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PRELIMINARY REPORT ON THE GAMAHARA TORRENT DEBRIS FLOW OF 6 DECEMBER 1996, JAPAN

Hideaki MARUI, Osamu SATO and Naoki WATANABE
Research Institute for Hazards in Snowy Areas, Niigata University

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ABSTRACT

The background and process of the Gamahara Torrent debris flow of 6 December 1996 is reported. It is very unusual that the debris flow occurred at the beginning of December in terms of the necessary water supply. Clearly the debris flow was triggered by slope failure which occurred at the geological formation border at an elevation of about 1,300m. The soil layer above the formation border probably contained very much water due to antecedent rainfall before the slope failure. Chemical analysis of the water contained in the debris flow deposit should provide an effective means of identifying the origin of this water. Chemical analysis results showed that the water in the debris flow deposit did not originate directly from rainfall and snow melt but came from stored groundwater.

1. INTRODUCTION

On 6 December 1996, a debris flow occurred in the Gamahara Torrent in Otari Village, at the border between Niigata and Nagano Prefectures, Japan (Fig. 1). Fourteen workers were killed and eight injured, after being caught in the deluge of mud, sand and rocks by the debris flow that hit the torrent control dam construction site near the confluence of the Hime River as well as at another site about 1 km upstream. Photo 1 shows the slit-type torrent control dam near the confluence. The highest part of the debris flow passed over the crown of the dam. Photo 2

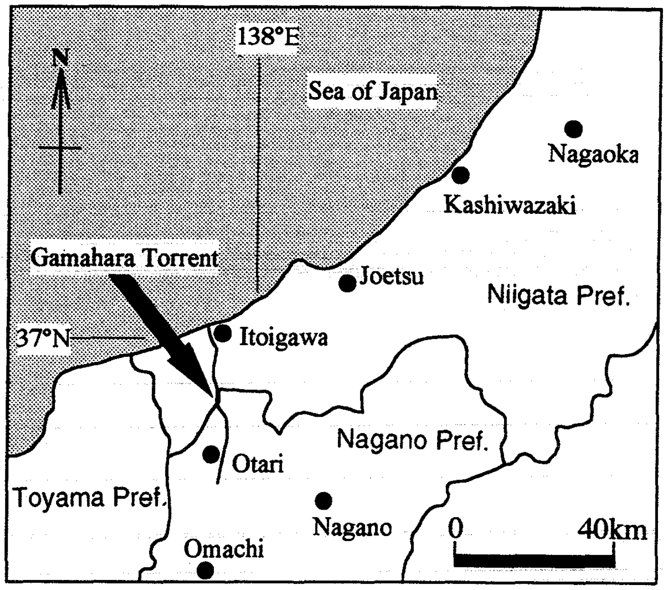

Fig. 1. Map showing the location of the Gamahara Torrent.

KEY WORD: debris flow, triggering slope failure, Quaternary Kazafuki volcanics, snow melt, electric conductivity.

shows the deposited debris material, including a transported big rock and a destroyed truck. The total volume of the deposited debris material in the neighborhood of the confluence is estimated to be about 24,000 m^3 [1], but the volume of the debris material that flowed downstream in the Hime River is unknown. The Gamahara Torrent leading to the Hime River was severely damaged by a larger debris flow caused by extremely heavy rainfall on 11 July 1995. At that time, the Kokkai bridge was washed away and destroyed by the impact of the debris flow. After that severe disaster, a large slit-type torrent control dam and channel works near the confluence and other dams about 1km upstream were to be constructed. About 160 persons were working at the two sites at the time of the debris flow on 6 December 1996. The background and characteristics of the debris flow are described here.

2. TOPOGRAPHY and GEOLOGY

The Gamahara Torrent has a catchment area of 4.0km^2, a channel length of 4.6km, and is a very steep torrent with a mean bed inclination of 20 degrees. Its plane is shown in Fig. 2. The shape of the catchment area is asymmetrical and the slope on the right side is very steep and narrow, whereas the slope on the left is gentle and wide. The adjacent Mae Torrent has almost same size of catchment area, 3.4km^2. It has a symmetrical plain shape and a mean bed inclination of 15 degrees. The longitudinal profile of the Gamahara Torrent is shown in Fig. 3. Its bed inclination has a very steep shape in the middle part, becoming gentler in the upper part.

The geology around the Gamahara Torrent watershed is divided into four units in

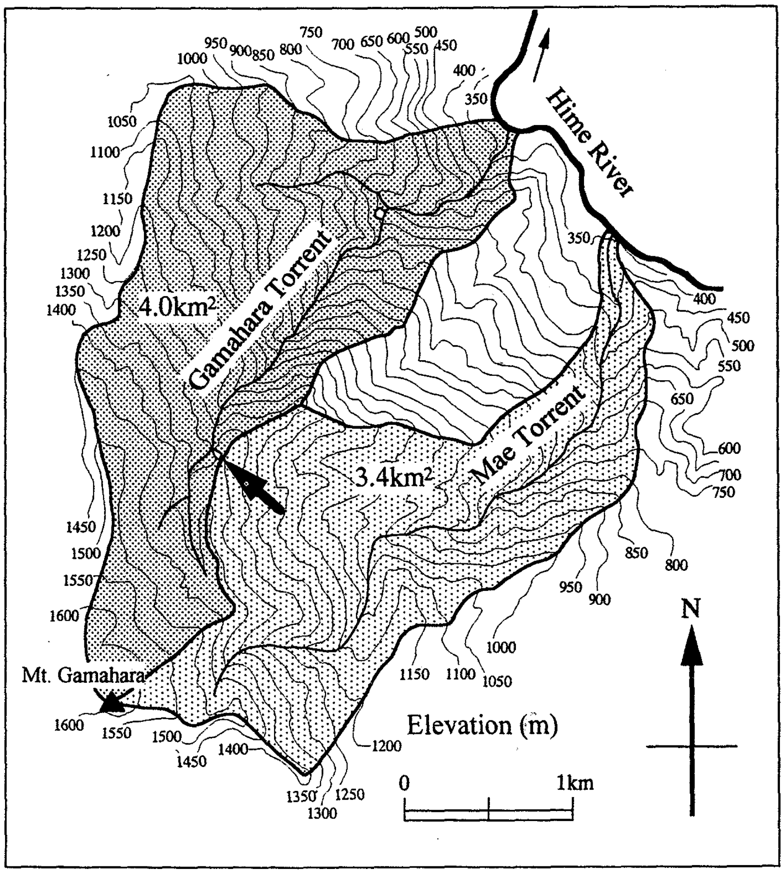

Fig. 2. Plane of the Gamahara and Mae Torrents. The arrow shows the slope failure in the upper area.

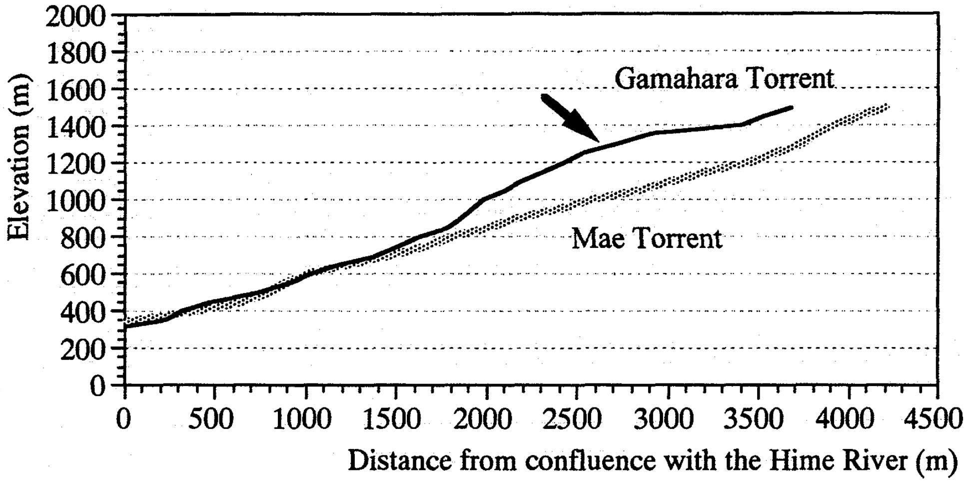

Fig. 3. Longitudinal profile down the main channel of the Gamahara Torrent. The arrow shows the slope failure in the upper area.

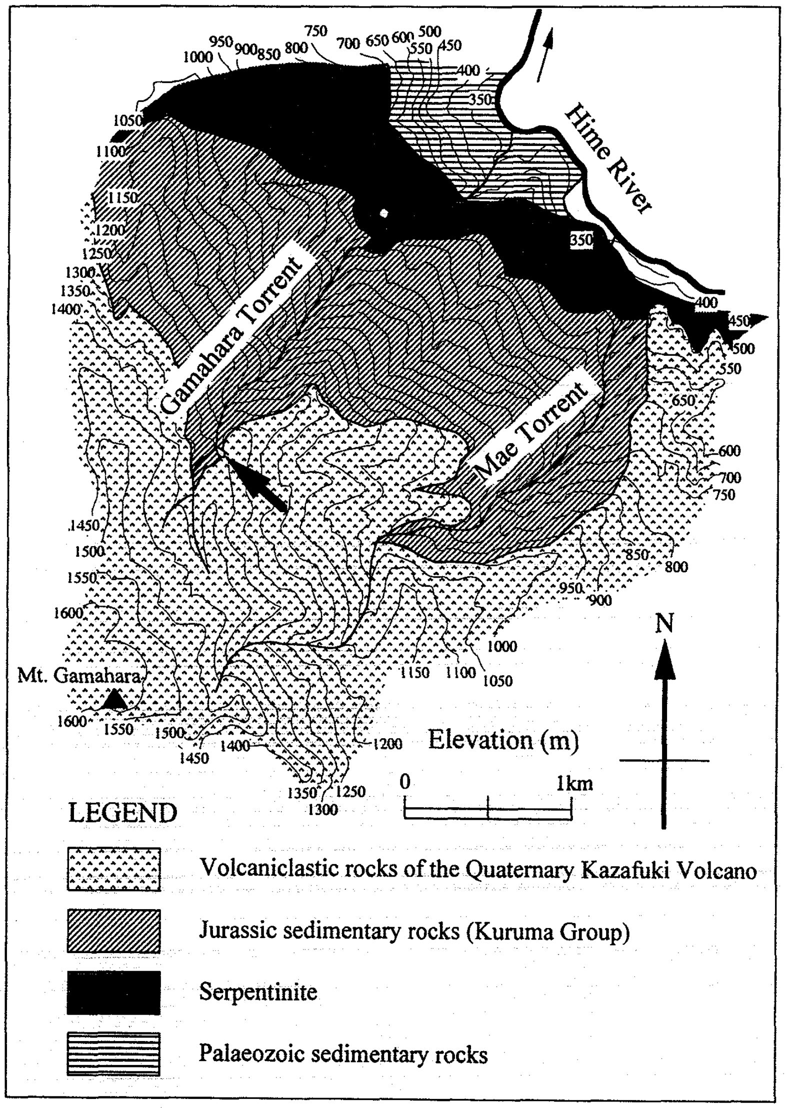

Fig. 4. Geologic map around the Gamahara Torrent (Partially simplified after Shiraishi, 1992). The arrow shows the slope failure in the upper area.

ascending order, Paleozoic sediments, serpentinite, the Jurassic Kuruma group, and Quarternary Kazafuki volcanics [2]. The Paleozoic sediments consists of sandstone, shale, and chert. The Kuruma group consists of sandstone, mud stone, and conglomerate. Fig. 4 shows the geological overview around the Gamahara Torrent watershed. Serpentinite is distributed in the lower part of the watershed and the Kuruma group in the middle part. The upper part of the watershed is covered with Kazafuki volcanics. The Kuruma group has a strike of E-W or NE-SW and dips 40–70 degrees to the south. The left slope of the Gamahara Torrent almost parallels the geological stratification and the right slope is diagonal to its. In general the watershed has a cuesta structure produced by the shape of the Kuruma formation.

3. WEATHER CONDITIONS

In terms of the triggering of the water supply, there are two types of debris flows in the tributaries of the Hime River. Debris flows caused by heavy rainfall in summer and those caused by snow melting in early spring. The debris flow on 6 December 1996 occurred during a dry season in which debris flows very seldom take place. Fig. 5 shows the weather conditions recorded by the nearest meteorological stations in Otari Village and Hakuba Village prior to the debris flow. On 6 December there was almost no rainfall and during the previous day only 47mm rainfall had been recorded. Furthermore, on 1 December a snow cover depth of 35cm was recorded. On 5 December the minimum temperature had risen suddenly, more than 10 degrees, and was higher than zero degree

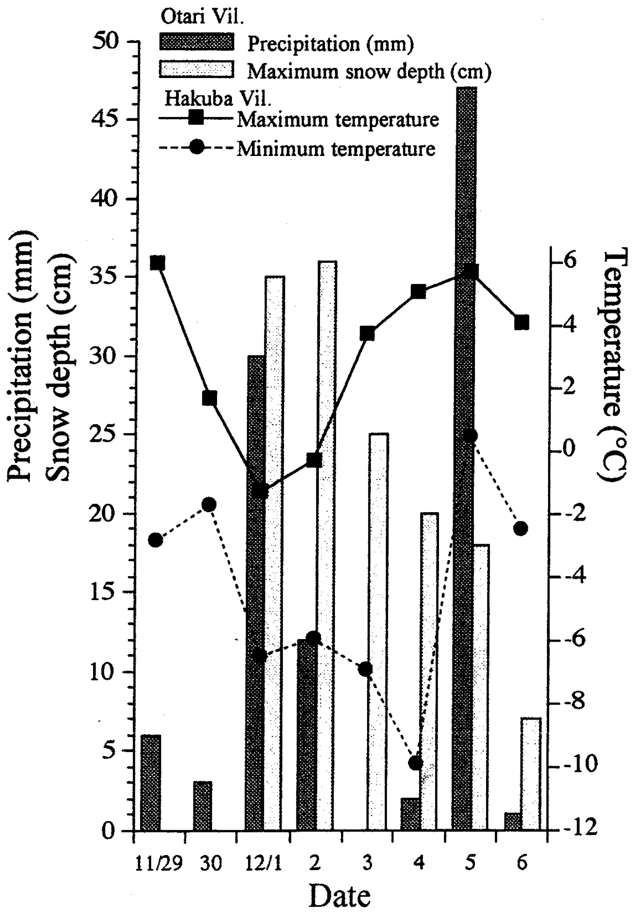

Fig. 5. Weather conditions preceding the debris flow (after values measured with AMEDAS by the Nagano district weather station).

Celsius. The measured snow cover depth decreased from 18 to 6cm during that day. The amount of snow melt water is estimated to have been at most about 24mm as based on the decrease in the snow cover depth, assuming that the mean density of the snow layer was nearly 0.2 g/cm^3. The total amount of the water supply therefore should have been about 70 mm, including the 47mm rainfall.

According to the snow depth, as measured by a meteorological station located at the same elevation (1340m) (and considered the trigger of the slope failure,) the change in depth should have been about 20cm on 5 December [3]. The amount of the snow melting water was estimated to be, at the most, about 40mm, assuming that the mean density of the snow layer was nearly 0.2g/cm^3. In this case, the total amount of the water supply should have been about 80 mm including the measured value of 38mm rainfall.

More detailed methods to evaluate the amount of snow melt, such as the heat balance method or that based on the viscous compaction theory are available. It is not especially useful to apply them in this case because the value for the snow melt as estimated by a simplified method using the change in snow cover depth gives a possible maximum value. Even if the above-mentioned amounts of water supply could have had a role in the slope failure, it is hard to see why these amounts of water would have severely affected the occurrence of the debris flow, as compared with the amounts of water supplied by intensive rainfall or snow melt that triggered past debris flows in this area.

4. OCCURRENCE OF THE DEBRIS FLOW

Aerial observation suggests that the debris flow was triggered by slope failure at the elevation of about 1,300m (marked in Figs, 3 and 4). Photo 3 shows a distant view of the triggering slope failure and traces of the debris flow. Photo 4 shows a near view of the same slope failure. At first the volume of the slope failure was estimated to be at most 5$\sim$6 thousand m^3 from simple optical aerial observations. Later it was estimated to be 33,000 m^3 by aerial photo interpretation [1]. Probably, this slope failure material fell down the slope to the torrent bed, struck torrent deposits saturated with water, and

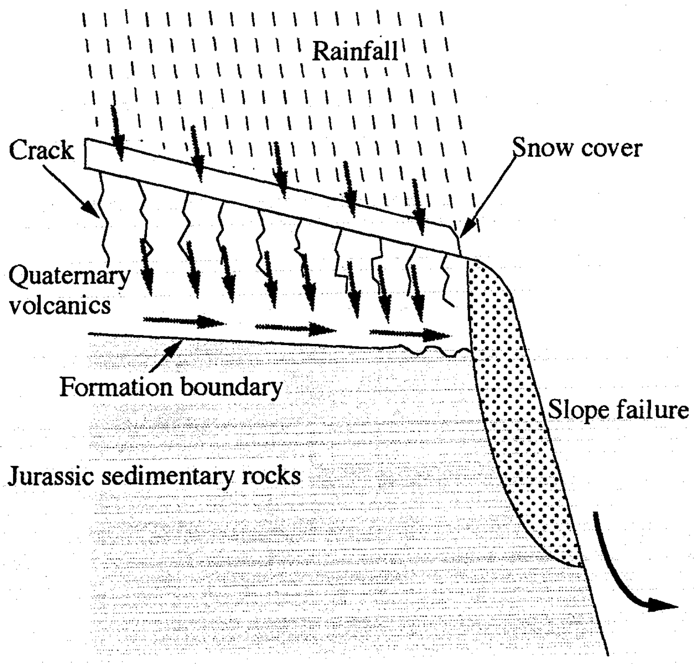

Fig. 6. Schematic model of the slope failure which triggered the debris flow.

triggered the debris flow. Possibly, the torrent bed was eroded by the debris flow, making the flow larger than the initial volume of the slope failure, because of containing the eroded material.

The slope failure occurred in the upper part of a very steep slope failure scar that was caused by extremely heavy rainfall on 11 July 1995. The failure is located at the topographical knick point and the geological formation border between the Quaternary Kazafuki volcanics and the Jurassic Kuruma group. There are many joints and fissures in the upper soil layer of the Quaternary Kazafuki volcanics so that the layer has a high infiltration rate. The lower soil layer of the Jurassic Kuruma group has a low infiltration rate. Water from rainfall and snow melt therefore could easily infiltrate the upper soil layer, reach the geological formation boundary, then be discharged along the boundary to the slope surface (Fig. 6). The slope failure should have been triggered by this type of discharged water.

5. CHEMICAL ANALYSIS OF TORRENT WATER

Water samples for the chemical analysis of the major ions and electric conductivity (EC) were obtained from the Gamahara Torrent before and immediately after the debris flow. One sample was stream water taken 22 October 1995 (before the debris flow) at its confluence with the Hime River. The other was water extracted from loose debris flow deposit (after the disaster) on 7 December 1996. Analytical results are given in Table 1 and shown as pattern diagrams in Fig. 7. The EC value of the water after the disaster was 2.4 times that before it. Fig. 7 shows that the high EC value of the water after the debris flow was caused mainly by an increase in the sulfate and calcium ion concentrations. The sulfate ion was produced by the oxidation of the pyrite contained

Table 1. Chemical compositions of the torrent and debris flow waters.

Sample	W.T. (℃)	pH	EC (mS/cm)	Na (ppm)	K (ppm)	Ca (ppm)	Mg (ppm)	Cl (ppm)	HCO3 (ppm)	SO4 (ppm)
Before Disaster (Torrent Water)	13.8	8	0.186	4.56	0.67	23.31	8.24	2.51	101.48	10.96
After Disaster (Debris Flow Water)		8.5	0.45	9.87	3.00	86.64	1.33	18.14	103.73	124.60

W.T.: Water Temperature
E.C.: Electric Conductivity

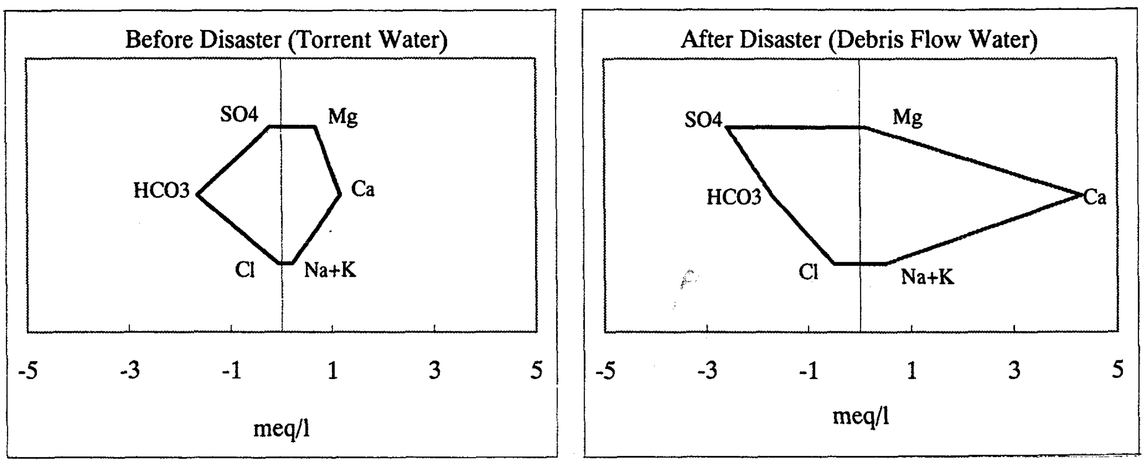

Fig. 7. Pattern diagrams of the major ions in the torrent and debris flow waters.

in the altered volcanic materials in this area. The high EC value suggests that the water in the debris flow did not originate from rainfall and snow melt which have low EC values, but from groundwater which has a high EC value.

The probable explanation is that rainfall and snow melt water infiltrated the porous Kazafuki volcanics, pushing out groundwater along the boundary between the Kazafuki volcanics and the impermeable Kuruma formation. The groundwater stored in the Kazafuki volcanics was discharged into the debris deposits on the torrent bed. The debris flow therefore contained this stored water and brought it downstream. Geological structure composed of two different strata easily could cause a slope failure at this geological boundary.

6. CONCLUDING REMARKS

The process of the Gamahara Torrent debris flow was discussed on the basis of the current available data and information. It is certain that the debris flow was triggered by a slope failure at the elevation of about 1,300m. The following scenario suggests a possible process:

1) As background, the soil mass above the geological formation boundary stored much groundwater owing to prior rainfall.

2) At first the slope failure was triggered at the upper edge of the very steep scar of a previous slope failure near the geological formation boundary.

3) The material from the slope failure fell down the slope to the torrent bed, struck the torrent deposits already saturated with water, triggering a debris flow.

4) The debris flow flowed downward and enlarged, containing the eroded material.

To ascertain whether the above scenario is valid and to identify the actual mechanism of that started of the debris flow, it is necessary to perform in situ field investigations after the dissipation of the snow cover.

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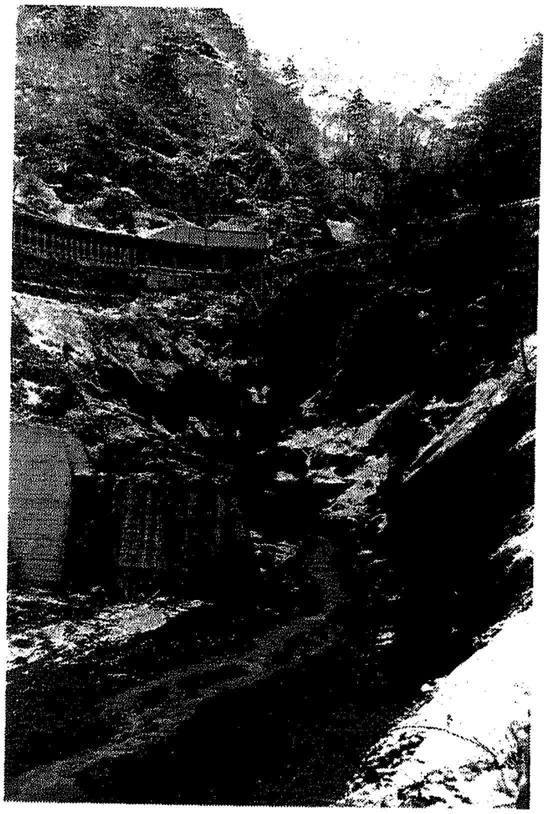

Photo. 1. Torrent control dam near the confluence with the Hime River (after the passage of the debris flow)

Photo. 2. Debris flow deposit including a transported big dam and a destroyed truck

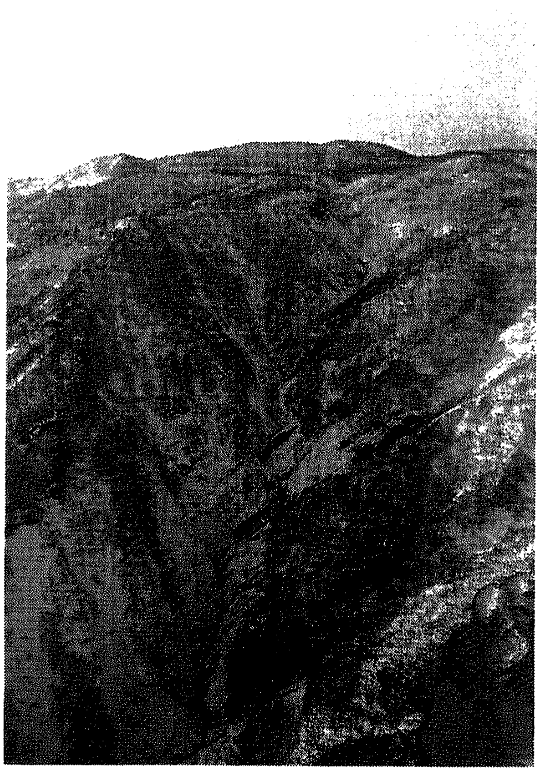

Photo. 3. Distant view of the triggering slope failure and the trace of the debris flow.

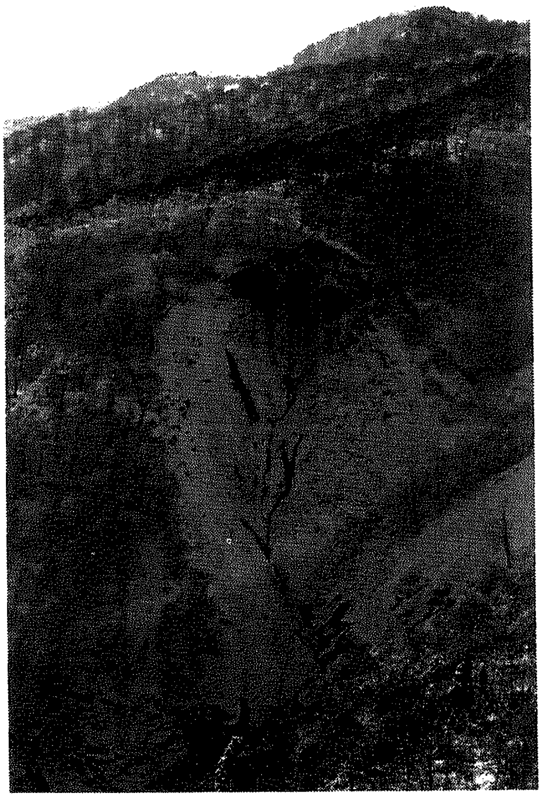

Photo. 4. Near view of the same slope failure in Photo 3.