phoksundo may be just before this time (Yagi 1997).

Additionally, the landslide of Darbang gives an idea of the recent actuality of such hazards in the Himalayas, and an example of two almost simultaneous devastating events – the landslide and its outbreak.

STABILITY OF LANDSLIDE DAM

In general, the stability of a landslide dam depends on the size of the dislocated clasts in the landslide debris, the shape of the landslide deposit, and the composition of the involved material constituting the dam. However, this study shows that there are the following other important factors.

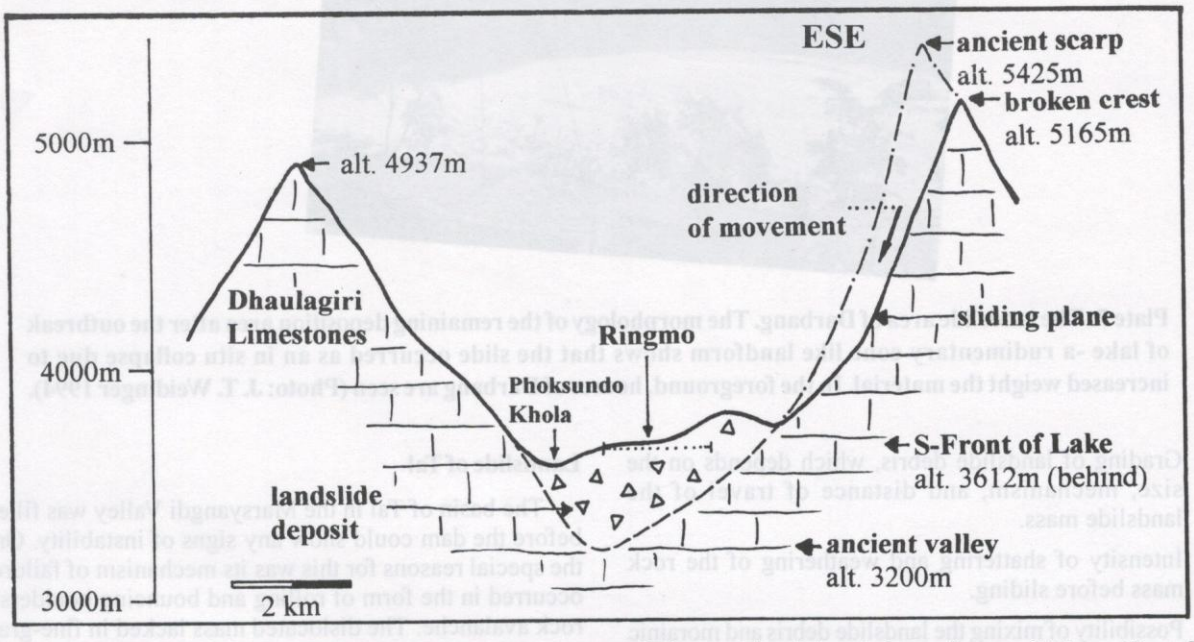

Fig. 3: Profile from ESE to WNW through the landslide area of Ringmo. The dislocated mass forms a 1.5 km wide and 2.5 km long barrier with an estimated volume of about 1.5 billion cubic metres. Discontinuous tension cracks within the deposit. Landslide back scar is seen on the right side on the NW-facing mountain flank. Lake Phoksundo is behind and not visible.

Table 2: Stability conditions of five landslide dams in the Nepal Himalayas

S. N.	Name/location	Lengthxwidthxdepth	Water volume	Stability of the dam	Durability of the lake
1	**Tal** Marsyandi Valley	1.0x0.3x<0.1 km	10–15 million m^3 (different width and depth)	Stable due to "cementation" with sediments (seepage)	Successively filled up by alluvions within 200 years
2	**Latamrang** Marsyandi Valley	Estimated 5x0.8x0.4 km Evident <2x0.3x0.05 km	Estimated 500–800 million m^3 Evident 15 million m^3	Unstable due to outwash of cataclastic material (seepage)	Seepage-tunnels and rapid flow after <1000 years
3	**Ghatta Khola** Galwa	0.3x0.1x<0.1 km	1 million m^3 (varying depth)	Stable due to "cementation" with sediments; top erosion	Successively filled up by alluvions within <100 years
4	**Ringmo** Dolpo	5.0x0.8x<0.2 km	350–400 million m^3 (varying depth)	Stable due to cementation with sediments and mineralised mountain waters	Still stable after 30,000-40,000 years (low sedimentation)
5	**Dharbang** Myagdi Khola	0.7x0.1x0.05 km	Estimated 1.7 million m^3	Unstable due to outwash of cataclastic material (seepage)	Seepage-tunnels and overflow after 6 hours

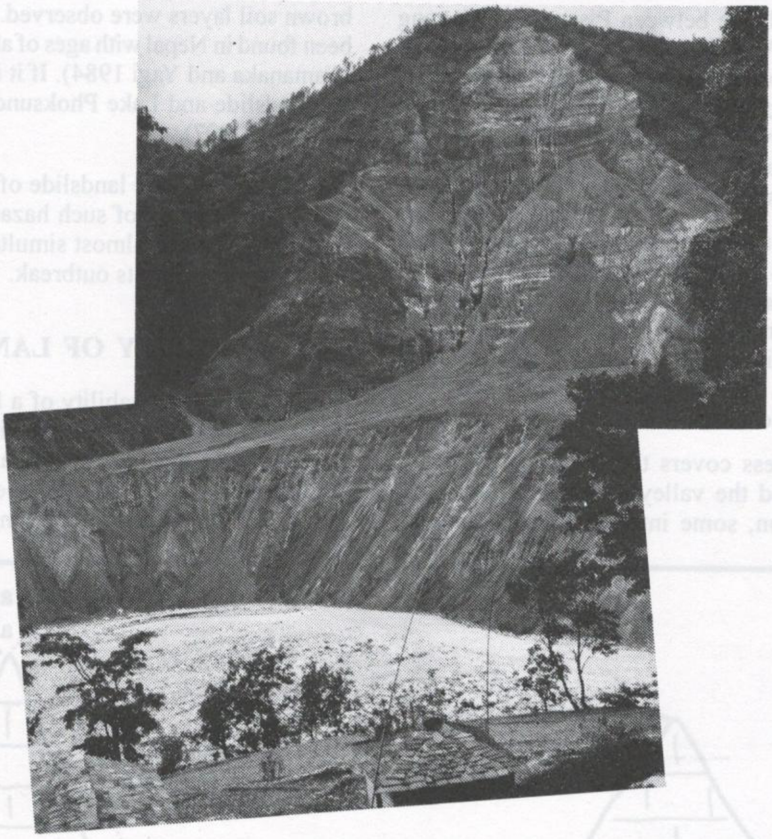

Plate 7: The landslide area of Darbang. The morphology of the remaining deposition area after the outbreak of lake -a rudimentary cone like landform shows that the slide occurred as an in situ collapse due to increased weight the material. In the foreground, houses of Darbang are seen (Photo: J. T. Weidinger 1994).

- Grading of landslide debris, which depends on the size, mechanism, and distance of travel of the landslide mass.
- Intensity of shattering and weathering of the rock mass before sliding.
- Possibility of mixing the landslide debris and morainic deposits during the movement of the landslide.
- Possibility of secondary cementation and compaction not only by seepage waters and transported sediments but also by mineralised or sometimes thermal springs in the landslide areas.
- Watershed area of the main river dammed by the landslides, as the available volume of alluvial sediments is most important for filling up of the dammed lake.
- Climatic conditions of the area (i.e. within the monsoon or within the rain shadow of the high mountain ranges), such as heavy rains, for example, give the means of an easy and rapid transport of sediments in the lake before the dam gets its chance to break.

The stability conditions of the five landslide dams are discussed below.

Landslide of Tal

The basin of Tal in the Marsyangdi Valley was filled up before the dam could show any signs of instability. One of the special reasons for this was its mechanism of failure – it occurred in the form of rolling and bouncing boulders as a rock avalanche. The dislocated mass lacked in fine-grained material and contained exclusively boulders of 0.2 –10 m in diameter.

The most important stabilising input to the dam was provided by secondary "cementation" of the material (Shaller 1991). It took place during the flow of finer sediments from the river and lake into the interstices of the huge boulders.

In other words, the rate of sedimentation in the lake, climatic conditions (e.g. monsoon climate), and the rate of seepage through the landslide dam controlled the stability of this barrier, the durability of the lake, and the severity of hazard downstream. In this case, the situations were favourable and the dam did not fail, and the lake disappeared due to sedimentation.

Landslide of Latamrang

Although this mass movement in the Marsyangdi Valley occurred in crystalline rocks and quartzites, the estimated volume (>1 billion cubic metres) was too gigantic for developing any kind of rock avalanche. Sledge-like movement of the masses led to the deposition of heavily shattered, brecciated, and fragmented debris. The distribution of exposed landslide material (Schramm and Weidinger 1996; Weidinger et al. 1995; Weidinger et al. 1996) shows that the fragments of dislocated crystalline rocks were almost pulverised due to mechanical stress while sliding.

It is evident that the lake water seeped extensively through such a cataclastic material (thickness of more than 100 m) and formed channels and tunnels within the natural barrier. Similar situation was also reported from the landslide of Köfels in the district of Tyrol, Austria (Heuberger et al. 1984).

That was the main reason why this type of gigantic natural dam, which is usually stable for thousands of years (Yagi 1997), failed just within some hundred years.

Landslide of Ghatta Khola

The bulk of landslide material consists of the brownish grey weathered dolomite of the Shali Formation. The boulders are flattened and cracked along pre-existing joints. Huge boulders reach a diameter of 4–5 m, although the bulk of the material is smaller.

Due to rock avalanching (similar to that of Tal), the whole mass was not shattered heavily. That is why the seepage water through the material led to sedimentation instead of destruction of the dam. Morphology and sediments indicate that the former lake never developed a catastrophic outbreak or flood. It was filled up due to sedimentation into itself and slight erosion of the landslide dam. Today, the former basin is filled up with an estimated total volume of about 1 million cubic metres of sediments.

Landslide of Ringmo

Besides the gigantic volume of the deposit, the mechanism of sliding played a major role in the stability of the landslide dam. The back scar of the landslide has an almost vertical wall, indicating an in situ collapse of the rock mass. The zone of transport was relatively short. Huge, shattered (but not disintegrated), and sometimes interlocking blocks of several dozens of metres and more stabilised the dam. Furthermore, the intercalated fine-grained material of the landslide deposit underwent secondary cementation by mineralised waters. Several outlets of iron-rich mineralised springs were detected within the deposit.

Owing to the local climatic conditions, Lake Phoksundo is still not filled up with sediments. The area is situated behind the mountains of the Higher Himalayan Chain, within the rain shadow of the seasonal monsoon. Although the watershed of the lake about 150 sq km, the sediment transport is not enough to fill up the basin.

Landslide of Darbang

At Darbang, a huge landslide dam of 5 million cubic metres collapsed within a very short period of less than 6 hours. Rock type and climatic conditions were the main factors responsible for the collapse. The landslide debris composed of schists, phyllites, and quartzites – the rock mass tending to pulverise by the mechanical stresses of a movement – were soaked with rainwater during the monsoon season (Ibetsberger and Weidinger 2000). The morphology of remaining materials after the outbreak of the dam indicated that the movement of the slide was in the form of an in situ collapse. The failure occurred due to the increased weight of the material, which became like a suspension of particles in water with no sign of inner rupture (Plate 7). That is why the bulk of the mass did not get the chance to be compacted after the deposition, and became more and more saturated with river water and was rapidly washed away due to overtopping of the dam.

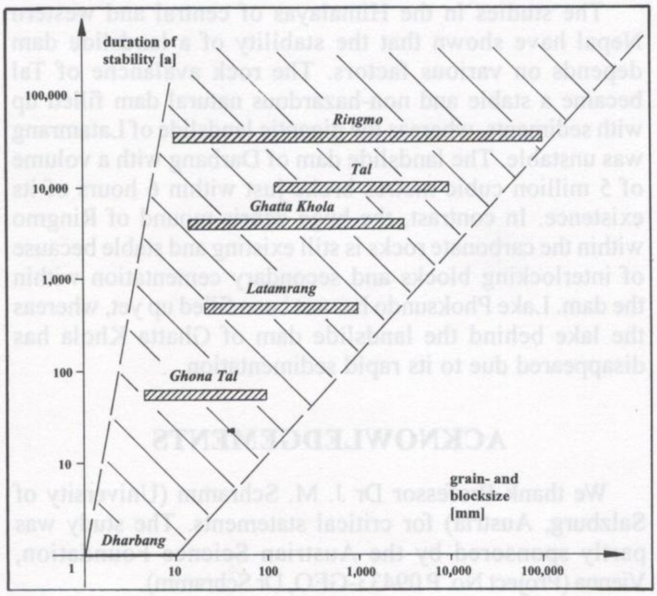

Fig. 4: Plot of stability versus block size in various landslide dams

HAZARD ESTIMATE

The above considerations lead to a simple but helpful tool in estimating the extent of hazard of a slide. Mathematical analyses have shown that there is a good correlation between the grain size of the landslide debris and the duration of the landslide dam. Fig. 4 shows that the five landslides of Nepal and the Ghona Tal Landslide (Weidinger 1998a) plot within the predicted range. Although this is a first attempt in predicting the hazard, more examples of landslide dam must be investigated to verify this diagram.

CONCLUSIONS

The study of landslide dams and their stability is very important, as the failure of it or a new slide into the lake may cause a hazardous flood in the main valley downstream. A detailed analysis of the landslide deposits and the crown area as well as conditions of stability of them are therefore necessary to prevent catastrophes.

The studies in the Himalayas of central and western Nepal have shown that the stability of a landslide dam depends on various factors. The rock avalanche of Tal became a stable and non-hazardous natural dam filled up with sediments, whereas the gigantic landslide of Latamrang was unstable. The landslide dam of Darbang with a volume of 5 million cubic metres broke just within 6 hours of its existence. In contrast, the huge debris mound of Ringmo within the carbonate rocks is still existing and stable because of interlocking blocks and secondary cementation within the dam. Lake Phoksundo has not been filled up yet, whereas the lake behind the landslide dam of Ghatta Khola has disappeared due to its rapid sedimentation.

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