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Rain-induced Landslides in the Canadian Cordillera, July 1988

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Article abstract

Rain-induced landslides are a major geological hazard in the Canadian Cordillera that impact directly on the economic infrastructure of the region. In July 1988, heavy rains triggered debris flows and related sediment-water flow processes which severed the Alaska Highway in three areas: Muncho Lake, BC, Rancheria, Yukon, and Kluane Lake, Yukon. The events paralysed travel in the region for several days. In addition, the heavy rainfall caused wide spread landsliding over a large area of the northern Cordillera. One of the largest events was acomplex failure at Nahanni Butte, NWT Debris flows originating in the steep watersheds of the Sentinel Range of the RockyMountains severed the highway at six locations in the vicinity of Muncho Lake. At Kluane Lake, the highway was severed innumerous places by debris flows and related processes and at one location, near theSlims River, a debris flow covered over 500 m of highway. A large landslide, covering nearly 2 km2, threatened a National Parkranger station near Nahanni Butte. North-east of the station a large mobile mudflow travelled almost 2 km to the Liard River. The direct cost of restoring the Alaska Highway was in the order of $1.8 M. The paper points to the vulnerability of transportation facilities in mountainous terrain where the location ofroutes necessarily involves the traversing of active geomorphic surfaces.

Features

Active Earth

Rain-induced Landslides in the Canadian Cordillera, July 1988

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Abstract
Rain-induced landslides are a major geological hazard in the Canadian Cordillera that impact directly on the economic infrastructure of the region. In July 1988, heavy rains triggered debris flows and related sediment-water flow processes which severed the Alaska Highway in three areas: Muncho Lake, BC, Rancheria, Yukon, and Kluane Lake, Yukon. The events paralysed travel in the region for several days. In addition, the heavy rainfall caused widespread landsliding over a large area of the northern Cordillera. One of the largest events was a complex failure at Nahanni Butte, NWT. Debris flows originating in the steep watersheds of the Sentinel Range of the Rocky Mountains severed the highway at six locations in the vicinity of Muncho Lake. At Kluane Lake, the highway was severed in numerous places by debris flows and related processes and at one location, near the Slims River, a debris flow covered over 500 m of highway. A large landslide, covering nearly 2 km^2, threatened a National Park ranger station near Nahanni Butte. Northeast of the station a large mobile mudflow travelled almost 2 km to the Liard River. The direct cost of restoring the Alaska Highway was in the order of $1.8 M. The paper points to the vulnerability of transportation facilities in mountainous terrain where the location of routes necessarily involves the traversing of active geomorphic surfaces.

Introduction

Rainfall-induced landslides are a major geological hazard in the Canadian Cordillera (VanDine, 1985; Lister *et al.* 1984; Church and Miles, 1987). They impact directly on elements of economic infrastructure of the region including transportation facilities (*e.g.*, Evans and Lister, 1984) and settlements (*e.g.*, Nasmith and Mercer, 1979; Lister *et al.*, 1984). Of particular concern are debris flows which occur on steep mountain slopes and in steep mountain watersheds as a result of heavy rain. These types of landslides are rapid movements and have considerable destructive force, characteristics which have necessitated the construction of costly defensive structures at several locations in southwestern British Columbia (*e.g.*, Nasmith and Mercer, 1979; Martin *et al.*, 1984; Hungr *et al.*, 1987).

In July 1988, debris flows and related processes caused by heavy rainfall severed the Alaska Highway in three areas: Muncho Lake (west of Fort Nelson, British Columbia (BC)), Rancheria (east of Whitehorse, Yukon Territory (YT)), and Kluane Lake (west of Whitehorse, YT) (Figure 1). The events drew national attention and paralysed travel in northern BC and southern Yukon Territory for a number of days at the height of the tourist season.

The heavy rainfall caused widespread landsliding over a large area of the northern Cordillera. One of the largest of the landslides was a complex failure near the Nahanni National Park Ranger Station at Nahanni Butte, NWT.

This paper describes debris flows, associated sediment-water flows, and other landslide types, which occurred in the region in July 1988. It examines the relationship between their occurrence and the timing and magnitude of the rainfall which caused them, and documents the impact on physical facilities at the sites investigated. The paper is based on field inspections carried out at Nahanni Butte in July and in the Muncho Lake and Kluane Lake areas during August 1988. Information on road closures and associated rainfall has been assembled from local newspapers and data provided by Alaska Highway officials and staff of Environment Canada.

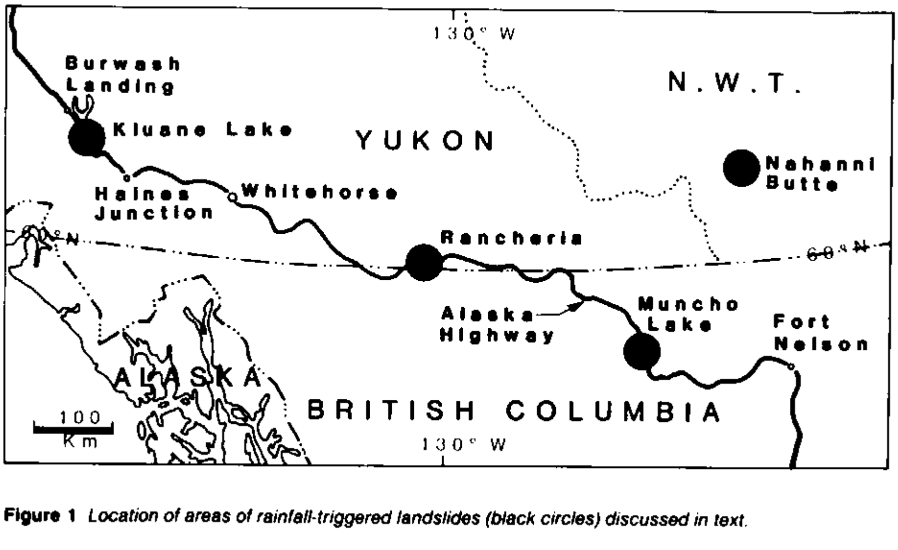

Figure 1 *Location of areas of rainfall-triggered landslides (black circles) discussed in text.*

Terminology

Throughout the paper we use the term debris flow in a very broad sense, because no first hand observations were made on the velocity or sediment concentration of the events in question. A wide range of flow processes may be active on alluvial fan surfaces in a mountainous environment, ranging from sediment-laden water floods to debris flows proper. We accommodate this possibility by referring to the events as "debris flows and associated sediment-water flows" (*cf.* Pierson and Costa, 1987).

Landslides at Muncho Lake

The Alaska Highway crosses the Sentinel Range of the Rocky Mountains, 170 km west of Fort Nelson, BC. Over the 60 km distance between the Toad River and Trout River bridges (Figure 2), the highway traverses more than 15 active alluvial fans located at the mouths of steep mountain watersheds in the Sentinel Range (Figure 3). The watersheds contain steep bare slopes underlain by Paleozoic carbonate rocks; these slopes are a major source of sediment to fans along the Alaska Highway. The fans debouch into Muncho Lake at elevation 817 m a.s.l., while peak elevations within the watershed range from 2000 to 2220 m. The presence of lobate fan surfaces, matrix-supported diamictons and clast-supported fluvial gravels indicates that the fans are subject to a spectrum of processes ranging from debris flows to sediment-laden floods.

Debris flows and sediment-water flows severed the Alaska Highway in this area in 1974, 1975 and 1979 (Eisbacher, 1980). Their repeated occurrence led to a major relocation of the highway in the area of Petersen Creek (Figure 2). Public Works Canada, the owner of the highway, has attempted to maintain the highway across the fans by the construction of protective works such as gravel deflection dykes and excavated channels. Highway maintenance workers who have observed the onset of debris flow events in this area have reported that fan surfaces appear to "come alive"; the noise of such an event is likened to a busy railway marshalling yard (*cf.* Costa, 1984).

In 1988, the Alaska Highway was closed at 2000 h on July 12. It was severed in six locations by sediment-water flow processes, either by the destruction of the roadbed itself or by the deposition of material on the surface of the road (Figure 2). These flows were triggered by rainfall of 68.8 mm in 48 hours on July 12 and 13 (Figure 4). The Alaska Highway was re-opened at 1800 h on July 14, 1988.

The cumulative rainfall for the 1988 event, as measured at the Muncho Lake meteorological station, is compared to the rainfall for the destructive storm events of 1974 and 1975 in Figure 5. Data for the 1979 event were unavailable. It appears that although there are substantial differences in antecedent rainfall, there is a broad similarity between the intensity and magnitude of the rainfall that triggered the debris flows.

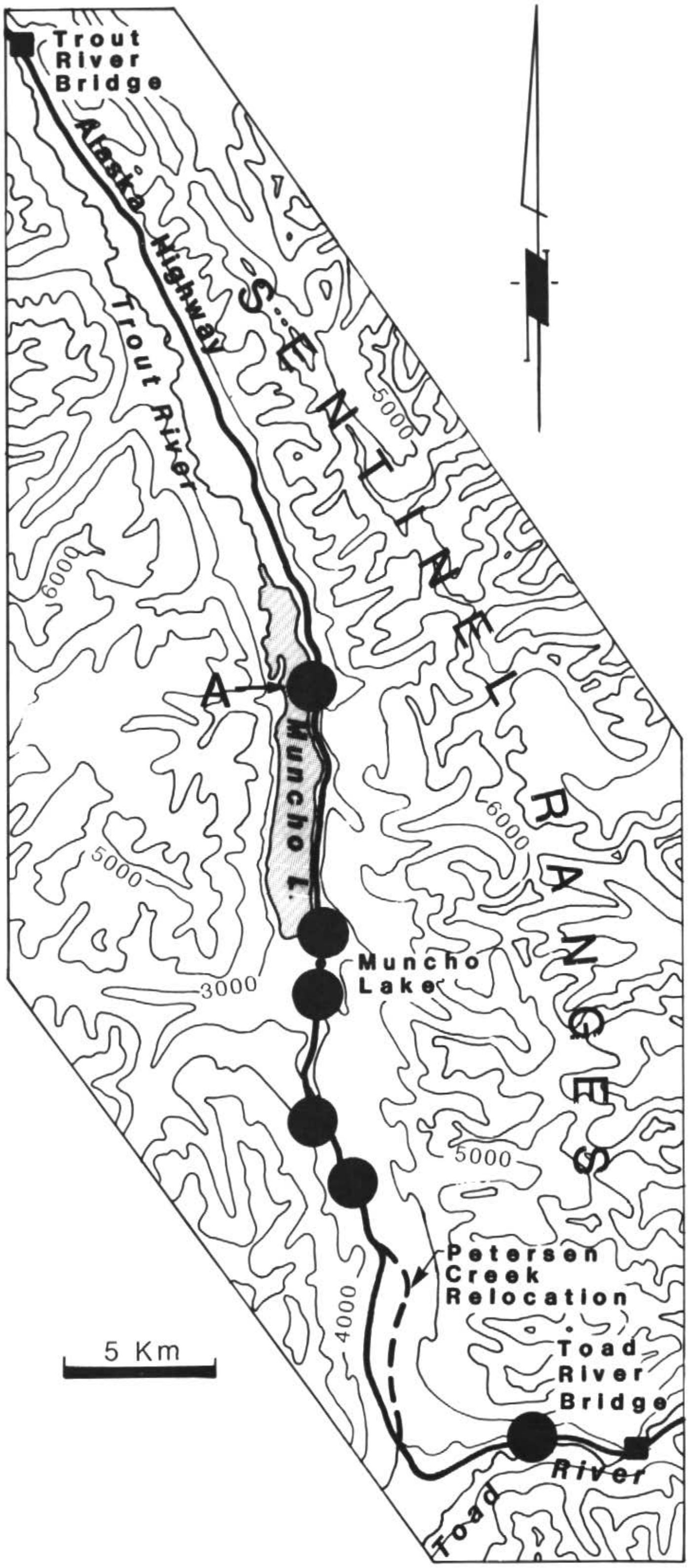

Figure 2 *Alaska Highway route in the vicinity of Muncho Lake, British Columbia. The Highway was severed at 6 locations (black circles) by debris flow and associated sediment-water flow processes during the July 1988 rainstorm.*

Figure 3 *Oblique aerial photograph illustrating the nature of the watersheds developed in the Paleozoic carbonates of the Sentinel Ranges in the vicinity of Muncho Lake. Note active fan surface and steep bare slopes. The Alaska Highway was severed at the location indicated by the arrow (A in Figure 2) during July 1988 rainstorm. Elevation difference between Muncho Lake in foreground and peak on centre skyline is 1255 m.*

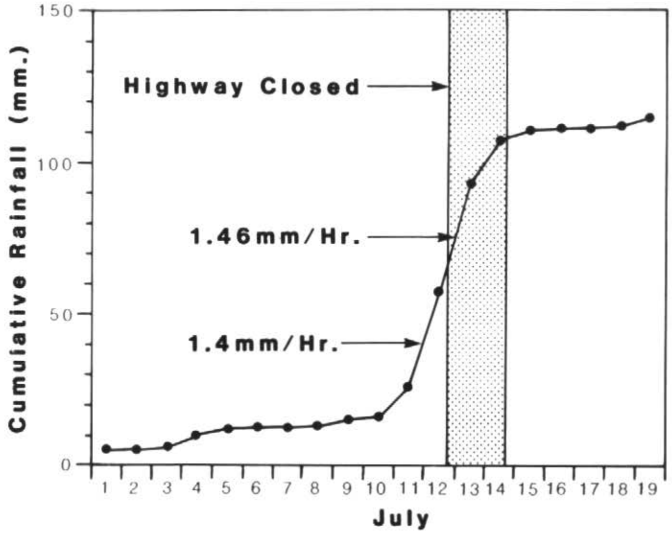

Figure 4 *Cumulative rainfall measured at Muncho Lake, July 1-19, 1988. The Alaska Highway was closed at 2000 h on July 12 and was re-opened at 1800 h on July 14.*

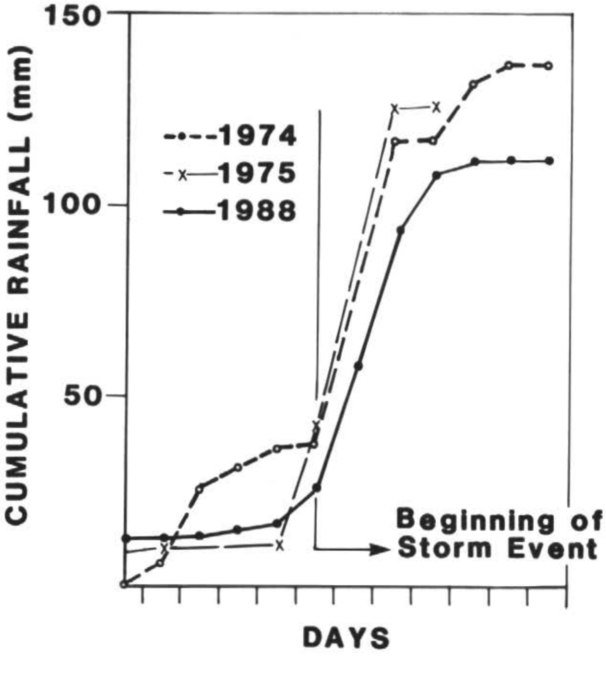

Figure 5 *Comparisons of cumulative rainfall at Muncho Lake for the 1974, 1975 and 1988 debris flow events.*

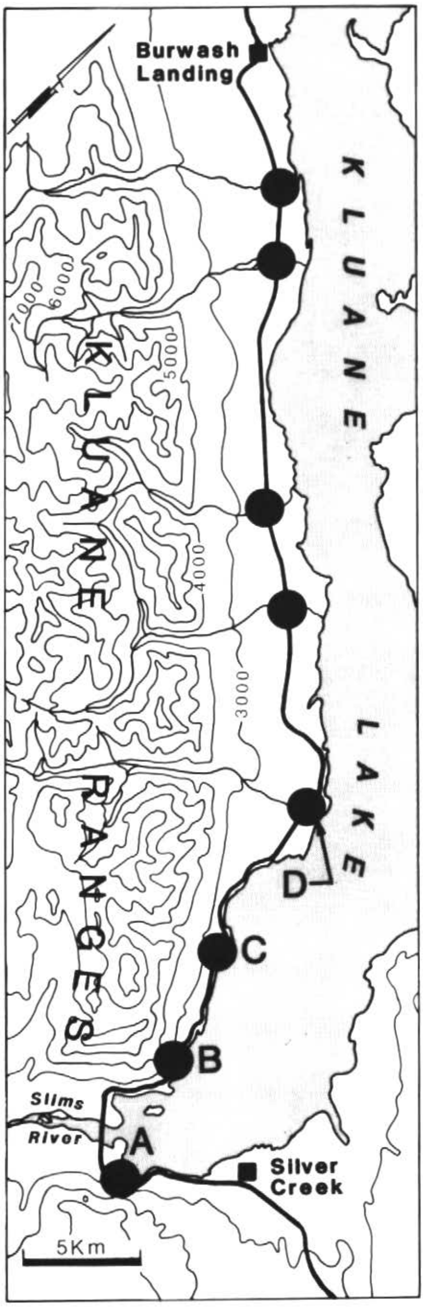

Figure 6 *Alaska Highway route in the vicinity of Kluane Lake, Yukon Territory. The highway was severed at 8 locations (black circles) by debris flow and associated sediment-water flow processes during the July 1988 heavy rainfall. A-D are locations discussed in text.*

Figure 7 *Aerial photograph (Canada A23820-19) showing the location of a major rainfall-triggered debris flow (A) which blocked the Alaska Highway in July 1988. Also shown (B) is the location of a debris flow which blocked the Alaska Highway in 1967.*

Landslides in the Kluane Lake Area

In the 65 km between Silver Creek and Burwash Landing (Figure 6), the Alaska Highway skirts the southern tip of Kluane Lake, crosses the Slims River and follows the base of the Kluane Ranges. Over this distance, it traverses numerous active alluvial fans and the debris of a major pre-historic rock avalanche (Clague, 1981). The fans have developed at the mouths of steep mountain watersheds and debouch into Kluane Lake at elevation 781 m a.s.l. Peak elevations within the watersheds range from 1600 and 1720 m to the south of the Slims River, whilst to the north they reach 2590 m and some watershed support glaciers. Based on reconnaissance observations, fans south of Congdon Creek (D in Figure 6) have smaller areas, higher gradients and are dominated by debris flow processes, whilst north of (and including) Congdon Creek the fans are much larger, exhibit lower gradients and appear to be dominated by fluvial processes. It is of interest that Clague (1981) noted that "a greater hazard (than rock avalanches) to future development in the south Kluane Lake area is posed by debris torrents and debris flows on fans and aprons fronting the Kluane Ranges ..." (p. 969).

In July 1988, the Alaska Highway was severed at numerous locations between Silver Creek and Burwash Landing (Figure 6). A major debris flow covered more than 500 m of highway about 1.5 km east of the Slims River bridge (A in Figure 6, Figure 7). It occurred approximately 2 km west of the site of a previous major debris flow (Figure 7) which blocked the Alaska Highway after a period of intense rainfall in the summer of 1967 (Hughes *et al.*, 1972).

Two debris avalanches occurred in Holocene colluvium on slopes above the highway approximately 3.5 km north of the Slims River (B in Figure 6). Debris of one of these landslides blocked the road (Figure 8).

Between this point and Burwash Landing, the Alaska Highway was severed by debris flows or sediment-water flows at six locations where it crosses major alluvial fans. Large amounts of coarse material were mobilized on the surfaces of these fans as braided channels shifted due to the plugging of existing channels, the erosion of natural levees and the breaching of artificial berms. A typical example of an active fan along the foot of the Kluane Range (Williscroft Creek) is shown in Figure 9 (C in Figure 6).

The Alaska Highway in the Kluane Lake area was closed at 0315 h on July 13 and reopened to the travelling public at 0100 h on July 19. Records from Burwash Landing indicate sustained rainfall from July 8 to July 15 (Figure 10). During this period 91.6 mm fell at an average rate of 13 mm/24 hours.

The magnitude of the July storms may be illustrated by the fact that rainfall measured at Haines Junction and Burwash Landing for the period July 1-17 was 263% and 209% of normal values. These figures correspond to 32% and 42%, respectively, of average yearly totals for these stations.

Landslides at Nahanni Butte

The July rainstorms triggered a large landslide (*ca.* 1.5-2 km^2 in area) in Quaternary sediments 3 km northeast of the Nahanni National Park Ranger Station at Nahanni Butte, NWT (Figures 1 and 11). There were numerous other smaller slope failures in this region during these storms.

The large landslide took place on a slope that dips about 10° away from a 200 m high limestone escarpment toward South Nahanni and Liard Rivers (Figure 11). Sediments underlying this slope are over 100 m thick and heterogeneous in character. Much of the sediment is colluvium (rubble and diamicton) derived from the escarpment by rockfall and other processes. The slope

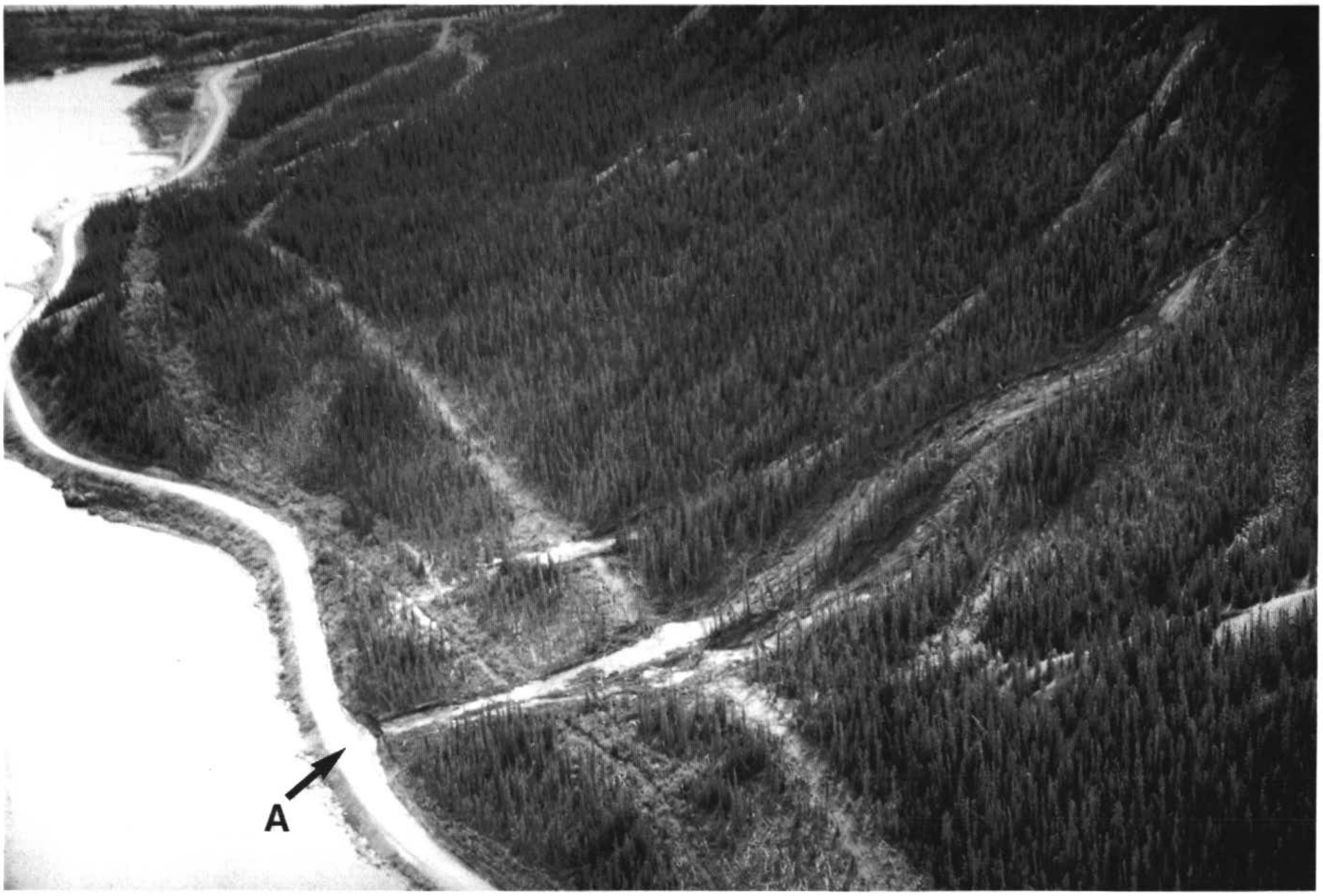

Figure 8 *Oblique aerial photograph of two debris avalanches which occurred on open slopes above the Alaska Highway during the July rains. The Highway was blocked at A. Kluane Lake is seen on the left of the photograph.*

below the escarpment has an irregular, hummocky to undulating form, which suggests that it has been affected or shaped by prior landsliding and/or solifluction.

This part of NWT is within the zone of discontinuous permafrost. The presence of rock glaciers near Nahanni Butte shows that some ice is present in the Quaternary sediments. Ground ice may have a complex distribution and likely contributed to the slope failures in this area in July.

Approximately 136 mm of rain fell at Nahanni Butte between June 28 and July 2, 1988 (Figure 12). This is far in excess of normal precipitation for the entire months of June and July. Interestingly, there appears to have been a lag of about one week between the termination of the heavy rains and the large failure northeast of the ranger station; only 6 mm of precipitation is recorded between July 3 and July 8 when the landslide is thought to have occurred.

The large landslide northeast of the ranger station (Figure 11) developed over a period of several days, although most of the displacement probably occurred within hours of initial failure. On the upper part of the colluvial slope, directly below the limestone escarpment, sediments moved downward and outward along one or more deep-seated, curving shear planes. Farther downslope, sediments slid rather passively along shear planes oriented more or less parallel

Figure 9 *Aerial photograph (Canada A23820-50) of a typical mountain watershed in the eastern slopes of the Kluane Ranges (Williscroft Creek). The Alaska Highway was severed at A during the July rains.*

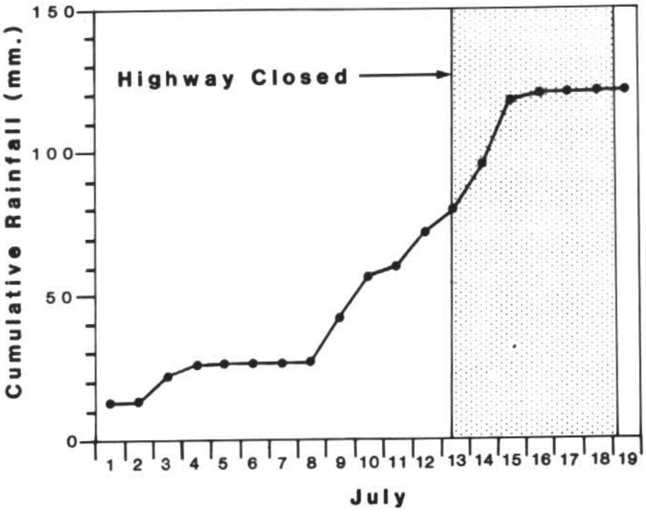

Figure 10 *Cumulative rainfall at a Burwash Landing, July 1-19, 1988. The Alaska Highway was closed between 0315 h on July 13 and re-opened to traffic at 0100 h on July 19, 1988.*

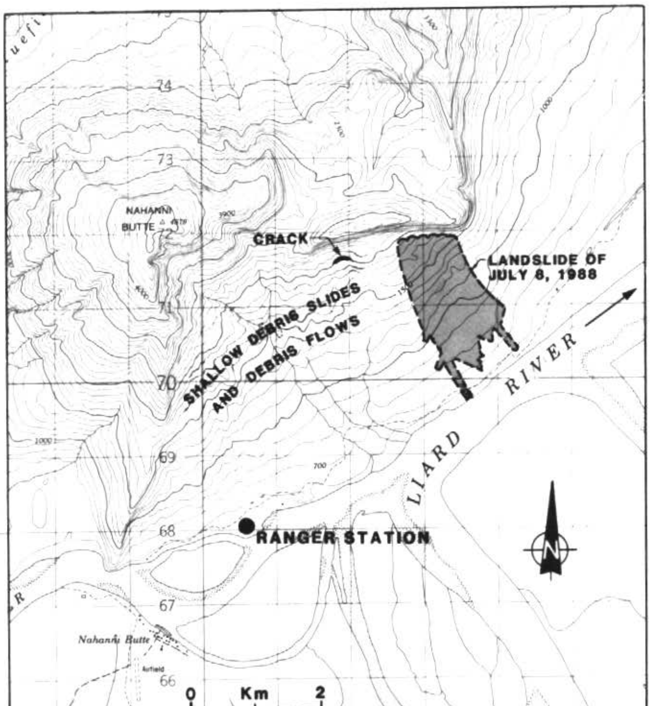

Figure 11 *Topographic map of the Nahanni Butte area, NWT, showing the locations of the Nahanni National Park Ranger Station and the large landslide that occurred on July 8, 1988.*

to the ground surface, disrupting and locally destroying vegetation and extensively fracturing the ground. A large, mobile mudflow swept across this portion of the slope to beyond the terminus of the main slide (Figure 13). A tongue of this flow reached Liard River after travelling almost 2 km. Other tongues of debris moved downslope from the south and west margins of the landslide; these, however, retained surface vegetation and thus probably moved more slowly than the main mudflow.

Scores of other, much smaller landslides occurred on the slope directly north of the ranger station during late June and early July. All of these were shallow debris slides and debris avalanches; a few transformed into small debris flows that travelled short distances down ravines and gullies.

The landslides at Nahanni Butte raise concerns about the safety of the Nahanni Park Ranger Station which is located at the foot of the colluvial slope on a low terrace adjacent to South Nahanni River. The Ranger Station was not affected by the 1988 landslides, but there is a possibility of it being damaged or destroyed in the future during a prolonged period of heavy rain. Although the hazard in the short term is low, since heavy rains similar to those in June

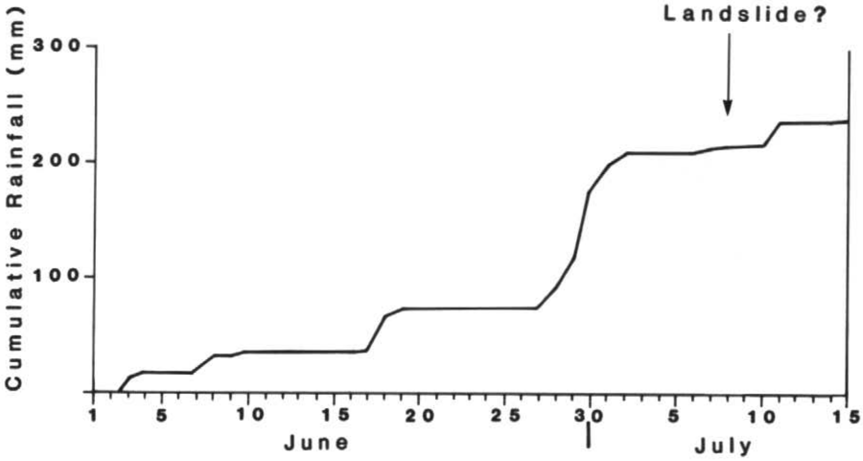

Figure 12 *Cumulative rainfall at Nahanni Butte, June 1-July 15, 1988.*

Figure 13 *Oblique view of the landslide complex noted in Figure 11. The boundary of the landslide is indicated by a dotted line. Note the unvegetated track of a multi-lobed mudflow that travelled from the upper part of the complex to the Liard River.*

and July 1988, are infrequent, there is sufficient danger in the long term to consider relocating the station.

Summary

This paper has documented debris flows and related sediment-water flows which disrupted traffic on the Alaska Highway in northern BC and southern Yukon Territory during July 1988. It also describes an active landslide complex which developed on a colluvial slope at Nahanni Butte, NWT. The paper provides examples of major impacts of rain-induced landslides and related processes on transportation routes in the Cordillera (*cf.* Eisbacher, 1980; Evans and Lister, 1984; Church and Miles, 1987). It also points out the vulnerability of transportation facilities in mountainous terain, where the location of routes necessarily involves the traversing of active geomorphic surfaces.

It is estimated that direct costs of restoring the Alaska Highway to its pre-storm standard were in the order of $1.8M (Public Works Canada, unpublished sources). The significant economic loss may be compared with the cost of highway reconstruction after the 1974 and 1975 events in the Muncho Lake area of $2.0M and $1.3M, respectively (Eisbacher, 1980).

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