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L A N D F O R M E V O L U T I O N I N M O U N T A I N A R E A S

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AMBOOTIA LANDSLIDE VALLEY — EVOLUTION, RELAXATION, AND PREDICTION (DARJEELING HIMALAYA)

Abstract. The Ambootia landslide of October 1968 is the largest landslide triggered by extreme continuous rainfall in the Darjeeling Himalaya. The landslide developed as a result of linear erosion and was called a "landslide valley". It continued to expand until 1987–89 when revegetation slowly began to take place. In 1989, a geomorphological survey and other hydrological and soil research were performed in the area (Froehlich et al. 1991, 1992). The Ambootia landslide valley has been under continuous observation for the last 20 years. Gradual reforestation and progressing relaxation have been observed in the valley, partly in conjunction with the watershed protection and revegetation programs initiated by the Ambootia TE. However, given that several decades have passed since the last major landslide, a recurrence of landslide rejuvenation and expansion cannot be ruled out in light of the weathering processes affecting metamorphic rocks in the region today.

Key words: Darjeeling Himalaya, Ambootia landslide valley, revegetation, landslide relaxation, extreme rainfall

AIM AND RESEARCH METHODS

On October 2–5, 1968, numerous earth flows, debris flows, and larger landslides were formed during extreme rainfall in the Darjeeling Himalaya (Starkel 1972). Among hundreds a greatest one at the Ambootia TE was developed. In 1988, following the reactivation of the Ambootia landslide, Mr. Bansal from Ambootia invited a Polish team of researchers from the Geomorphology and Hydrology Department at the Institute of Geography of the Polish Academy of Sciences in Krakow to see the landslide and accomplish a number of research goals. The pertinent question was: "Why is the Ambootia landslide still active?" After 15–20 years, all other debris flows and landslides in the area had become revegetated and covered by young jungle, with trees reaching 10 meters in height — all except Ambootia (Froehlich and Starkel 1987).

In the autumn of 1989, W. Froehlich, L. Starkel, and I. Kasza performed a detailed study of relief in the Ambootia area and assessed the nature and magnitude of processes (Froehlich et al., 1992). The basis for the research study was an old topographic map (Scale: 1 : 63 346) and a pre-landslide land use survey of Ambootia TE. Our topographic survey mapped the boundaries of the landslide and characterized its expansion. Morphometric parameters were also measured. Geomorphological mapping was done on a 1 : 5000 scale by measuring directions and estimating distances from points at the landslide margin. The lithology, rock bedding structure, and thickness of overlaying loose deposits were analyzed. The infiltration rate for soil horizons was measured in the field by W. Froehlich. Finally, granulometric and physical properties were determined in the laboratory. Special attention was paid to groundwater circulation by W. Froehlich.

Rainfall data for Ambootia were collected at a distance of 1.2 km from rain-gauge. Oral information on landslide activity, damage to homes and roads, and losses of cultivated areas was also considered. Sketches produced in March of 1983 by a team from the St. Alphonsus School in Kurseong, featuring the location of roads and homes along with the names of homeowners, proved to be quite valuable as well.

In our preliminary report in November of 1989, and later in papers published in 1991–92, we made a number of recommendations concerning the protection and stabilization of the Ambootia landslide valley. We have visited the landslide at least 15 times between 1989 and 2009 in order to observe changes, map active fragments, and take new photographs of selected landslide fragments to document revegetation and stabilization. L. Starkel surveyed active landslide areas about 13 times, while W. Froehlich, R. Soja, as well as others have visited the main landslide gully and fan several times.

This paper is not only meant to be a final report, supplemented by a number of maps and a photo album made in the course of various on-site visits, but its aim is to show the gradual stabilization of this large landslide valley during last 20 years.

THE ENVIRONMENT

The Ambootia landslide developed at the southern edge of the Ambootia TE on the left side of the Balasan River Valley, dissecting the W-E marginal ridge rising 1200–1800 m above sea level (Fig. 1). The Polish researchers observing Ambootia (Froehlich et al. 1991, 1992) called it a "landslide valley" because it not only has the shape of a valley but its evolution is also the product of gravitational slope processes acting in conjunction with linear downcutting. The surrounding area is formed of the Darjeeling group of metamorphic rocks comprising gneiss, mica schists, and chlorite schists of various resistance, inclined 30–50° NNW. These rocks are deeply weathered and the high density of fractures in the area is most likely indicative of a high degree of seismic activity.

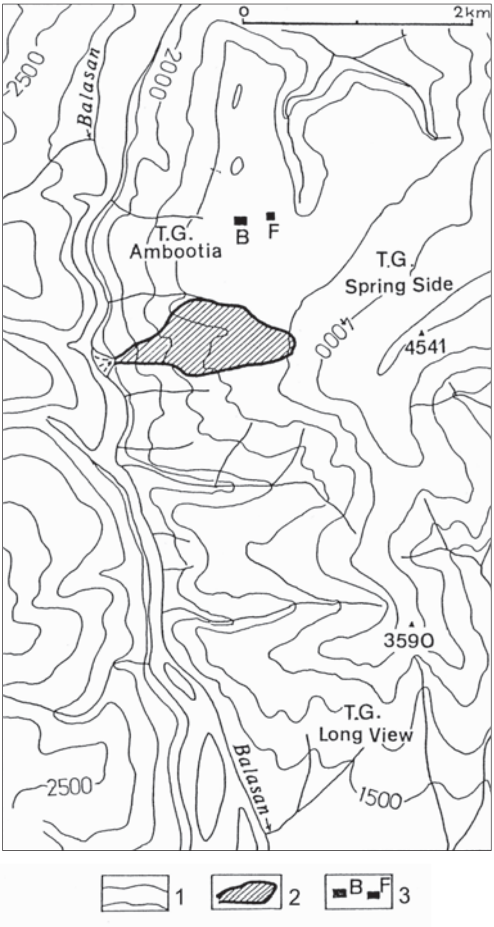


Fig. 1. Location of the Ambootia landslide valley in the Balasan River catchment. 1 — each 500 feet contour lines, 2 — landslide valley, 3 — tea factory and bungalow

PRE-LANDSLIDE LANDSCAPE

The Ambootia landslide valley developed on a slope (2.5 km long) falling down from the crest of a ridge, found at an elevation of 1350 m a.s.l. to the Balasan River at an elevation of 410–430 m (Fig. 1). The upper part of the slope is inclined 15–20° and fragmented by shallow niches and one deeper hollow located just to the north of the landslide. The middle part, found at an elevation of 950–900 m, forms a flat area open towards the north. This includes a broad surface of colluvial fan inclined 3–6° towards the west and the north, with a tendency for radial distribution of water. The lower part of the main slope forms a steep convex (over 30° — partially vertical) valley side about 500 m high.

The old topographic map used in the research study indicates a small side valley dissecting this lower part of the slope. This side valley was found to be 120 m less deep than the present day landslide valley.

The regolith is 1–5 m thick in the vicinity of the landslide, with one exception. The loose deposits are up to 30 m thick within the wide colluvial fan zone (elevation: 900–950 m) and consist of gravel and stony layers, which alternate with impermeable silt and even clay horizons.

Prior to the 1968 landslide (Fig. 2), the steep lower part of the valley side was covered with forest (jungle) changing into shrubby jungle with bamboo (degraded jungle) upslope. The gentle slope above was occupied by tea plantations towards the north and two villages — Taar Gaon and Darah Gaon — closer to the landslide area in the south. The two villages had 174 and 126 homes, respectively. Both villages were surrounded by gardens and orange orchards. The location of the villages was most likely connected to the presence of water supplied by a small nearby stream and by a spring in the north. On the map, it is indicated by a wet area ("thatch") of about 2 ha.

RAINFALL REGIME AND HYDROLOGIC CONDITIONS

Total rainfall in Ambootia fluctuated from 2,500 mm to 4,335 mm (Fig. 2) between 1964 and 2009. Even greater amounts of rainfall were recorded on Kurseong Ridge and towards the edge of the mountains where mean annual rainfall reached 5,000 mm. Between June and early September, it rains mainly in the afternoon or evening. During the summer months, total rainfall increases to 500–1,000 mm. Every year, 10 to 30 days with over 50 mm of rainfall are recorded (Tab. 1). Frequently, heavy rainfall occurs on consecutive days and can cause soil saturation, which leads to an excess supply of groundwater.

The infiltration rate in the regolith — and later in strongly fractured bedrock — is at first controlled by the granulometric composition of soil, which tends to vary across the slope. In the upper part of the slope, sandy-silty soil (50 cm thick) contains only 4% of clay fraction. Across the colluvial fan, its content increases to 12%. The infiltration rate for the first 100 mm of rainfall fluctuates between under 10 minutes to as much as 40 minutes, and generally decreases with soil depth — as low as 55–60% at a depth of 1 m (Froehlich et al. 1991, 1992).

A V-shaped gully cut into the bedrock can be found north of the upper landslide niche. The gully had earlier served as a channel for a perennial creek, which was full of water following heavy rains. In 1986, following another landslide episode, an artificial channel was created by the Ambootia TE in order to remove all water from the gully as well as that gushing from a large spring (Fig. 2) found in the vicinity of a wide depression open to the north. In October of 1989, we observed a dessication of the creek, which appeared once again in a horizon formed of thick colluvial sediments. This indicates that water was percolating deeper in the colluvia and fractured bedrock.

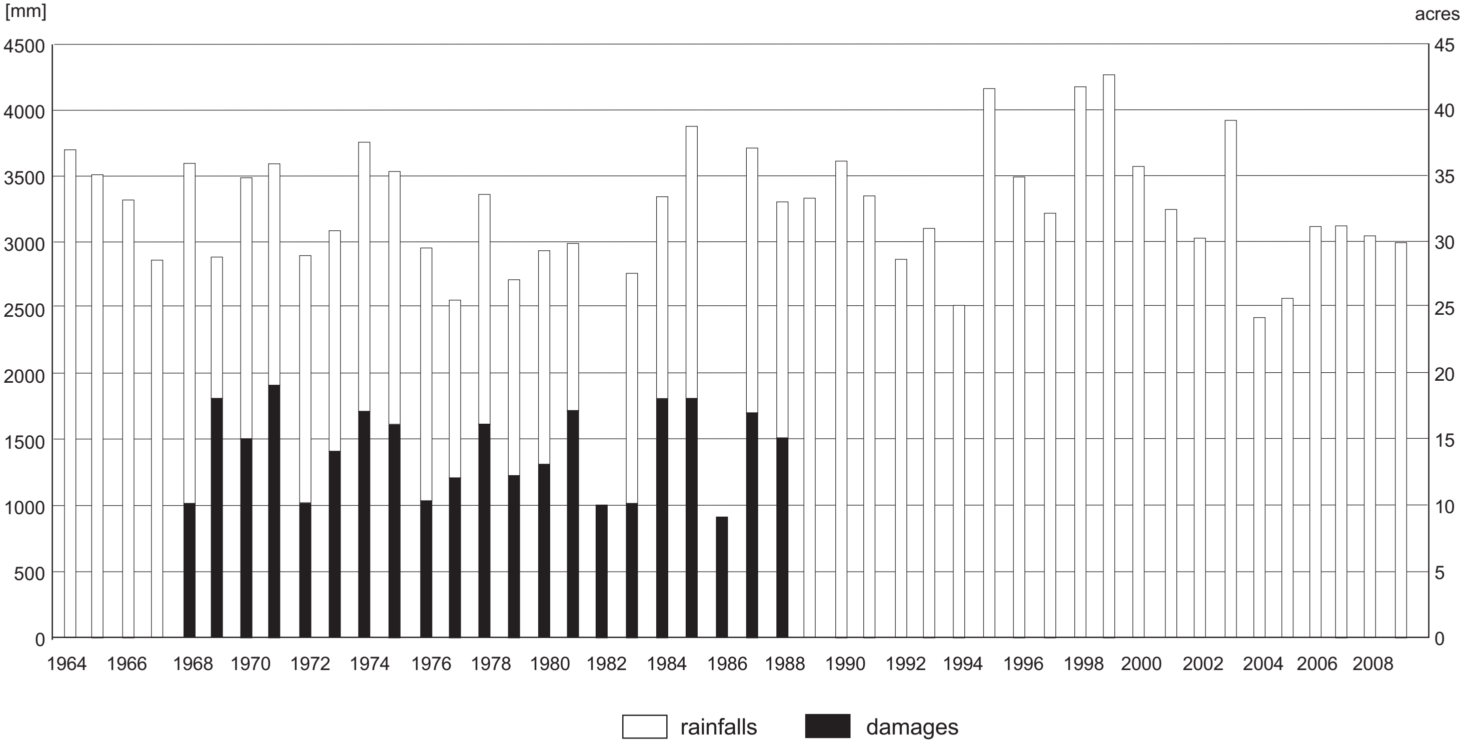


Fig. 2. Annual rainfall at the Ambootia TE between 1964 and 2009. Areas with damage in black (in acres)

In order to better understand the direction and rate of subsurface flow, two luminescent dyes — fluoroscein and fuchsine — were used in the upstream part of the creek and in the spring (F r o e h l i c h et al. 1992). It was hoped that this experiment would help explain the lengthy period of activity of the Ambootia landslide. More than 10 hours after the dyes had been used, W. Froehlich noticed creek water in the upper part of the landslide valley at the point where colluvium meets bedrock as well as creek water flowing from within fractured bedrock. The dyed water from the spring appeared in small niches at the northern edge of the landslide. The high rate (5–12 m per hour) of subsurface flow was used to explain the permanent supply of landslide from outside.

THE OCTOBER 1968 EVENT AND THE ORIGIN OF LANDSLIDE

Between 600 mm and 1,100 mm of rain fell across the Darjeeling Himalaya Mountains over the course of 50–60 hours between October 2nd and 5th in 1968. In the Ambootia TE area, the recorded rainfall amount was 890 mm. An automatic rainfall gauge at the Nagri Farm (6.5 km north of Ambootia) recorded a rainfall intensity in excess of 50 mm h^{-1} (S t a r k e l 1972) during last four hours of October 4th. Thick saturated colluvia and the underlying weathered rocks in the shallow valley head slumped down and spread out like debris flow, carving out a channel 30–60 m deep and pushing out a mass of 10–15 million m^3. Some of the material became deposited in the form of a fan in the Balasan riverbed. The debris fan

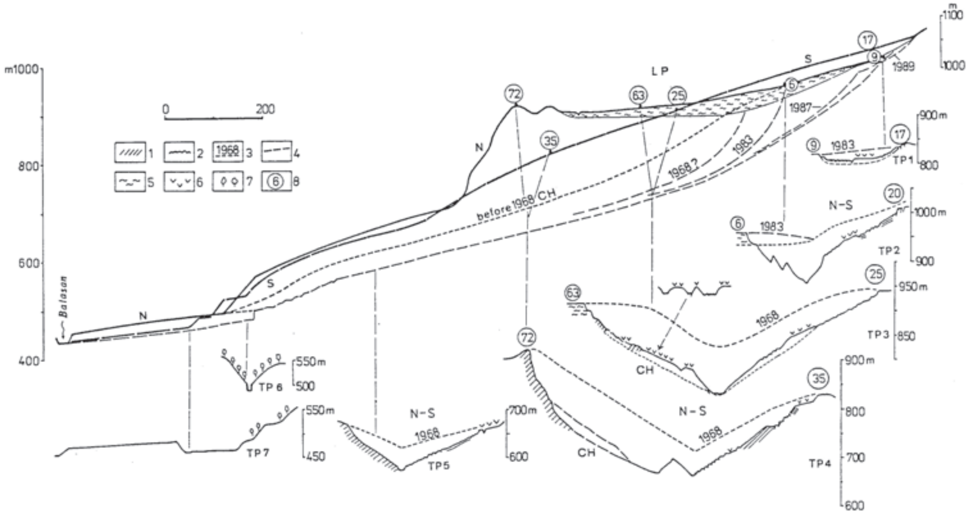


Fig. 3. Longitudinal (LP) and transversal (TP) profiles of the Ambootia valley – showing gradual expansion prior to 1989 (F r o e h l i c h, S t a r k e l, K a s z a, 1991, 1992). Northern and southern edges (N.S). 1 — exposed bedrock, 2 — blockfields, 3 — calculated surface channel profile prior to the 1968 landslide, 4 — surface after October of 1968, 5 — thick colluvial series, 6 — revegetated slopes, 7 — jungle, 8 — control points

formed a dam. As a result, a lake several kilometers long also formed, storing about 10 million liters of water.

The undercutting of the right side in the middle part of the landslide (featuring several hummocks) led to the triggering of large rockfalls. On the opposite side, shallow penestructural earthflows and slips were triggered at the same time. We do not know the extent of the transformation that took place in October of 1968, as the first photographs, drawings, as well as written records only became available in 1983 and 1984.

It is clear that the subsequent transformation included a continuous retreat of right side niches, supplied by groundwater from a colluvial aquifer, as well as an extension of shallow slips and the formation of deeper cracks in the left slope. A simultaneous deepening of the main channel by debris flows led to the undermining of the upper parts and the dissection of the lower parts of valley sides by new chutes and slips (Fig. 3).

EVOLUTION OF THE LANDSLIDE BETWEEN OCTOBER OF 1968 AND MARCH OF 1983

In the course of its first 15 years of existence, the Ambootia landslide was inspected several times by a variety of experts, but no written records produced during these inspections have been preserved.

The first detailed information about the landslide was collected by two Jesuit priests, Edu Gurung and Cherian Nampeli, from the St. Alphonsus School in Kurseong. The priests, assisted by a group of boys, created a description of the event and portrayed the current situation using three photographs as well as simple sketches featuring numbers of homes and the names of their owners. That rudimentary collection of documents helped us to reconstruct the retreat of the main niche between 1983 and our survey in 1989.

In March of 1983, the main upper landslide niche resembled an amphitheater with its edge reaching probably no higher than 980 m above sea level. All area slopes had fresh features. At the outlet of the main valley, a large colluvial fan was found to be completely without vegetation. This indicates that – at least prior to 1983–1984 – the landslide must have been very active (Photo 1).

A mistake had been made in our report (F r o e h l i c h et al. 1991, 1992). We wrote that the report was prepared after the rainy season of 1983. This was not correct. The Kurseong team visited the landslide between March 4th and 7th of 1983. Therefore, the extent of the landslide was formed in 1982.

Annual rainfall between 1969 and 1982 fluctuated between 2,700 mm and 3,760 mm (Fig. 2). Rainfall over 3,400 mm had been recorded in 1970–1971, 1974–1975, and 1978. Unfortunately, no rainfall data is available for 1982.

Photo 1. Ambootia landslide – northern scarp. View from the opposite side of the Balasan River valley (July, 1984)

EVOLUTION OF THE LANDSLIDE 1983 and 1989

Our detailed survey, produced in November of 1989, was preceded by seven rainy seasons following the inspection of the landslide by the Kurseong team. The reconstruction of extent of the main niche between 1983 and 1989 (Fig. 3), associated with the undermining of the upper part of the landslide, shows not only a retreat of about 230 m prior to 1987 and another 70–80 m in the last two years, but also the damage inflicted on many homes. In the mean time, the colluvial fan had been dissected several meters deep because its main surface is no longer active and is covered by a variety of vegetation, including some pioneer trees several meters high.

Ambootia rainfall records contain a data gap for 1986. Nevertheless, several neighboring years have been characterized by very high precipitation (3,884 mm in 1985, 3,712 mm in 1987). We do know that the landslide was very active following heavy rains in 1983, 1987, and 1988, causing damage to the only road connecting Ambootia with Kurseong. July 17^{th} of 1988 saw a heavy downpour of about 200 mm of rain that continued to fall between 1:30 PM and 5.00 PM. The reactivation of the landslide prompted the damages of another 15–20 homes. Moreover, the newly built road slide off its designated course. Finally, a bypass was constructed north of the landslide area at the end of 1988. The size of the landslide area was then assessed, to be about 300 acres (1,214 km^2) at that time.

LANDSLIDE SURVEY AND DETAIL DESCRIPTION IN 1989

In November of 1989, a general topographic survey of the area was carried out and a geomorphological map (Scale: 1 : 5 000) was produced (Froehlich et al. 1991, 1992, photos from 1989). The Ambootia landslide valley is about 1,300 m long and its outlet includes a system of two embedded fans (400 m long). The upper edge of the niche is located at an elevation of 1,065 m and the fan extends down from an elevation of 488 m. Its width starts at about 200 m in the upper part, rises to over 600 m in the middle part, and then declines again to 250 m in the lower part. The landslide as a whole has the shape of a deep gully cutting into bedrock. Other characteristics of the landslide included a significant gradient, waterfalls, and slopes shaped by mass movements (Figs. 3, 4, Photos 2–5).

The uppermost part of the landslide found over 1,000 m above sea level had been actively shaped by sliding in the fractured bedrock, up to 20 m deep. Several deep cracks were also visible above the upper niche. Deep cracks could also be found in the walls of homes in the area (Photo 2).

Photo 2. Upper retreating part of landslide and extensive colluvial fan, undermined by niches (November, 1989)

The left (southern) deep slope had a straight or convex profile with an inclination of 25–45°. Areas of bare rock were exposed in the upper part. Fresh crevices — up to 4 m deep — indicated that the upper niche was still active and retreating. Further downslope, the bedrock was covered with blockfields — talus-type in

Photo 3. Fragment of pene-structural slope still actively being shaped by slips, creeping, and debris flows (November, 1989)

many cases (Photo 3). In the middle portion inactive revegetated plots existed, separated by block streams continuously incising.

The right (northern) slope was more diverse. Its eastern side had undercut an extensive colluvial fan sloping 3–6^{o}, overlaying deeply weathered bedrock. Its upper part had cut into 30 m thick colluvia forming two-story high niches of mainly inactive slumps with many seasonal springs. The middle and lower parts of the slope were carved in bedrock and formed alternating debris flow channels and sharp crests, which were gradually being revegetated by herbs and shrubs (Photo 2).

The lower central part of the right slope was steeper — up to 250 m high. The upper part consisted of a rocky cliff with fresh break-offs. The debris fan was dissected by chutes below. The absence of larger rockfall masses indicated that the falling of rock is a continuous process supplying the main outflow channel (Photo 4).

The floor of the main canyon-type valley was deeply cut in the bedrock with rocky steps (up to 5 m high), large boulders, and remains of unsorted debris flows formed during episodic floods (Photo 5).

The colluvial fan, 300–400 m long and more than 500 m wide, had earlier pushed the Balasan River channel to the opposite western bank. It was now covered by vegetation and dissected upto 15–20 m. The lower surface was as much as 100 m wide — a braided channel formed of gravel and several boulders as large as 1–2 m in diameter and supplied by debris flows. This surface continues down along the Balasan River, forming extensive gravel bars (Fig. 4).

Photo 4. Western active part of right slope with rockfalls and chutes (November, 1989)

Photo 5. Lower section of main landslide gully shaped by debris flows (November, 1989)

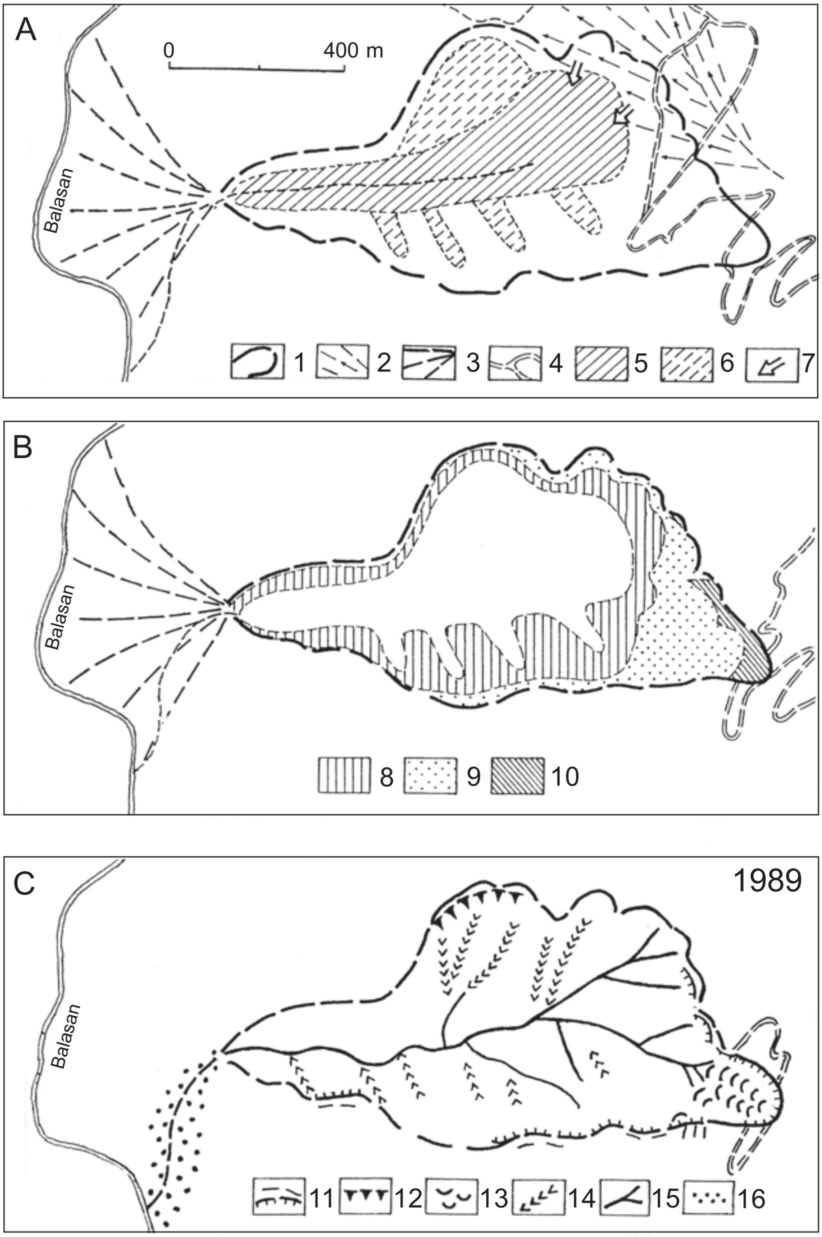
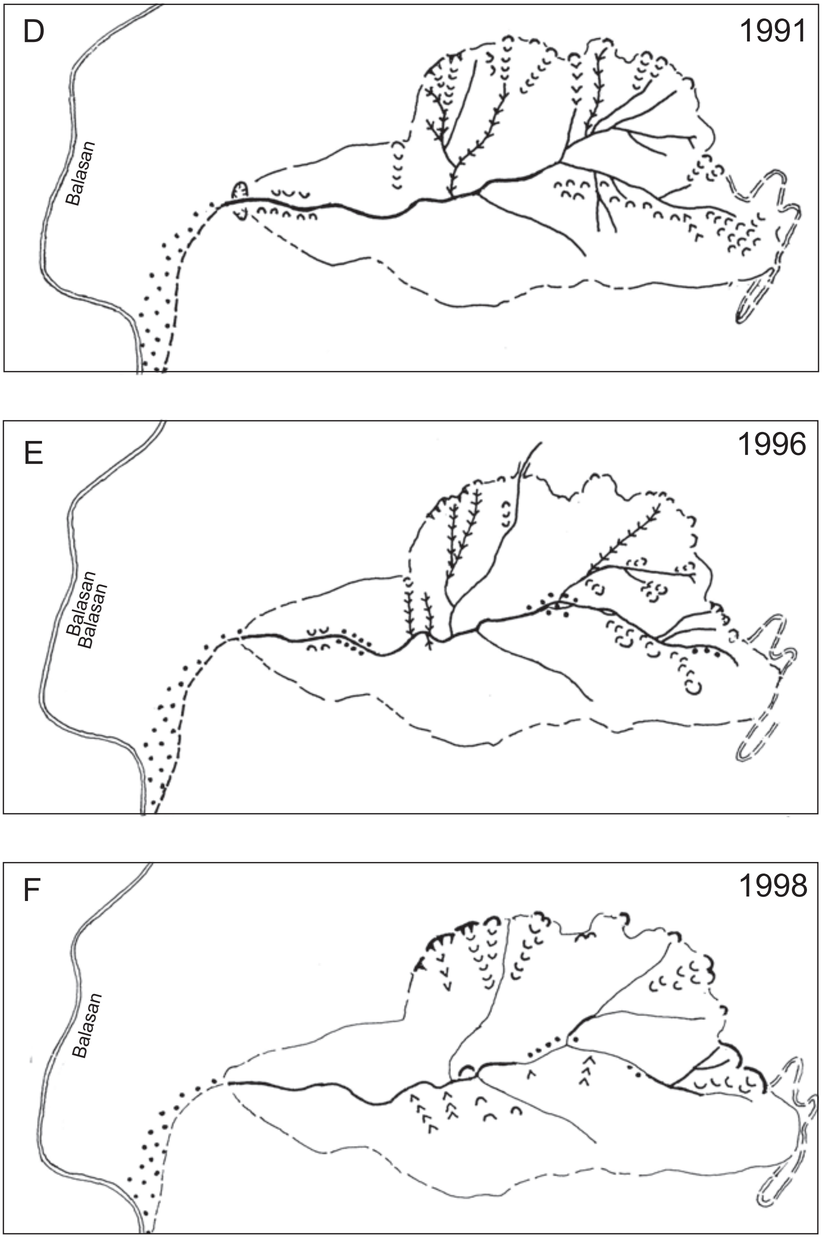


Fig. 4. Changes in the landslide valley — reconstructed for 1968–1989 — then surveyed and analyzed for 1989–2009 (L. S t a r k e l)

A. 1968, B. 1968-89, C. 1989, D. 1991, E. 1996, F. 1998, G. 2003, H. 2004, I. 2005, J. 2007, K. 2008, L. 2009. Signs: 1 — main edge of landslide, 2 — old upper colluvial fan, 3 — Ambootia landslide fan, 4 — road, 5 — earth masses removed in 1968, early phase, 6 — 1968 — late phase, 7 — subsurface drainage direction, 8 — extension in 1968–83, 9 — extension in 1983–87, 10 — extension in 1987–89, 11 — active niches and cracks, 12 — rockfall niche, 13 — sliding massed, 14 — block stream — debris flow, 15 — chutes and canyons experiencing downcutting, 16 — debris fans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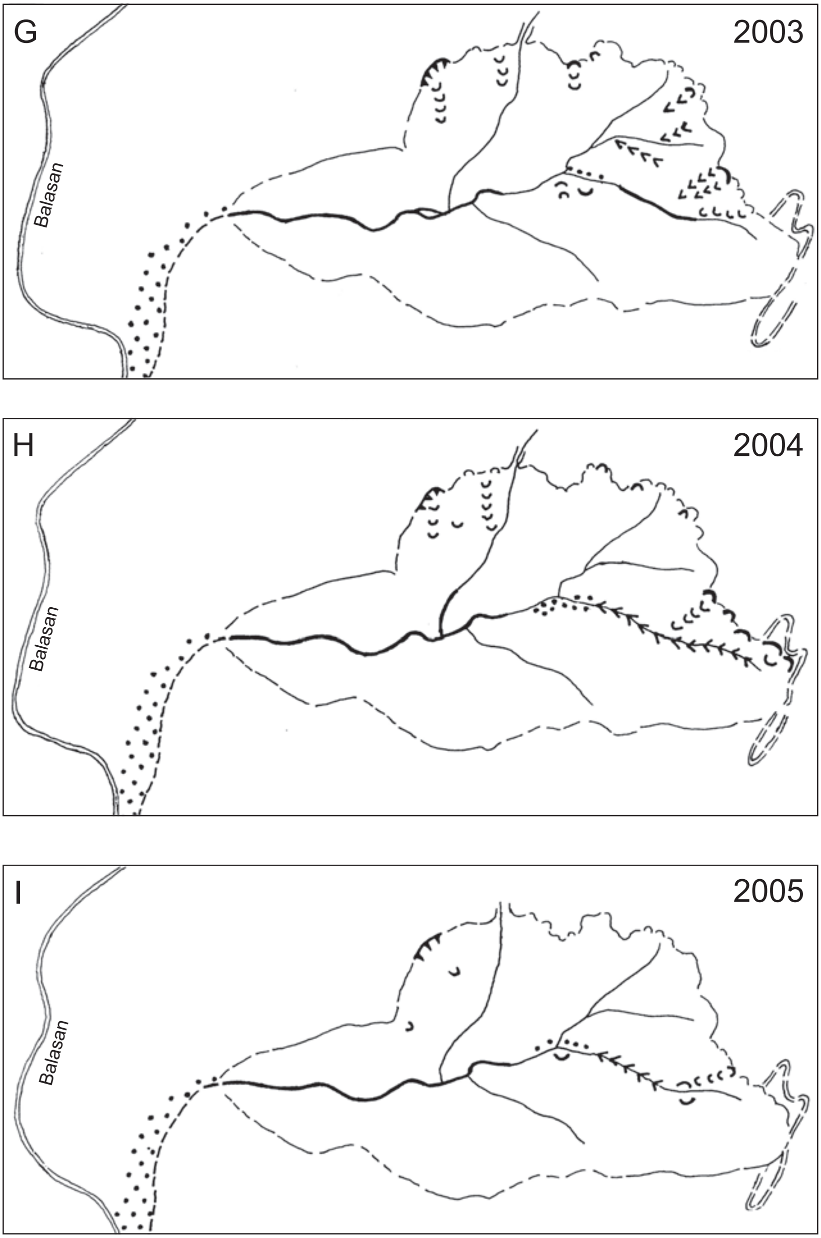
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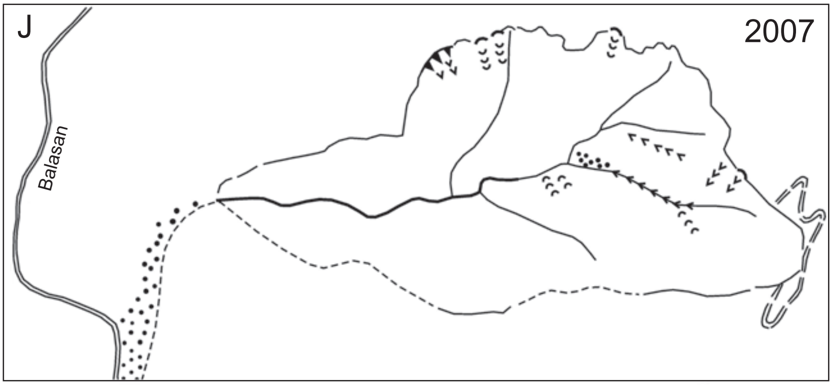
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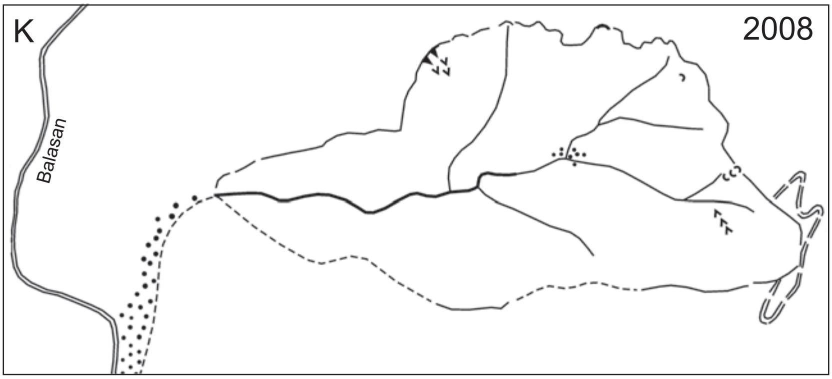
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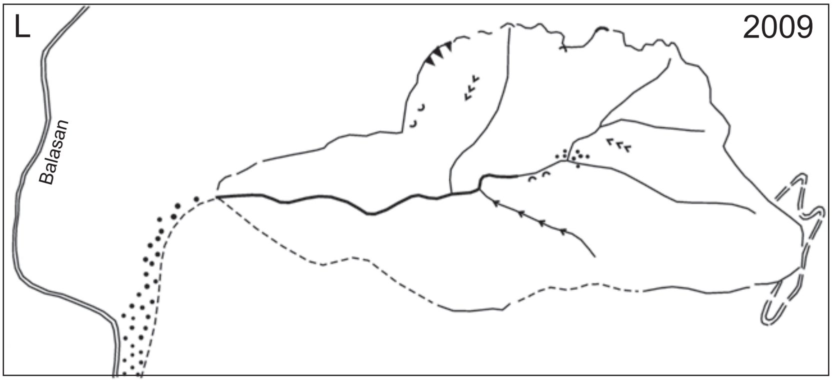
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STABILIZATION OF THE AMBOOTIA LANDSLIDE VALLEY BETWEEN 1989 AND 2009

Between 1989 and 2009, I made controlled measurements as well as additional observations partly with my colleagues. The aforesaid records are represented herein by rainfall data, sketches of the active parts of the landslide (Fig. 4), as well as photographs. The observations were made in December of 1991, January and November of 1993, January of 1996, January and November of 1998, November of 1999, November of 2000, November of 2001, February of 2003, March of 2004, November of 2005, 2006, 2007, 2008, and 2009 (Fig. 4, Tab. 1).

Table 1

Rainfall data for the Ambootia TE 1998–2009 (in mm)

Year	Total annual rainfall	Highest monthly rainfall	Highest daily rainfall	Highest 3-day rainfall	Number of days above 50 mm
1998	4,229	1,505	335	477	24
1999	4,335	1,043	226	337	26
2000	3,622	838	216	305	26
2001	3,352	835	134	305	21
2002	3,089	935	148	246	17
2003	3,879	1,219	234	491	23
2004	2,447	754	122	210	10
2005	2,617	799	93	178	16
2006	3,148	793	148	276	19
2007	3,151	1,030	165	292	18
2008	3,054	889	190	317	17
2009	3,015	1,004	356	361	16

Over the course of the 20-year observation period, annual precipitation fluctuated between 2,500 mm and 4,300 mm (Fig. 2). A clustering of years with higher precipitation can be observed in 1998–2000, when not only did annual totals frequently pass the 4,000 mm, but maximum daily rainfall also did pass the 200–300 mm mark and the number of days with rainfall over 50 mm reached 24–26 per year. On the other hand, the 2004–2005 period was characterized by very low values for all of the above parameters. The year 2009 was characterized by two episodes of heavy rainfall.

In December of 1991, following two rainy seasons, I surveyed the landslide valley. During the two previous years, total rainfall in the area had been relatively significant. In 1991, about 420 mm of rain fell in only four days. It was most likely that rainfall had reactivated many parts of the landslide and had caused two slips at the outlet of the canyon, which then destroyed the highest rocky step.

The next visit in January of 1993 took place after only one rainy season (2,876 mm). Yet another visit took place in November of 1993 (3,120 mm), with R. Soja observing only very small changes across the slope, but a continuous transformation of the main channel and the alluvial fan by flash floods combined with debris flows. It was also inferred that many new chutes and slips on the southern-exposed slope were the result of recurring heavy rainfall (July rainfall: 1,180 mm).

In March of 1995, the "Eco-development Plan for the Ambootia Tea Estate for 1996–2000" was produced and signed by J.L. Sharma. The plan included different types of watershed protection strategies such as the reforestation of the landslide and surrounding area using selected plant species, avulsion of water, check-damming, gully plugging (especially in the main "khola"), and grazing restrictions for landslide slopes. The program went into effect in 1996. The upper section of the creek had already been rerouted in the 1980s, hence the widest colluvial part had already ceased to retreat (Photos from various years).

The years that followed were very wet once again. In 1998, 4,229 mm of rainfall were recorded, with highest monthly rainfall at 1,505 mm and highest daily rainfall at 335 mm. The right bank of the upper part of the landslide slumped again and became dissected by a number of new gullies. The wetter years, combined with grazing restrictions, facilitated the revegetation of many parts of bare slopes. The revegetation process could be easily observed across the area. Moreover, several debris dams were constructed in the main river channel in 1998–99.

Following a wet 1999, the active parts resembled the situation from the year before. During the following rainy season (2000), revegetation was again observed across the landslide area, with only two active sites remaining: 1) dissected slumps on the right side of the upper part of the landslide, and 2) the vertical walls on the northwestern side.

The following year, 2001, was drier (3,352 mm). Reforestation was observed across the area previously affected by active landslide processes. In 2002, the Organic Biodynamic Research Centre was established close to the landslide area, with a nursery of tea bushes and trees, which were continuously planted along the northern edge of the landslide. In February of 2003, following a relatively dry 2002, the number and area of slips decreased again. In March of 2004, while revegetation continued to make progress, several small parts of the landslide became reactivated most likely due to greater rainfall in the summer of 2003, as shown on the attached map. Annual rainfall was 3,879 mm and July rainfall was 1,219 mm.

The following two rainy seasons (2004–2005) were characterized by very low precipitation (2,447 mm and 2,617 mm). Virtually the entire landslide area, except for small vertical slope sections, was covered by dense vegetation, young forest, and a dense carpet of grasses. Only the main gully, which collects water during rainstorms, transports coarse debris.

Over the course of the next three years (2006, 2007, 2008), annual rainfall increased to about 3,000 mm, but with no major rainstorms. Revegetation continued to make progress and only small slumps could still be observed on a number of steep slopes (Photo 6 and 7).

Photo 6. Upper revegetated part of landslide with single slides on steep slopes (November, 2008). Compare with Photo 2

Photo 7. Shallow slide on the reforested northern scarp, formed of thick colluvial sediments (November, 2008)

The year 2009 was affected by two rainfall events connected with cyclonic circulation in late May and late August, which caused a lot of damage in other parts of the Darjeeling Himalaya. In Ambootia, the first rainfall event brought 257 mm of precipitation in one day (over 335 mm in three days), while the second rainfall event brought 356 mm of precipitation in one day. While revegetation was widespread, only two existing bare slumps had become reactivated. A number of niches formed in colluvia saturated by water had also become reactivated (Photo 8). I was also able to observe several fresh fractures and block sliding in the uppermost part of the landslide.

Photo 8. Western part of revegetated right slope with small falls and slumps (November, 2009). Compare with Photo 3.

CONCLUDING REMARKS

In summary I conclude that the Ambootia landslide valley has reached a stage of maturity and stabilization over the last few years. This is primarily the result of revegetation and the development of anti-erosion measures across the valley floor. Only a number of steep rocky parts are still exposed to small rockfalls, slumps, and slides. Localized earth flows may become accidentally triggered on the vertical walls of niches formed in colluvial deposits and debris flows in the main river channel during episodes of high intensity rainfall.

It cannot be ruled out that after decades of bedrock weathering by continuous rainfall since the 1968 landslide, the upper niche of the landslide valley may retreat again or the main gully may become dissected again by robust debris flow.

In the Darjeeling Himalaya, there exist many deep and wide valleys segmenting mountain slopes. Such valleys probably formed in a manner similar to that of the Ambootia landslide valley via the combined long-term effects of gravitational processes and linear erosion. Long-term observations carried out in the Ambootia landslide valley have shown that the stabilization of a large landslide is a gradual process and requires several decades of time in order for this type of process to reach completion.

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Moreover, I would like to extend a special thank you to the Bansal Family, the managers of the Ambootia TE, and their coworkers for immense hospitality and assistance during fieldwork. Every time I visited Ambootia over the last 20 years, I was able to not only collect rainfall data, but I was also provided free accommodation and transportation. Furthermore, each time I visited, I also had the opportunity to discuss a variety of issues related not only to landslides but also water management, tea-based agriculture, and the protection of natural resources.

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