Five-Mile Creek Debris Flow

Banff National Park, near Banff, Alberta

August 4th, 1999

OPEN FILE #3876

Source: Banff National Park

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Natural Resources Canada
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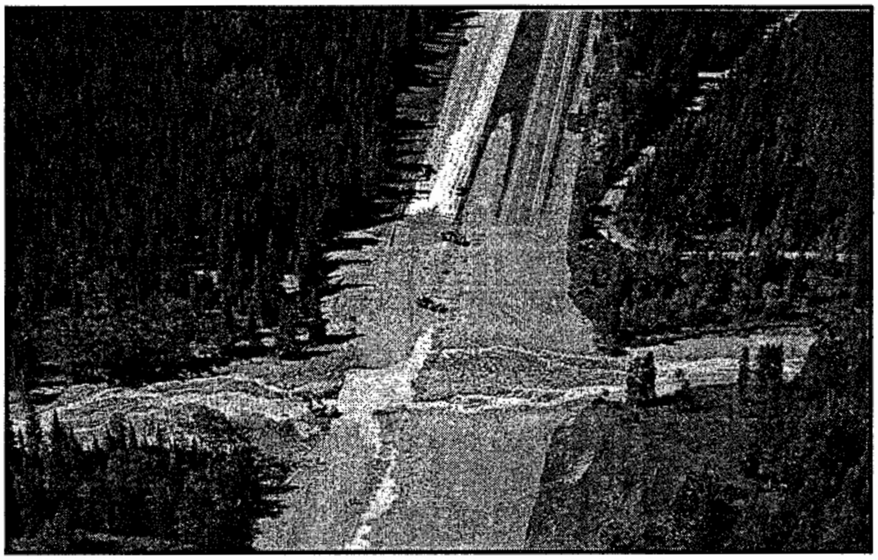

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Summary

At about 6:45 pm on Wednesday August 4th, 1999, a substantial amount of water, mud, boulders and uprooted trees buried all four lanes of the Trans-Canada Highway about 5 km west of main exit to Banff, Alberta. About 200 m of the highway was covered by debris varying in thickness from 0.5 m to 2 m. The debris was moved by an exceptionally high flow in Five-Mile Creek triggered by severe rainfall. A 4-meter diameter culvert beneath the highway was rapidly filled by boulders and tree limbs and then the highway was covered by a large amount of mud. Debris traveled more than 3 km from the source area to the highway and reached the Canadian Pacific railway about 250 m beyond the highway. Highway service crews worked for about 3 weeks for normal traffic to resume, and to clean the creek bed upstream and downstream the highway. Thousands of motorists were affected by the closure of the highway by having to take alternative routes or waiting 24 hours for the highway to reopen. The debris flow also cut buried optic fiber cables depriving the Lake Louise community any telephone communication.

Geological, geomorphic, and climate data obtained from available documents and from field investigations are presented and discussed here. Five samples were taken along a transect from the source area to the deposition zone for grain size distribution analysis. It appears that the debris flow was triggered by localized rainfall over the source of Five-Mile Creek. However, two local climate stations did not record the high localized rainfall. The debris involved in the debris flow originated from colluvial deposits on the eastern and western slopes of the Five-Mile Creek valley. No large rock mass failure was identified as possible trigger mechanism for the Five-Mile Creek debris flow. This study shows that other creeks in the vicinity of Banff are also loaded with colluvium and thus represent potential hazards for debris flows.

1.0 INTRODUCTION

A team from the Geological Survey of Canada investigated the debris flow that blocked the Trans-Canada Highway (#1) for 24 hours near Banff at the beginning of August 1999. This report describes the source area, debris flow path and the depositional area of the debris flow and the impacts on the transportation corridor. It also provides recommendations for further studies.

The site of the debris flow is located in the Bow River valley 5 km west of the Banff townsite in Banff National Park, Alberta (Figure 1.1). Banff is located near the eastern entrance of Banff National Park, the oldest National Park and one of the most visited with over 4.7 million visitors each year. The Bow River Valley is an important transportation corridor through the Canadian Rocky Mountains, containing the 4-lane Trans-Canada Highway (#1), the Bow Valley Parkway (#1A), and the Canadian Pacific Railway (CPR). At the debris flow site, both the Trans-Canada Highway and the CPR traverse a large debris fan, built at the outlet of the Five-Mile Creek.

At 6:45 pm on Wednesday August 4th, 1999, a substantial torrent of water, mud, boulders and trees buried all four lanes of the Trans-Canada Highway about 5 km west of main exit to Banff, Alberta (Figure 1.1). About 200 m of the highway was covered by debris varying in thickness from 0.5 m on the eastbound lanes to 2 m oon the westbound lanes (Figure 1.2a & b). Debris was carried by an exceptional high flow in Five-Mile Creek triggered by a severe rainfall. A 4-meter diameter culvert beneath the highway was rapidly filled by boulders and tree limbs and then the highway was covered by a large amount of mud. Debris traveled more than 3 km from the source area to the highway and then another 250 m where it reached the Canadian Pacific (CP) railway (Figure 1.2c).

The debris flow cut buried optic fiber cables depriving the Lake Louise community of all telephone communication. Thousands of motorists were affected by the closure of the highway by having to take alternative routes or waiting 24 hours for the reopening of the highway. Highway service crews worked for about 3 weeks to clean the highway and adjacent creek bed for normal traffic to resume (Appendix 1). During the first week, road maintenance workers worked on 18-hour shifts schedule, and on 10-hour shifts for the next 2 weeks. Consequences may have been more catastrophic if the debris flow occurred earlier in the day when traffic is heavier. Despite the rapid reopening of this crucial transportation corridor, the debris flow had substantial impacts on tourism and the transportation industries.

2.0 DEBRIS FLOW – DEFINITION AND DESCRIPTION

Various aspects of debris flows have been recognized and studied by a number of authors (Eisbacher 1982; VanDine 1985; Jackson et al. 1987; Pierson & Costa 1987; Benda & Cundy 1990; Podor 1992; Rickenmann 1999). Recently, Coussot & Meunier (1996) proposed a toxanomic and a mechanical description of debris flows, with a distinction between debris flows and other mass movements. Debris flows take the form "...of strongly transient flows, often as almost periodic surges of heavily debris-laden slurry separated by periods of relatively low flow rate or zero flow" (Coussot & Meunier 1996). Thus, a debris flow is a spatially continuous movement in which surfaces of shear are short-lived, closely spread, and usually not preserved (Cruden & Varnes 1996). Debris flow involves a water-debris mixture which, as a first approximation, can be considered as a flow of a viscous fluid (Coussot & Meunier 1996). They are composed of a significant proportion (between 20% to 80%) of coarse material (> 2mm) and the density may exceed that of wet concrete. During movement, the solid fraction within a debris flow varies from 50% to 90% (Coussot & Meunier 1996). As pointed out by Jackson (1987), debris flows signify both a landform and the sedimentary deposits that it creates. Since debris flow materials are very viscous, strongly sheared and mixed during the flow, debris flow deposits are nonsorted (Coussot & Meunier 1996).

The debris flows often occur during torrential runoff flowing exceptional rainfalls. Channelized flows, common in the Rocky Mountains, follow existing channels or creek beds. Rock debris on steep slopes unprotected by vegetation are prone to debris flows (Figure 2.1a). Once initiated, debris may be added to the stream by erosion of banks increasing the power of the flow. Debris flows have the ability to transport large clasts, several meters in diameter, by buoyant forces. Debris flows can travel very long distances (several kilometers) on slopes of <10° (Figure 2.1a) with velocity varying from 0.5 m/s to 10 m/s.

Debris flows usually advance downslope as series of kinematic waves, which overtake one another. This type of movement is probably created by periodic mobilization of material or by bursting of debris dams in the channel. Coarser material may form natural levees, leaving the fines in suspension to move down the channel (VanDine 1996). Levees are due to a decrease in the fluid flow depth from the front to the tail of the surge. In a given cross-section, the lateral parts of the flow are generally shallower that the central part (Figure 2.1b).

Upon leaving the main channel and entering an open valley, debris spreads out on fan-shaped alluvial fans usually largely consisting of deposits from previous debris flow events (Jackson 1987) (Figure 2.1b). In mountainous areas, this type of mass movement is an important mechanism transfering large amounts of sediment from the mountain side to valley bottom over a short period of time. Debris flows are very common through the Canadian Cordillera (Winder 1965; Podor 1982; Desloges & Gardner 1984; Jackson et al. 1987; Jordan 1994; Bovis & Jakob 1999). VanDine (1985) investigated debris flows in the southern Canadian Cordillera and discussed active and passive mitigation methods.

3.0 GENERAL REVIEW

3.1 Documents reviewed

The following information was reviewed by the authors for this study:

- 1: 50,000 scale National Topographic System (NTS) map, Banff 82-0/4, Edition 3, 1996.
- 1: 100,000 scale topographic and recreation map, Banff and Mount Assiniboine, Gem Trek Publishing, 1998.
- 1: 35,000 scale topographic and recreation map, Banff Up-Close, Gem Trek Publishing, 1997.

- 1: 100,00 scale topographic map, Warden Office, GIS sector, Banff National Park, 1999.
- 1: 50,000 scale Geology map and diagrammatic structure sections, Banff (East half), #1294A, by R.A. Price & E. Mountjoy, 1972.
- 1: 50,000 scale Surficial geology map, Banff area (sheet 2), #1324A, Geological Survey of Canada, 1972.
- 1: 125,000 scale Relative ages of surficial deposits, Banff area, #1325A, Geological Survey of Canada, 1972.

Air photos were also examined for this study (Appendix 2). Exceptionally good live images of the debris flow event were recorded by a CBC TV crew during the flow event (CBC 1999). The images show the debris overwhelming the highway and give an excellent idea of the behavior of the flowing mass (Figure 3.1). The GSC has two copies of the live TV report. Excellent photographs were also taken by the Banff National Park authority the day after the debris flow and were graciously given to GSC for its investigation.

3.2 Geomorphological and geological setting

This debris flow site is located in the rugged Front Range of the Canadian Rocky Mountains. Elevations reach 3000 m but are generally less than 2700 m and relief can exceed 1300 m. The mountain slopes are marked by small creeks, avalanche tracks and talus cones. The slopes are predominantly forested below the tree line at 2250 m.

The Front Range is characterized by a series of sedimentary rocks stacked by thrust faults (Price & Mountjoy 1972) (Figure 3.2). West of Banff lies a large syncline (Sawback Range), where the axial surface corresponds to the WSW-ENE alignment of the Bow Valley. The rock formations in the vicinity of Five-Mile Creek are wedged between two major NNW-SSE thrust faults: the Sawback and Bourgeau thrust faults (Figures 3.2 and 3.4). Secondary reversed faults parallel to the major thrust faults and undefined faults mostly perpendicular to the thrust faults also affect the sedimentary layers.

In the vicinity of Five-Mile Creek, the geology is characterized by Paleozoic formations of Middle Cambrian to Mississippian age (Figures 3.2 & 3.3), dominantly shale, mudstone, dolomite, limestone, and sandstone (e.g. Cairn, Survey Peak, Bison Creek and Mistaya formations). The ridge east of Five-Mile Creek is formed by thickly bedded to massive Devonian dolomite (Palliser, Alexo and Southesk formations), while the western ridge is composed of upper to middle Cambrian massive limestone and interbedded shale limestone (Eldon, Pika and Lyell Formations). On the eastern flank of Five-Mile Creek valley, and also east of Sawback Thrust Fault (STF), the bedding is steeply dipping east (Figure 3.4). West of STF, the sedimentary layers are steeply dipping west.

3.3 Surficial geology

The regional surficial geology in the vicinity of Five-Mile Creek is illustrated on Figure 3.5. Most of the Bow Valley is mapped as postglacial floodplain deposits (alluvium) varying from gravel to clay (16 on Figure 3.5). In places the floodplain deposits are covered by fans composed of alluvium and debris flow deposits. On both sides of the Bow Valley, the slopes are covered by till (gravel, sand and silt) related to the Canmore glacier advance (Rutter 1972). However, till was not mapped in the vicinity of Five-Mile Creek. Before it reaches the Bow River, Five-Mile Creek crosses through fan deposits (15 on Figure 3.5), while on the eastern margin of the fan, talus deposits (12 on Figure 3.5) from local rockfalls overlap the alluvial deposits.

3.4 Review of aerial photographs (1947 to 1999)

The following is a summary of observations made from air photos flown between 1947 to 1993 and obtained at the National Air Photo Library in Ottawa, as well as an air photo taken about one month after the debris flow event by Foto-Flight based at Calgary. The series of air photos covering Five-Mile Creek can be seen on Figure 3.6, while a series of enlargements of the fan surface is shown on Figure 3.7.

1940's

In the Forties, Five-Mile Creek ran down both on the eastern and western side of the fan (Figures 3.6a and 3.7a). The western arm was the main channel, at that time the Trans-Canada Highway was only 2 lanes. It crossed the fan deposits intersecting the highway and reached the CP track (Figure 3.7a). Both were probably affected by occasional creek surges. The western arm bifurcated into secondary arms near its junction with the road.

1950's

According to a park warden, C. Pacas (personal communication, Banff National Park, the Canadian Pacific Railway installed a small berm at the apex of the fan in the Fifties (encircled in Figure 3.7b), where Five-Mile Creek divided in two arms, forcing the Five-Mile Creek to flow only in the eastern arm. It is the author's understanding that occasional problems to the CP track caused by the creek surges forced the CP authorities to undertake this protective action.

1960's

In the Sixties (Figures 3.6b and 3.7b), the Trans-Canada highway was rebuilt, passing south of the former national road (arrow in Figure 3.7b). By this time, Five-Mile Creek had definitively abandoned the western arm on the fan deposit. Work was undertaken upstream and downstream of the highway to channel Five-Mile Creek through the middle of the fan deposits. A channel had to been grooved on the north side of the CP track leading to a culvert at the eastern side of the sharp bend of the Bow River to facilitate the evacuation of water from the Five-Mile Creek. A small knob of fresh deposits at the outside mouth of the culvert can be seen along the north shore of the Bow River (arrow in Figure 3.7b).

1970's

In the Seventies, the small culvert installed in the Sixties through the CP track foundations seems to have been blocked, since the evacuated deposits did not extend any further in the river (arrow in Figure 3.7d), runoff was going towards the Vermilion Lakes.

1980's

After the mid-Eighties, the highway was twinned to 4 lanes and a 4-meter culvert was installed to facilitate the flow of Five-Mile Creek (Figure 3.7f). Further cleaning and grooving were done in the creek bed upstream and downstream of the highway (arrows in Figure 3.7f). Again. This is no evidence that the western arm of Five-Mile Creek was active.

1990's

During the Nineties, Canadian Pacific railway installed two small culverts, west of the culvert installed in the Sixties, to allow water to reach the Bow River while reducing the pore water pressures within the track foundations (C.Pacas, personal communication). It should also be noted that through the last fifty years the Five-Mile Creek does not seem to take a well-defined channel downstream of the highway, except for the human-worked section (Figures 3.7a to 3.7f).

Through the years, the source area and Five-Mile Creek valley do not show any major changes in its morphology (Figures 3.6a to 3.6e). No failure surface is observed along the valley, in the source area, or either side of the valley. Numerous tributary streams feeding Five-Mile Creek also show no change in its path direction, shape and emplacement.

4.0 FIELD INVESTIGATION

4.1 Summary of activities

Table 4.1 gives the detailed schedule of the investigation. The members of the GSC party were Dr. Réjean Couture, Ms. Dana Ayotte (UBC Ph.D. student) and Mr. Matthew Evans (GSC volunteer) under the supervision of Dr. Steve Evans.

A short field reconnaissance was conducted on August 18, 1999 on the section of Five-Mile Creek from Highway #1 to the Bow River, and from the highway to a small wooden bridge about 300 m upstream (green dashed line on Figure 4.1 & Figure 4.2). The same day, the GSC party met Mr. Bruce Porteous (Road Maintenance Supervisor) and Mr. Douglas Kerr (Area Manager), both from the Highway Service Center of East Banff/Kootenay Area, who provided details on the debris flow and the highway cleaning process. A helicopter reconnaissance was conducted on August 19, 1999 over Five-Mile Creek from the source area of the debris flow to the Bow River valley, and over the Spray River valley. About 1.7 hour plus ferry time from Golden was spent on this helicopter reconnaissance, during which the weather was clear and warm. On August 20, 1999. The party took the Cory Pass trail up to the source area (black dashed line on Figure 4.1 & Figure 4.3), and then descended along the debris flow path. About 8 hours were spent on the August 20 ground traverse.

During the investigation, samples of debris were taken along the flow path from the source area down to the CP railway track to obtain the particle size distribution of debris (black dots on Figure 4.1 & Figure 4.2, Table 4.2). Width, depth, length, and slope angle along the flow path were also measured at specific sites along the flow path. Several aerial oblique photos and photographs from the ground were taken to complete the field investigation.

Table 4.1 Timetable of activities, Five-Mile Creek debris flow investigation.

Date	Activities	Details	Duration
August 18, 1999 **am**	Meeting with	Highway Maintenance Service B. Porteous (Supervisor) D. Kerr (manager)	3 hrs
pm	Field work	Reconnaissance from CP track up to small bridge	4.5 hrs
August 19, 1999 **am**	Meeting	C. Pacas, Banff National Park Warden	3 hrs
pm	Field work	Helicopter reconnaissance	1.7 hrs
August 20, 1999 **am**	Field work	Source area through the Cory Pass trail & flow path descending	3 hrs
pm	Field work	Source area through the Cory Pass trail & flow path descending	5 hrs

Meetings were scheduled with Park Warden Charlie Pacas on August 19 and 20, 1999 where information was exchanged including the need to initiate collaboration concerning risk assessment along the transportation corridor through Banff National Park.

Table 4.2 List of samples taken at Five-Mile Creek debris flow

No	Details	Location	Elevation (Altimeter readings)
1	Alluvial deposits on east slope of Five-Mile Creek	N51°11.7' W115° 39.7'	2100 m
2	Alluvial deposits on east bank of Five-Mile Creek	N51° 11.4' W115° 39.6'	1715 m
3	Clayey silt lining creek bed	N51° 10.7' W115° 39.5'	1570 m
4	Debris flow deposits in a forested area east of the channel, 10 m south of the Trans-Canada highway	N51° 10.5' W115° 39.2'	1423 m
5	Debris flow deposits sampled beside the CPR track	N51° 10.3' W115° 38.8'	1420 m

4.2 Observations on the debris flow

4.2.1 Introduction

The Five-Mile Creek debris flow was triggered by intense rainfall several hours before the event. According to Banff Park authorities, a localized, high intensity, thunderstorm restricted rainfall to the ranges about 10 km north-west of Banff including Mount Cory and Mount Edith (Figures 1.1 and 4.2). The nearest climate stations to Five-Mile Creek, Banff and Lake Louise (Figure 1.1) did not record high rainfall just before the debris flow event. The Banff climate station (elevation 1397 m) is located about 10 km east of Five-Mile Creek, while the Lake Louise climate station (elevation 1524 m) is about 45 km north-west of the debris flow site. Daily rainfall data recorded at the Banff climate station for June to August 1999 show small rainfall for the 3 first days of August, but does not record the high rainfall event that occurred in the source area of Five-Mile Creek (Figure 4.1). The Lake Louise station however did record high rainfall 48 hours before the Five-Mile Creek debris flow. In July, the total monthly precipitation at the Banff station exceeded twice the average monthly normal precipitation recorded for the period 1887-1990 (Table 4.4). This suggests that the unconsolidated deposits on nearby mountain slopes would be saturated when the thunderstorm event triggered the debris flow.

Some debris, essentially mud and water, reached the Canadian Pacific Railway (CPR) but without any damage to the track (Figure 1.2c). The mud just spread out through the forested area; once a small culvert was reopened, the mud went down into the river. According to Highway Service workers, about 15,000 m^3 of debris were removed from Five-Mile Creek downstream of the highway. In total, about 50,000 m^3 of debris were removed, including the material covering the highway. According to Banff National Park wardens, this was the first time that a debris flow affected Five-Mile Creek. The 4-meter culvert had been blocked once in the past, four or five years ago (D. Kerr, personal communication). It is our understanding that the Five-Mile Creek area was not a problematic sector in the past.

Table 4.3 Location of Banff and Lake Louise climate stations.

	Location	**Elevation**
Banff	N 51° 11' / W° 115 34'	1397 m
Lake Louise	N 51° 26' / W 116° 12'	1524 m

Table 4.4 Comparison between 1999 monthly precipitation and average monthly normal precipitation during the period 1887-1990 for the months of June, July and August recorded at the Banff (Source: Environment Canada, 1999).

	June	**July**	**August**
1999 Precipitation	28.8 mm	126.8 mm	64.6 mm
Average Normal Precipitation (1887-1990)	57.5 mm	60 mm	51.2 mm

4.2.2 Source area

The source area is largely comprised of colluvium-covered slopes above tree line, as well as gullies and the creek bed, where material is effectively ereoded. The source area extends to Mount Cory in the west and to Mount Edith in the east (Figure 4.2).

Our investigation showed no evidence of major rock failures in the source area of the debris flow, other than a few minor fresh rock failure surfaces on the east and west slopes of the Five-Mile Creek source area.

Morphometric details of the 4.5 km^2 drainage basin as defined in Figure 4.2 are given in Appendix 3. Several streams have carved gullies into the colluvium and bedrock outcrop on both sides of Five-Mile Creek valley (Figure 4.2 & Figure 4.9a). Four main streams in the source area are numbered in Figure 4.2. Adjacent small gullies are indicated by arrows in Figure 4.2. Surface runoff brought a large amount of unconsolidated material to the main stream of Five-Mile Creek.

Ten gullies can be traced on the western flank of Mount Edith which would have provided a significant source of water and debris to the main stream of Five-Mile Creek (Figure 4.2). Except for one stream, other gullies are relatively small, averaging about 1.5 m deep and 3 to 4 m wide (Figure 4.4). The gullies have levees with lateral gradation in particle size gradation evident in the coarser levees (Figure 4.5). Gullies depth is limited by the presence of bedrock. The Figure 4.6 shows the uppermost channelized portion of Five-Mile Creek where most of the material has been eroded. A sample of the matrix of the alluvial deposits, or source material, (sample #1 in Table 4.2) was taken at the elevation 2100 m within this major gully (Figure 4.7). The material is mostly pebbles and gravel with sand and silt (Figure 4.8) (55.6%, 31.8%, 12.3%, and 0.3%, respectively; Table 4.6).

On the eastern flank of Mount Cory, four major tributaries (numbered 1 to 4 from north to south on Figures 4.2 & 4.9), join Five-Mile Creek. The upper part of the eastern flank of Mount Cory is covered by colluvium mostly derivated from the brownish Upper Cambrian formations (Survey Peak, Mistaya, Bison, and Lyell) and the dark gray Middle Cambrian formations (Waterfowl, Arctomys, Pika, and Eldon). It is the authors' understanding that these major tributaries were charged with colluvium when the high rainfall that triggered the debris flow.

Table 4.5 Percentage of each grain size class for samples taken at Five-Mile Creek (see Table 4.2 for location).

No	Gravel (>4.75 mm)	Sand (0.08-4.75 mm)	Silt (0.002-0.08 mm)	Clay (<2μm)
1	55.6%	31.8%	12.3%	0.3%
2	73.1%	18.9%	7.0%	1.0%
3	-	0.2%	61.8%	38.0%
4	42.5%	28.0%	24.5%	6.0%
5	6.1%	42.8%	43.1%	8.0%

Most of the tributaries on the western slope show bare rock at the bed, indicating that any material stored in the gullies had been washed out during the debris flow. However, the upper parts of some major tributaries are still partially charged with colluvium (Figure 4.6).

4.2.3 Five-Mile Creek

The profile of the Five-Mile Creek valley indicates that the slope angle gradually decreases from about 23° in the source area to 3° at the south tip of the fan (Figure 4.10). The creek profile is also broken by steps, circled on Figure 4.10, corresponding to lithological changes and the intersections with major structural lineaments (Figure 3.2).

In its uppermost portion, Five-Mile Creek gully is 3 m deep and 15 to 20 m wide. In descending the valley, the width of this creek varies between 5 m to 30 m. Narrowest sections are due to incisions into bedrock (Figure 4.11). At these locations, the debris flow was about 4 m deep as seen by mud veneer on vertical rock faces.

A second sample of alluvium (sample #2 on Table 4.2), *i.e.*source material, was taken on the east bank of Five-Mile Creek at an elevation of 1715 m (Figures 4.2 and 4.10). The sample consists of gravel, sand, silt and clay at 73.1%, 18.9%, 7.0%, and 1.0%, respectively (Figure 4.8 & Table 4.6). The sample was well cemented by calcium carbonate, probably limited the erodibility of these materials.

Between 1570 m and 1540 m asl, the creek bed is composed of a light to dark gray, stiff, clayey silt. The thickness varies between 0.3 m to >1 m (basal limit not defined). This silt layer provides the water downstream its whitish color. The origin of this silt layer is uncertain, but may relate to a perched glacial lake deposit. Sample material from this site (sample #3, Table 4.2, and Figure 4.8) consisted of 61.8% silt, 0.2% sand, and 38% clay (Table 4.6).

4.2.4 Fan deposits

At the head of the fan deposits, at the elevation 1480 and about 50 m upstream the power line (Figure 4.2), the ca. 1950's berm was partially destroyed by the debris flow (Figure 4.12). This berm was built by the CPR in order to direct the water flow towards the eastern margin of the fan. The berm, which is formed by conglomerate and concrete, is about 1 to 2 m high and 100 m long. A small amount of the debris flow took a former creek bed on the western side of the fan. Most of the coarser debris (boulders and trees) settled few tens meters downstream of the berm. The southernmost part of the former western arm of the creek is composed of mud, sand and gravel.

On both sides of the main creek, the debris flow eroded the creek bed and adjacent creek banks, creating unstable slopes (Figure 4.13). The newly eroded creek banks show failures that occurred during and after the debris flow. A small bridge located in a narrower section of the creek was washed out few meters upstream of the power line, but power line posts were not affected by the debris flow (Figure 14).

The debris, which included blocks, pebbles, and trees, quickly blocked the 4 meter-diameter culvert and overwhelmed the highway. The debris spread laterally for 200 m along the highway. The thickness of the debris flow was clearly recorded by mud on a road sign post (Figure 4.15). The coarser debris was overlain by fine material deposited by flooding creek after the main debris flow event. A 150 meter-long open section of Five-Mile Creek downstream of the highway was completely filled by debris (Figures 1.2a & b) with an average size of about 0.30 m (range 0.10 to 0.50 m). The thickness of the flow varied between 0.30 m to 0.50 m (Figure 4.16). The coarse clasts were generally rounded to sub-angular in shape with matrix comprised of coarse sand with gravel and clayey silt (Figure 4.17). Results of grain size analysis of a sample taken in a forested area about 10 m east of the channel and 10 m south from the highway (sample #4 in Table 4.2), is illustrated on Figure 4.8 and in Table 4.6. The percentage of gravel, sand, silt and clay are 42.5%, 28%, 24.5%, and 6.0% respectively (Table 4.6).

In the southernmost part of the path, the debris flow, at this point composed largely of water and fines, reached the CPR track (Figure 1.2c) but without damaging the railway. The average thickness of debris beside the track is 0.15 m. Debris is largely sandy silt with gravel and organic matter (Figure 4.18 & 4.8). Sand and silt represent over 85% of the material, while the percentage of gravel and clay are 6.1% and 8.0% respectively (Table 4.6). It is also noted that coarser blocks are covered by mud (Figure 4.19). A New Jersey concrete fence was found about 200 m from its original location along the highway (Figure 4.19).

4.2.5 Other observations

A helicopter reconnaissance over other creeks in the vicinity of Banff detected potential locations of future debris flows, and are indicated by blue stars on Figure 1.1. A unnamed creek above the Banff Training Area, about 4 km north-east of Banff (Figure 1.1), is charged with colluvium (Figure 4.20), which could generate a debris flow triggered high rainfall or rapid snow melt.

A helicopter reconnaissance of the Spray River valley examined 2 large debris flows that occurred on July 31, 1998 near the intersection of Goat Creek at the south tip of Sulphur Mountain (green stars on Figure 1.1). The debris flows followed two deeply channelized intermittent streams. The source area for both debris flows was located on the western side of Mount Rundle above the treeline (Figure 4.21 and Figure 4.22a). The debris traveled about 3 km from an altitude of 2500 m down to the valley bottom at 1500 m asl. Debris was deposited along the flow path and on a large fan in the valley bottom. Deposits on the fan are easily recognizable by their contrasting whitish color, apparently without fines (Figure 4.21 & 4.22b). The debris flow blocked the Spray River and impounded a lake upstream (Figure 4.21). A smaller debris flow occurred 1300 meters upstream (Figure 4.22a). Hiking trails were cut by the debris flows and access to a warden cabin was impossible.

4.3 Analysis of the debris flow

Available documents and field observations made made this allow certain remarks to be made regarding the debris flow at Five-Mile Creek.

The bedrock on the eastern slope of the Five-Mile Creek valley dips east into the mountain, while rocks on the western flank of the valley dip west, also into the mountain. As there is no potential of dip-slope failure in the source area, it is not prone to large bedrock failure.

Weathering, freeze-thaw cycles and fracturing of the rock mass has lead to the creation of large amounts of colluvium along the Five-Mile Creek, especially on the western slopes. These deposits are the main source of sediment for the debris flow that fed the Five-Mile Creek through several streams and gullies. Almost all the surface of the source area is underlain by bedrock, resulting in very poor water infiltration and high runoff. The rainfall event on August 4th, 1999 provided an extraordinary amount of runoff, which mobilized colluvium stored on the slopes and was transported down to Five-Mile Creek.

The relatively high flow path gradient (> 16°) in the first 2000 m of Five-Mile Creek bed (Figure 4.10) initiated a high flow velocity in the debris. Narrower sections of the Five-Mile Creek gully (Figure 4.11) helped to maintain the high velocity, and lead to higher levels of erosion. The large amount of fines also allowed the transportation of large blocks and debris.

Based on the thickness and the morphology of debris flow deposits, approximate calculations of volume of removed debris from upstream and downstream portions of the highway, as well as debris removed above the highway, give the following values:

- 15000 m^3 removed from the section downstream the highway
- 21000 m^3 removed from the highway
- 9000 m^3 removed from the first 100m-section upstream the highway

In total, about 45 000 m^3 of material from the debris have been removed in the vicinity of the Highway #1 to rebuilt the landscape and the creek bed in order to rehabilitate a normal flow in the Five-Mile Creek. This calculated volume is compatible to the Highway Maintenance Service's estimated volume, which is 50,000 m^3.

Five-Mile Creek has long been channelized in the vicinity of the Highway #1. The berm that was installed across the west channel in 1950's diverted water through the east channel. Downstream the highway, the creek bed has been channelized for over 150 m, whereas further downstream, the creek goes through a forested area without any well defined creek bed. Most of the water flow goes southeast to Third Vermillion Lake through wetlands. The human actions in increasing the channelization made this debris flow more severe that it would have been otherwise.

Finally, a significant amount of water goes down to the CP track and thus could create higher pore water pressures in the berm, leading to an unstable state. CP should be aware that pore pressure must be reduced to a minimum upstream the berm and culverts ensuring water flow to the Bow River must be kept clean and functional. A decision should be made and action should be undertaken by Banff Park in conjunction with CP to minimize the water flow towards the CP track.

5.0 CONCLUSION

On Wednesday August 4th, 1999, water, mud, boulders and debris of trees buried all four lanes of the Trans-Canada Highway about 5 km west of main exit to Banff, Alberta. Debris traveled more than 3 km from the source area to the Trans-Canada Highway. About 45,000 m^3 of material from debris have been removed in the vicinity of the highway. Material source of debris flow is comprised of colluvium-covered slopes above the tree line, as well as gullies and creek bed, where material is effectively eroded. Although no severe daily rainfall data was recorded at a weather station near Banff, it has been reported that the Five-Mile Creek debris flow was triggered by a localized, high intensity, thunderstorm rainfall. Total monthly precipitation in July 1999 exceeded twice the average monthly precipitation leading to saturation of unconsolidated deposits on the nearby mountain slopes. Most of the tributaries show bare rock at the bed, indicating that any material stored in the gullies had been washed out during the debris flow. Our investigation showed no evidence of large rock failure surfaces in the source area of the debris flow. Grain size distribution of debris matrix showed a decrease of the particle size from the source area to the deposition area. Other debris-loaded creeks are identified in the vicinity of Banff, and Park authorities should pay attention to these potential hazards.

6.0 ACKNOWLEDGEMENTS

The authors would like to acknowledge Ms. Dana Ayotte and Mr. Matthew Evans for their excellent work as field assistants for this project. The authors would like to thank the Banff National Park authorities for their collaboration in this investigation and allowing the GSC party to collect samples within Banff Park. A special thank you to park warden Charlie Pacas who has provided considerable information, maps and photographs to complete this study. The Geological Survey of Canada also thanks personal of East Banff/Kootenay Highway Service Center, especially Mr. Porteous and Mr. Kerr, which gave detailed information on the highway remediation work. This project would have not been possible without the financial support of the Geological Survey of Canada, Transports Canada, and the Climate Change Action Founds. We also would like to thank Canadian Helicopters (Golden base) and Chris Gaunt for their professional services.

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December 17th, 1999

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FIGURES

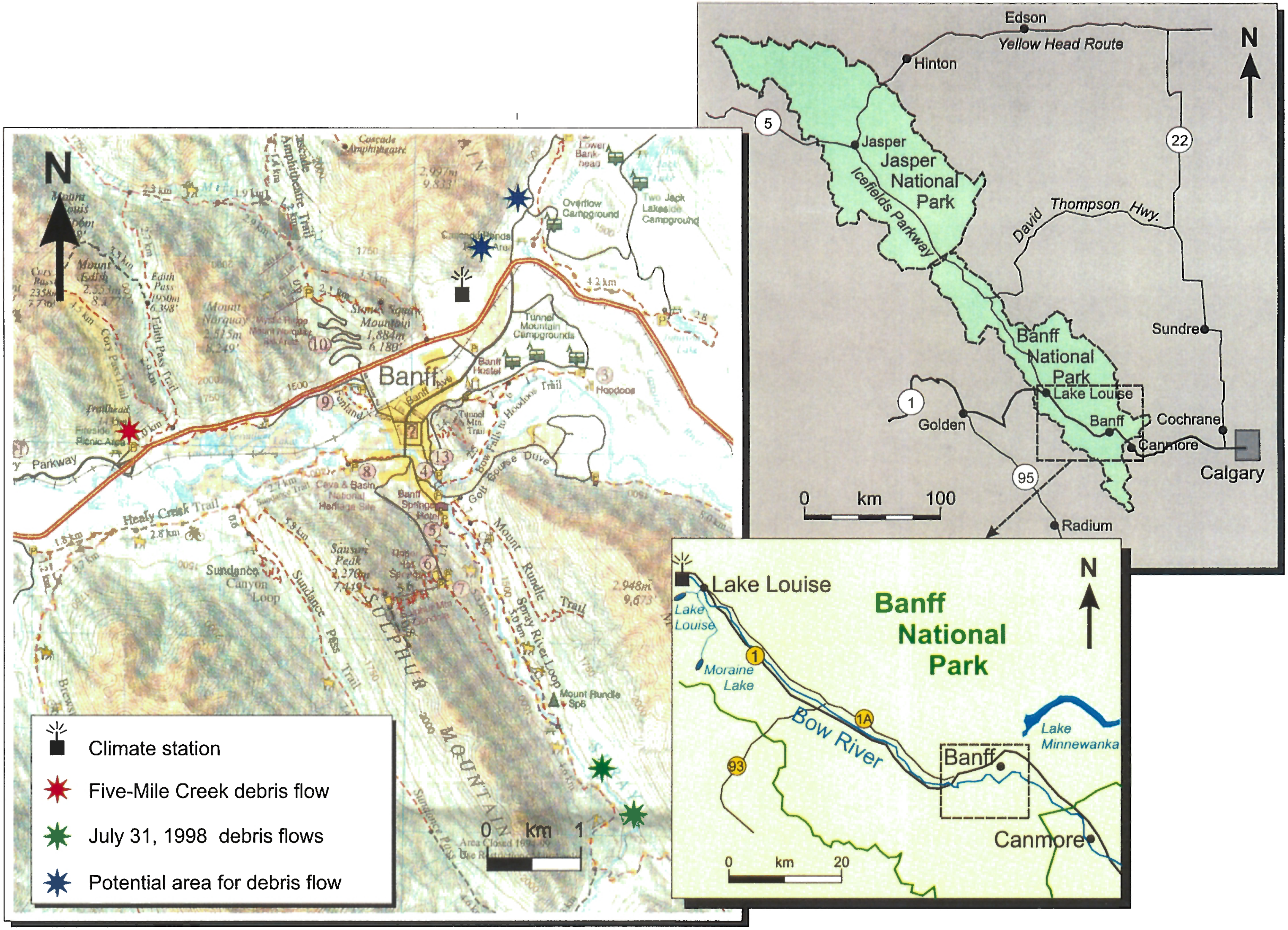
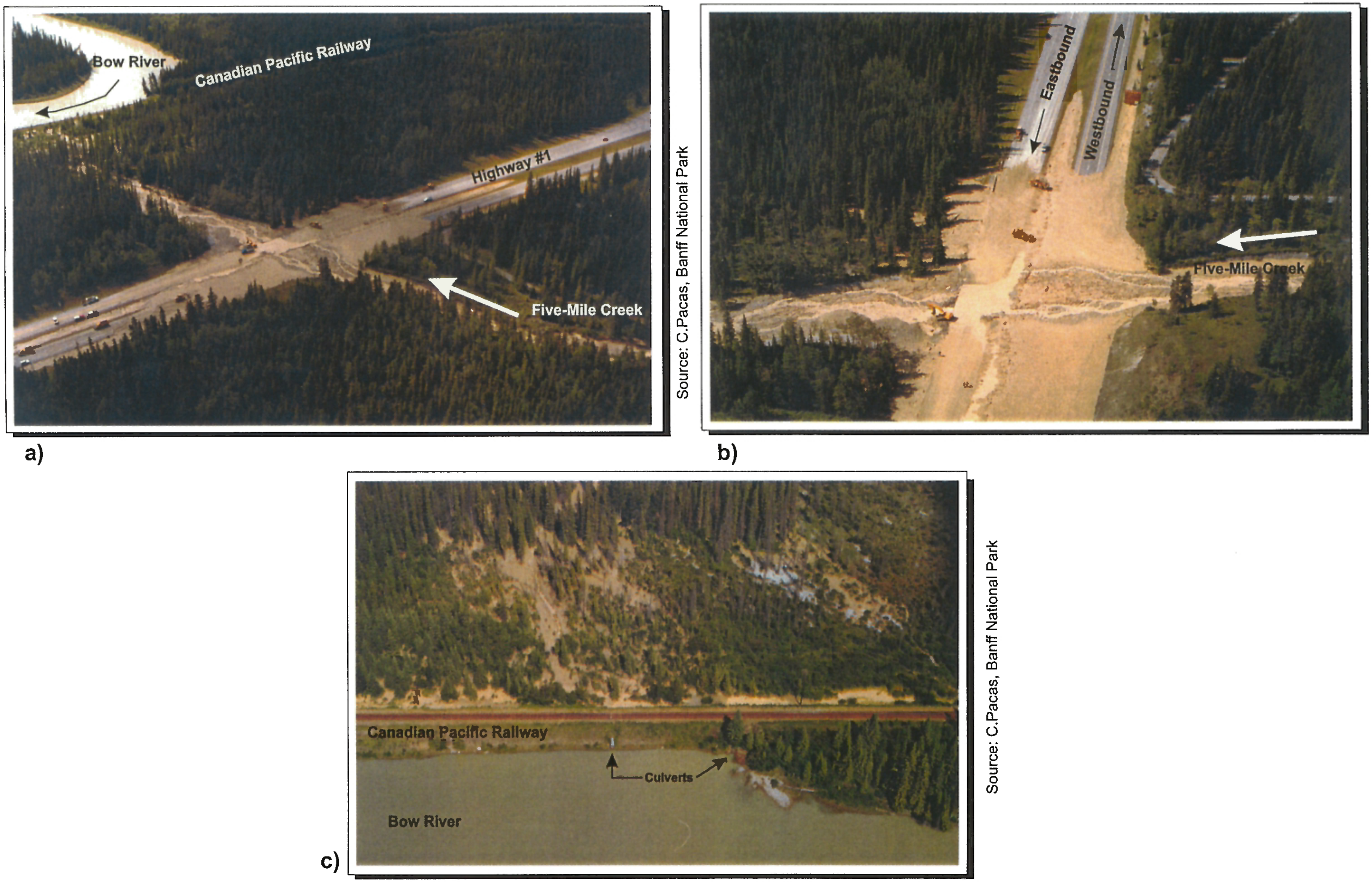


Figure 1.1 Location map of Banff National Park (Alberta) and region. The red star indicates the location of the August 4, 1999 Five-Mile Creek debris flow, green stars the location of July 31,1998 debris flow and blue stars locations of potential future debris flows. (After 1:10,0000 scale topographic and recreation map, Banff and Mount Assiniboine, Gem Trek Publishing, 1998).



Source: C.Pacas, Banff National Park

Source: C.Pacas, Banff National Park

Source: C.Pacas, Banff National Park

Figure 1.2 a) Five-Mile Creek debris flow overwhelming the highway #1, Banff (Alberta).
b) Zoom-in on the debris over the highway, about 0.5 m of debris over the eastbound lanes and about 2 m over the westbound lanes.
c) Mudflow reached the CP track but without any damage, note that the culverts are not working the day after the debris flow event.

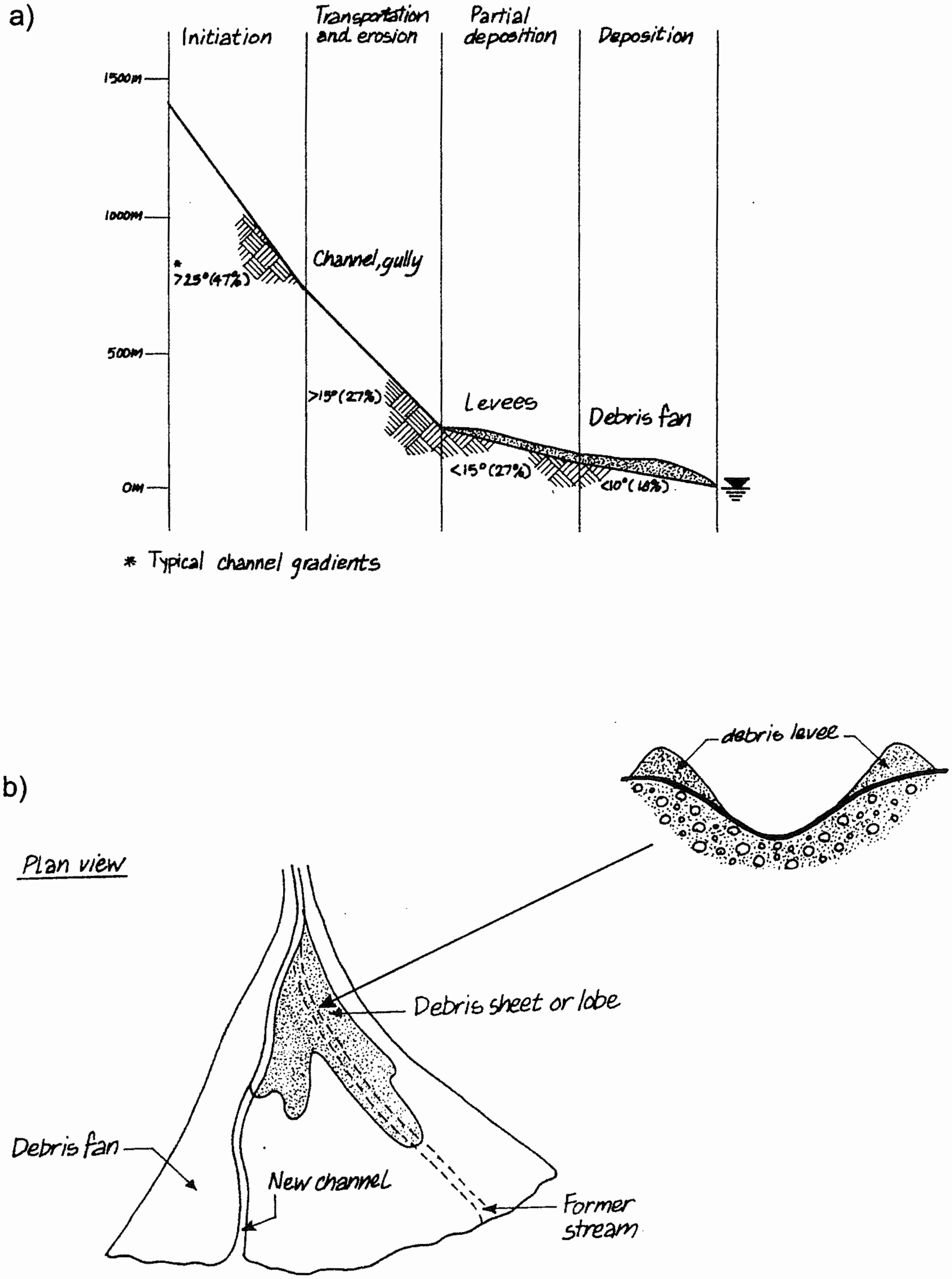


Figure 2.1 a) Zones of channelized debris flow (modified after Vandine 1996).
b) Plan view of form of channelized debris flow deposition (modified after Vandine 1996).

Figure 3.1 Machinery cleaning up the Trans-Canada Highway the day after the debris flow (Source: Calgary Hearld).

Figure 3.2 Air photos of the Five-Mile Creek area , Banff (Alberta) with surperimposed geological boundaries (from Price & Mountjoy 1972). See Figure 3.3 for description of geological units and Figure 3.4 for details on cross section. (Air photo number FF99043-#8, Foto-Flight, Calgary, Alberta).

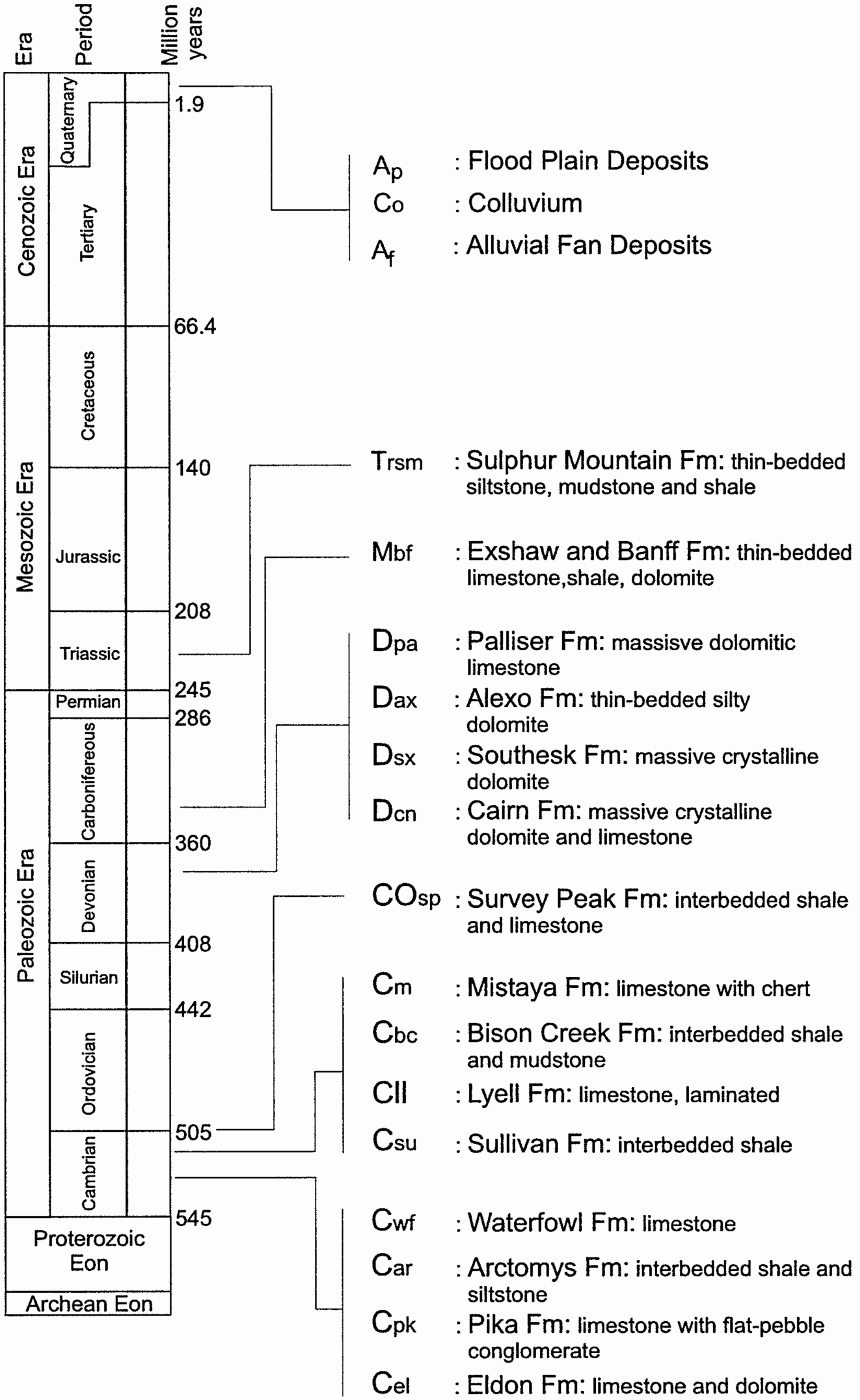


Figure 3.3 Stratigraphic column of rock formations in the vicinity of Five-Mile Creek, Banff National Park.

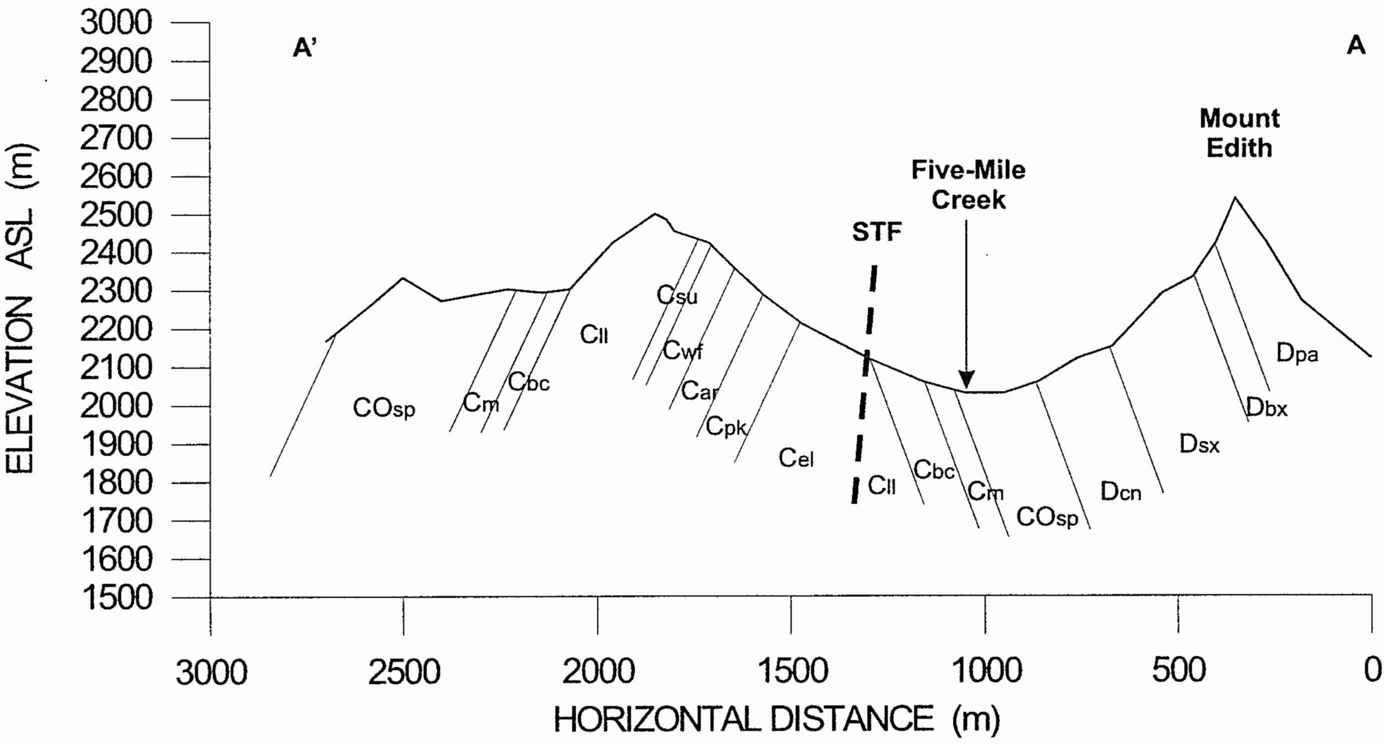


Figure 3.4 Schematic cross section through the upstream area of Five-Mile Creek. STF: Sawback Thrust Fault. See Figure 3.2 for location of cross section and Figure 3.3 for legend (After Price & Mountjoy 1972)..

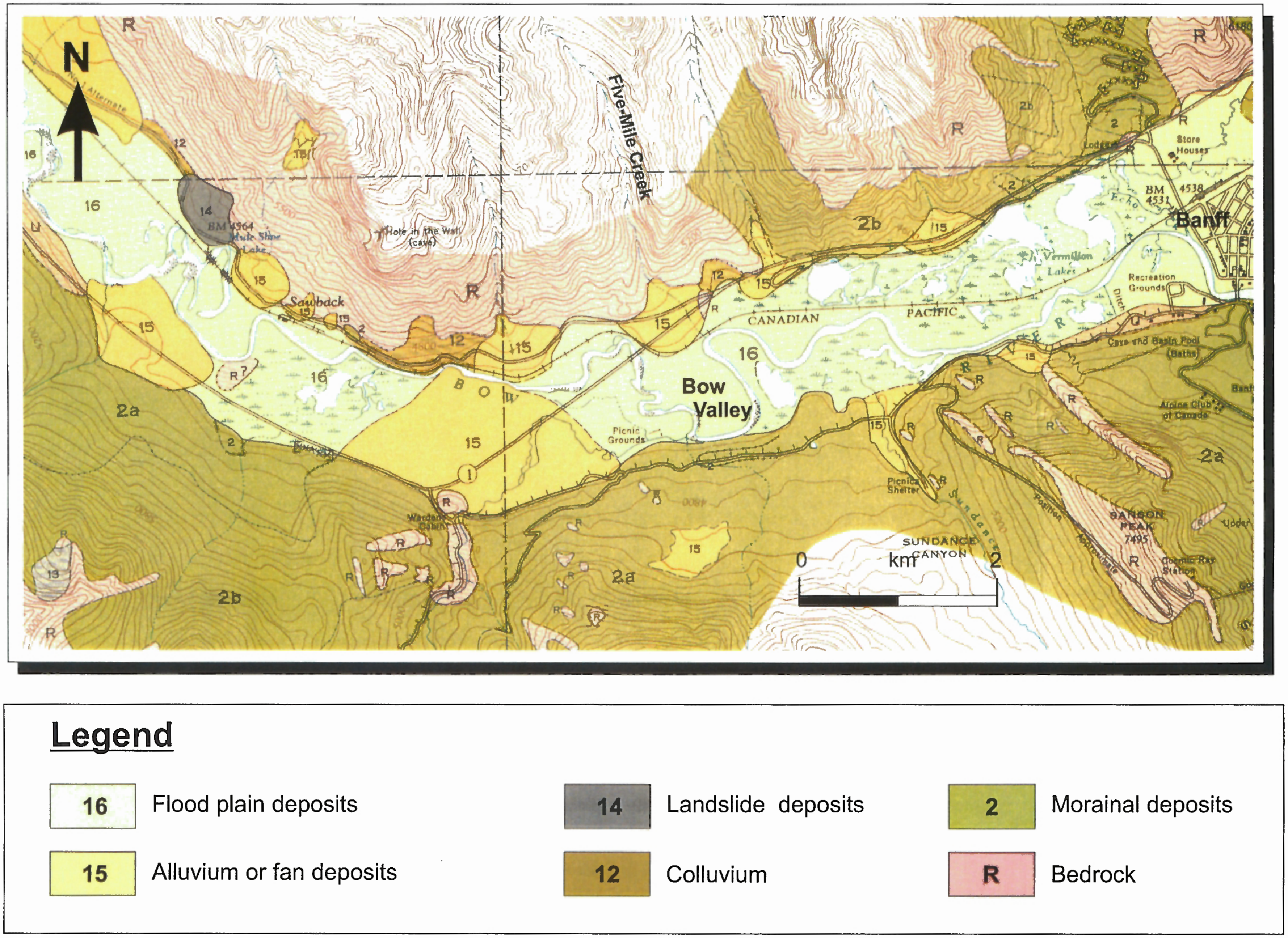


Figure 3.5 Surficial geology in the vicinity of Five-Mile Creek, Banff (Alberta) (After Rutter, 1972).

A10932 - #66, National Air Photo Library

Figure 3.6 Airphotos in the vicinity of Five-Mile Creek, Banff (Alberta): a) 1947

A20157 - #4, National Air Photo Library

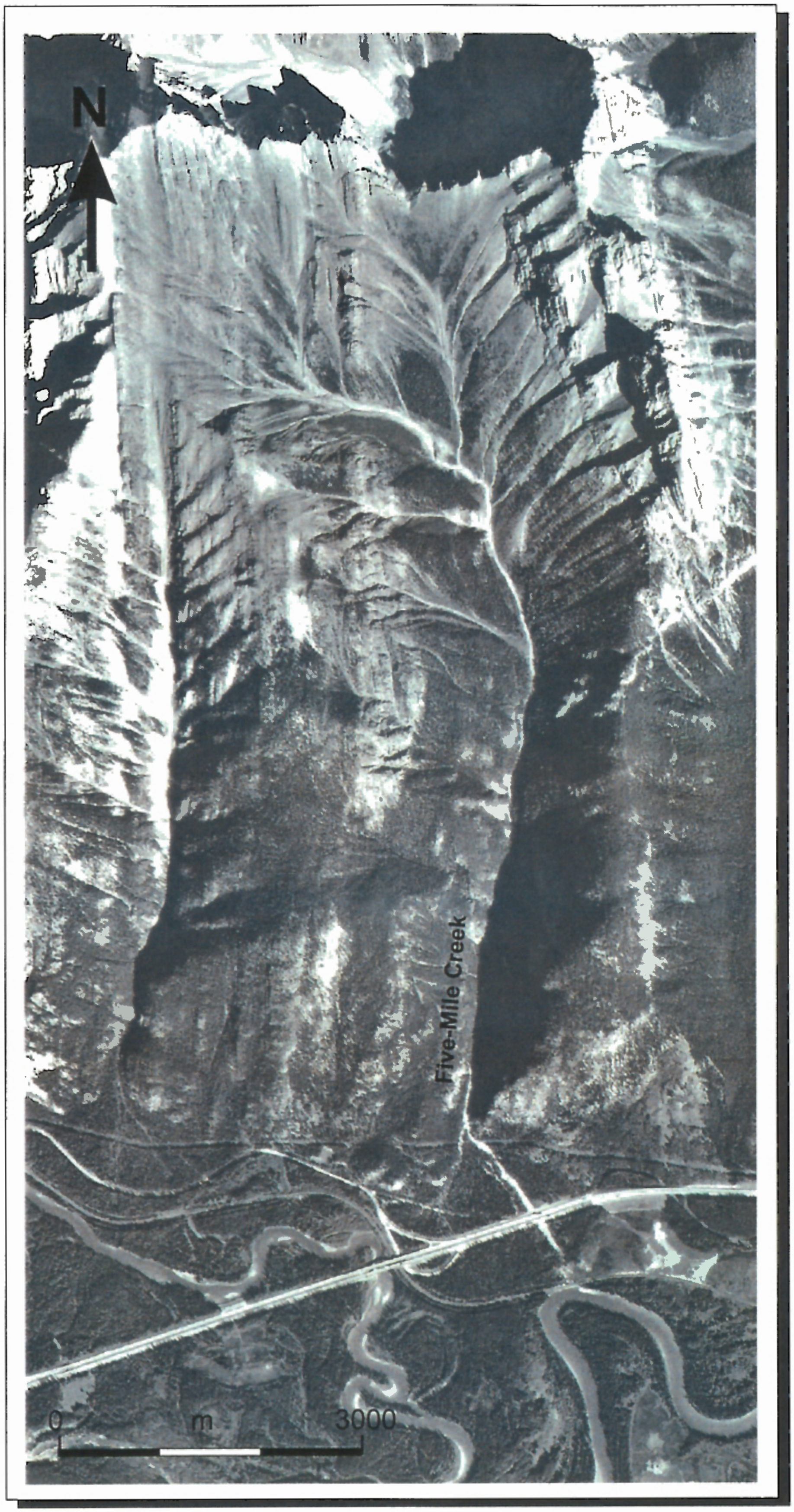
b) 1967

A24776 - #140, National Air Photo Library

C) 1977

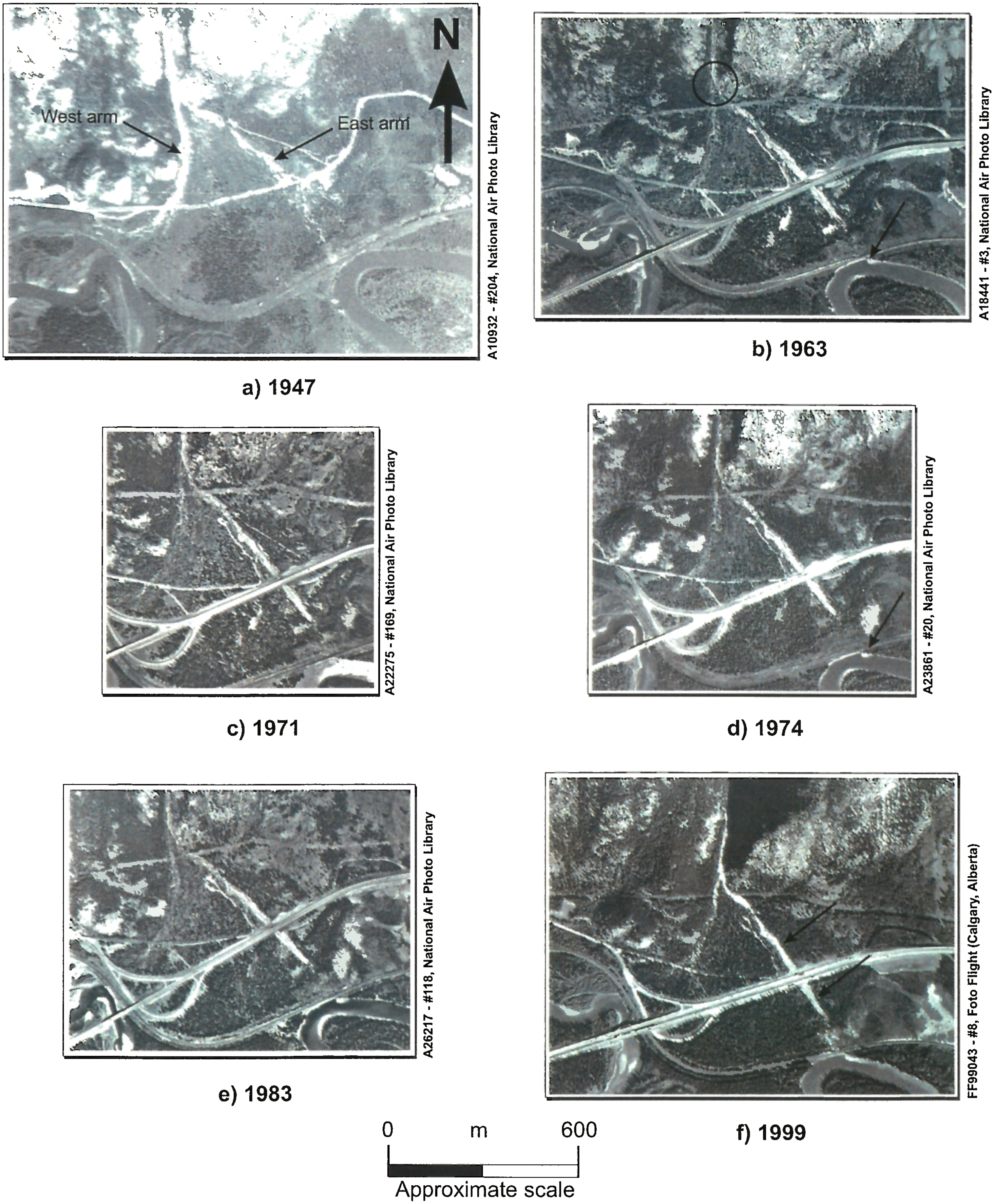
A27998 - #160, National Air Photo Library

d) 1993



FF99043 - #8,Foto Flight (Calgary, Alberta)

e) 1999



A10932 - #204, National Air Photo Library

a) 1947

A18441 - #3, National Air Photo Library

b) 1963

A22275 - #169, National Air Photo Library

c) 1971

A23861 - #20, National Air Photo Library

d) 1974

A26217 - #118, National Air Photo Library

e) 1983

FF99043 - #8, Foto Flight (Calgary, Alberta)

f) 1999

Figure 3.7 Series of aerial photographs of the Five-Mile Creek fan deposits, Banff (Alberta) from 1947 to 1999.Arrows and circle are referred to in the text.

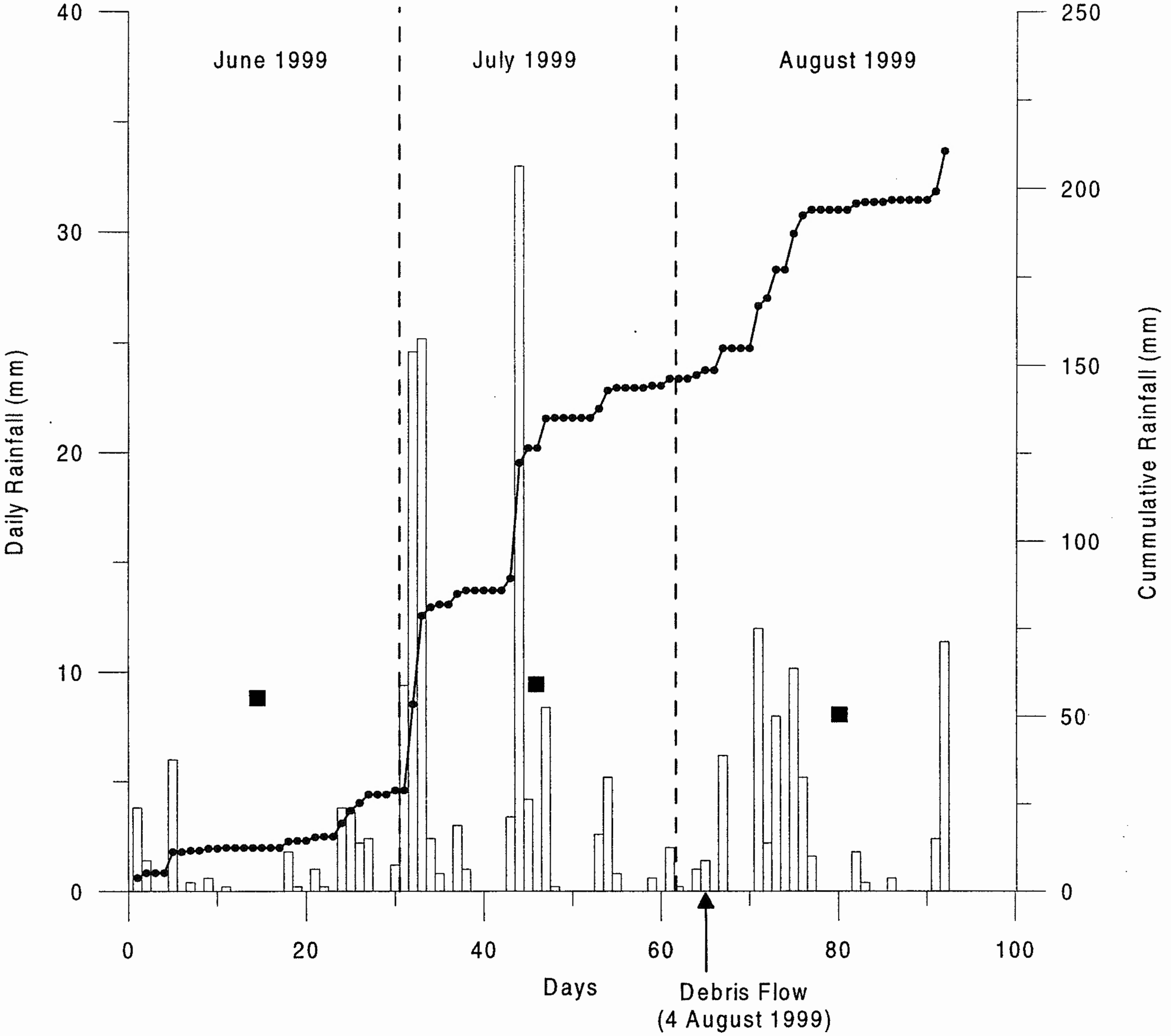


Figure 4.1 Rainfall data for June, July and August 1999 recorded at Banff (Bar chart). Continuous line is the cumulative rainfall for the three months. Day 1 is June 1st, 1999. Black square indicates the monthly average normal precipitation recorded during the period 1887-1990. The Five-Mile Creek debris flow occurred on August 4th, 1999 or on the 65th days on the graph. (Source: Environment Canada).

Figure 4.2 Major features and location of samples at Five-Mile Creek debris flow, Banff National Park, Alberta. (After 1:30,000 air photos No. FF99043 L2, #6-10, Foto-Flight, Calgary, dated 1999/09/08).

Figure 4.3 Location of photographs (•4.11)
(1:30,000 airphotos No. FF99043 L2, #6-10, Foto Flight, Calgary, dated 1999/09/08).

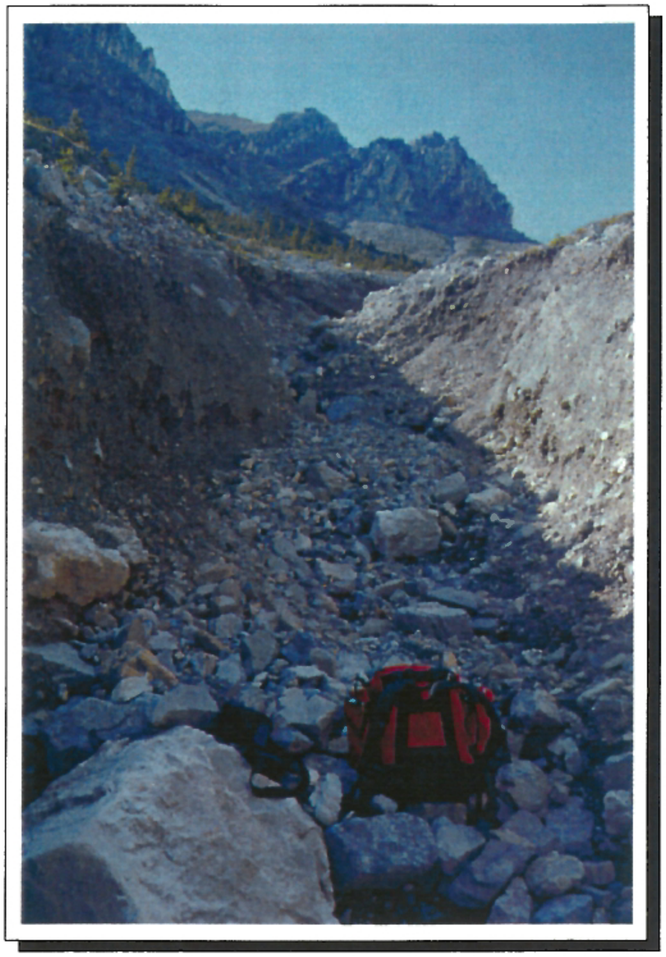


Figure 4.4 View upslope of a gully created by a small tributary at the elevation 2100 m on the western side of Mount Edith.
The gully is about 1.5 m deep and 3 m wide.
A back pack gives the scale.
See Figure 4.3 for location of the photograph.

Figure 4.5 View down slope of one of the small tributaries located at the elevation 2130 m on the eastern side of the Five-mile Creek valley and showing levees. Particle size decreases from outer to inner sides of the gully. The gully is 0.5 m deep and 1 m wide.
The depth of the gully is limited by the bedrock. See Figure 4.3 for location of the the photograph.

Figure 4.6 View upslope of a large gully that intersects the Five-Mile Creek at elevation 1975 m on the eastern side of the Five-Mile Creek valley . This gully is about 3 m deep and 5 m wide, and in which the material has been eroded and transported, as shown by levees, and where a small amount of material remains in place. A person gives the scale. See Figure 4.3 for exact location of the photograph.

Figure 4.7 Close-up of the colluvial material eroded during the debris flow by a tributary on the eastern slope of the Five-Mile Creek valley.
Sample #1 was taken in this deposit at elevation 2100 m. The material is mostly pebble, gravel, with sand and silt. See Figure 4.3 for location of the photograph. A field book gives the scale.

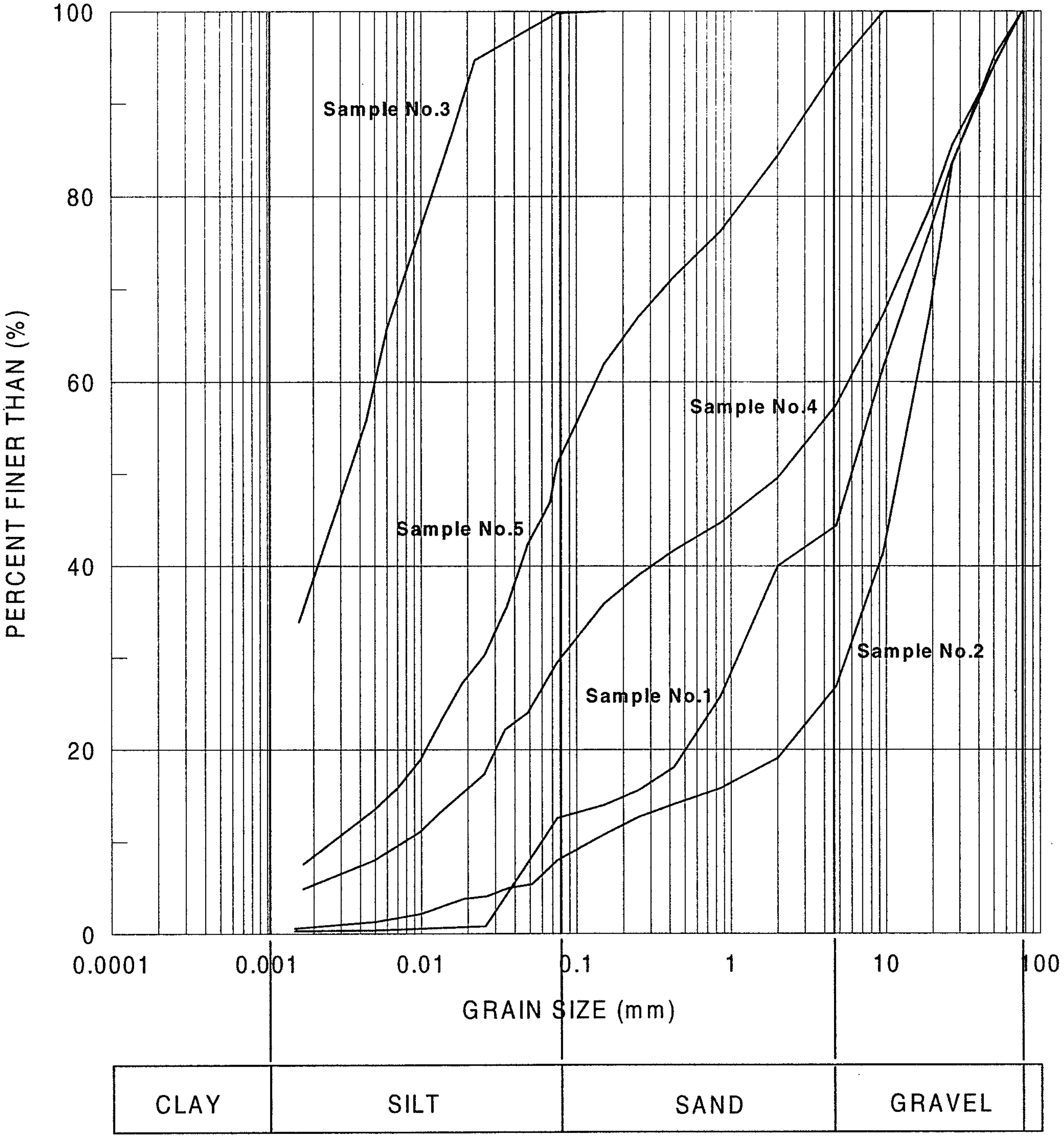


Figure 4.8 Particle size distribution for materials sampled at Five-Mile Creek debris flow, Banff National Park (Alberta). See Table 4.2 for more details on these samples.

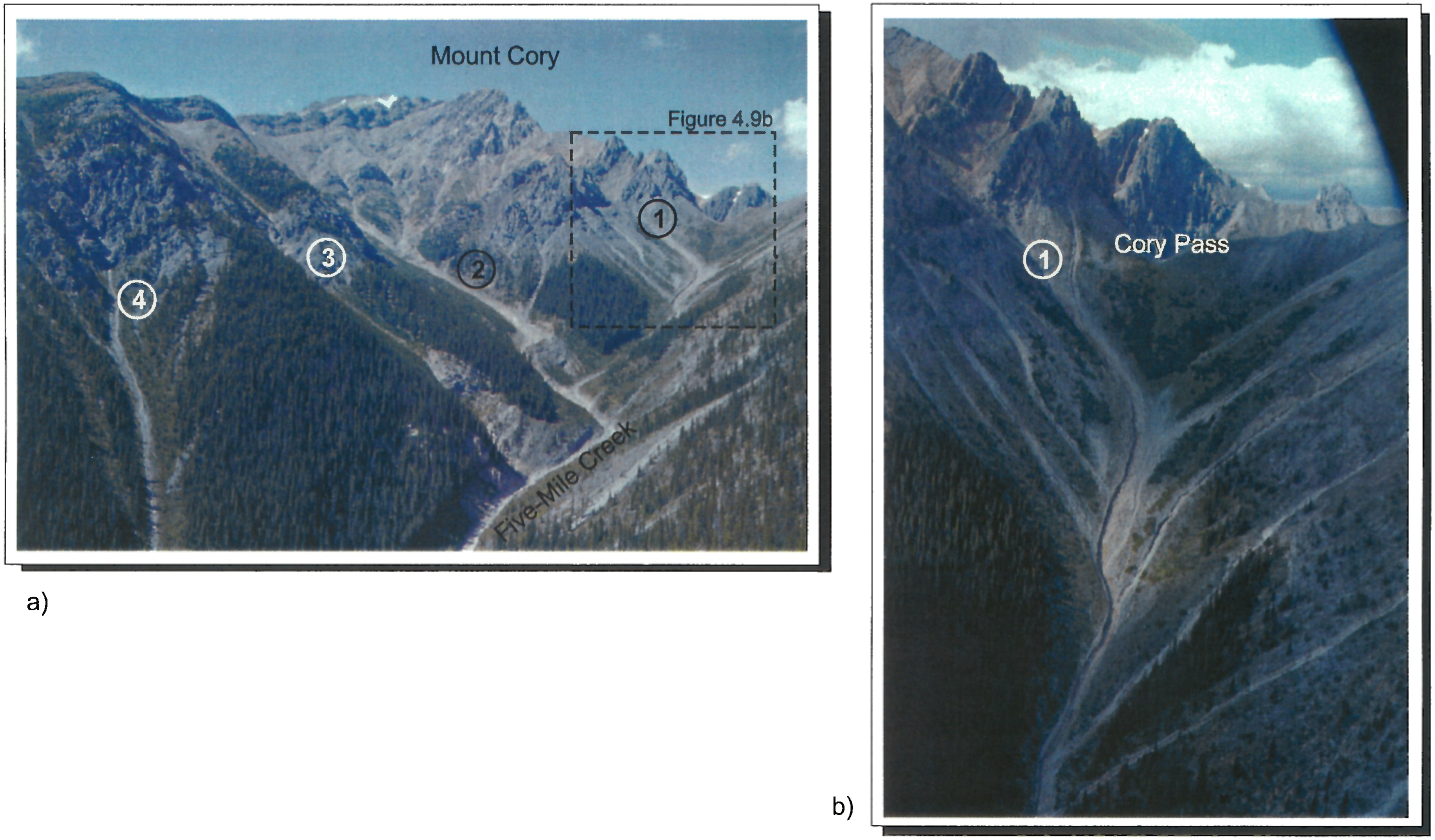


Figure 4.9 a) Oblique aerial view of the western slope of Five-Mile Creek valley showing four major tributaries. Note that the upper slope is mainly bedrock. See Figure 4.2 for location of numbered major tributaries.
b) Close-up on the upstream section of Five-Mile Creek. Note that some of the tributaries on the eastern slope of the valley are well grooved (right-hand side of the photograph). Cory Pass is in the background.

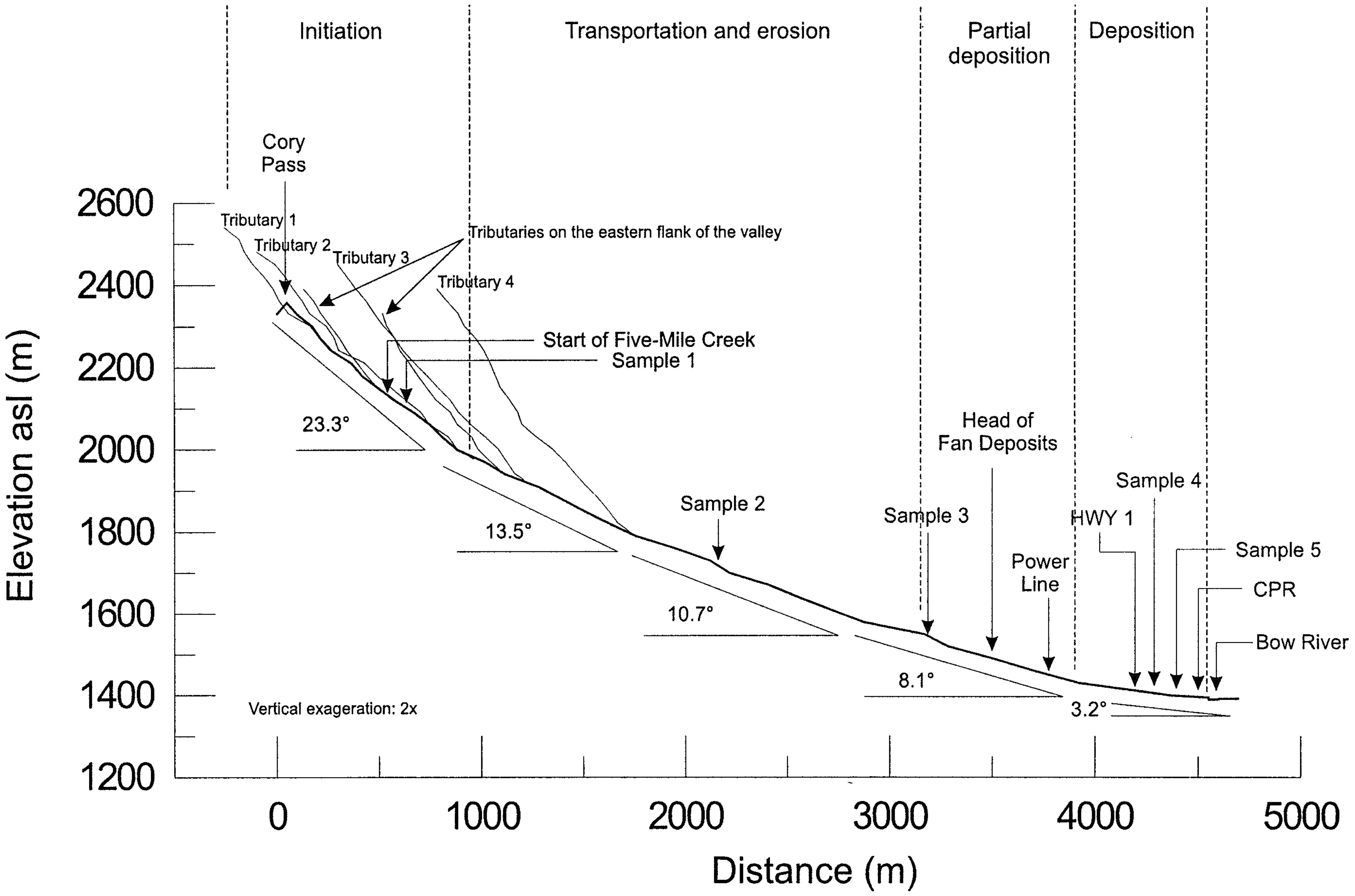


Figure 4.10 Profile of Five-Mile Creek valley from Cory Pass to Bow River. Circles indicate changes in topographic profile associated with changes in geological units.

Figure 4.11 View upslope of a narrow section in the Five-Mile Creek bed due to incision into the bedrock at elevation 1725 m (see Figure 4.3 for location of the photograph). Fluvial material has beenremoved by the debris flow. Distance between rock walls is about 4 m.

Figure 4.12 A section of a berm installed by Canadian Pacific Railway in the Fifties to deviate water flow through the middle of the fan. The berm was partially destroyed by the 1999 debris flow. Note the accumulation of wooden debris beside the berm. The berm is formed by man-made cemented pebbles and rounded boulders smaller than 30 cm. The berm was about 1 m high and 100 m long. A person gives the scale. See Figure 4.3 for location of the photograph.

Figure 4.13 View downstream of the Five-Mile Creek section showing the first 150 m upstream from the Trans Canada Highway partially cleaned by machinery about three weeks after the event. Debris flow has eroded material that was in the creek bed and on the banks, and thus created unstable subvertical slopes as shown by arrow. The photograph was taken at an elevation of 1430 m (see Figure 4.3 for location of the photograph).

Figure 4.14 The photograph shows a temporary wooden bridge installed over the Five-Mile Creek for hikers. The debris flow undermined the creek bed and completely destroyed the former bridge. Debris flow deposits can be seen on background and foreground.

Figure 4.15 The debris flow overwhelmed the four-lane Trans Canada Highway. Three weeks after the debris flow all the debris was removed from the highway. Mud on a sign post indicates how thick the debris cover was over the highway, (about 30 cm, as pointed by the arrow). See Figure 4.3 for location of the photograph.

Figure 4.16 The debris flow went through a forested area downstream the highway. Debris shows an average size about 0.30 m, ranging between 0.10 to 0.50 m, with an average thickness varying between 0.30 to 0.50 m. Trees are about 20 to 30 cm in diameter. See Figure 4.3 for location of the photograph.

Figure 4.17 Photograph of debris sampled (sample #4) downstream the Trans-Canada Highway. The shape of coarse blocks is sub-angular. The matrix, which corresponds to 25% to 30% of debris, is coarse sand with gravel and clayey silt. The field book gives the scale. See Figure 4.3 for location of the photograph.

Figure 4.18 Photograph showing debris deposited beside the CP track. The average thickness of debris is 0.15 m, but can be thicker at some locations. Debris is essentially silty clay with gravel and organic matter. The field book gives the scale. See Figure 4.3 for location of the photograph.

Figure 4.19 Photograph showing a section of a New Jersey concrete fence transported 200 m by the debris flow from its original location along the Trans-Canada Highway. Notice that coarser blocks are entirely covered by mud or fines (sample #5). See Figure 4.8 for grain size distribution. Figures 4.2 and 4.3 give respectively the location of the sample and the location of photograph.

Figure 4.20 Example of potential site for debris flow located about 4 km north-east of Banff. The section above the cliff is charged with colluvium, and the creek itself, downstream the cliff, is also charged with debris. The road could easily be blocked or damaged by a debris flow. This site is indicated by a blue star on Figure 1.1.

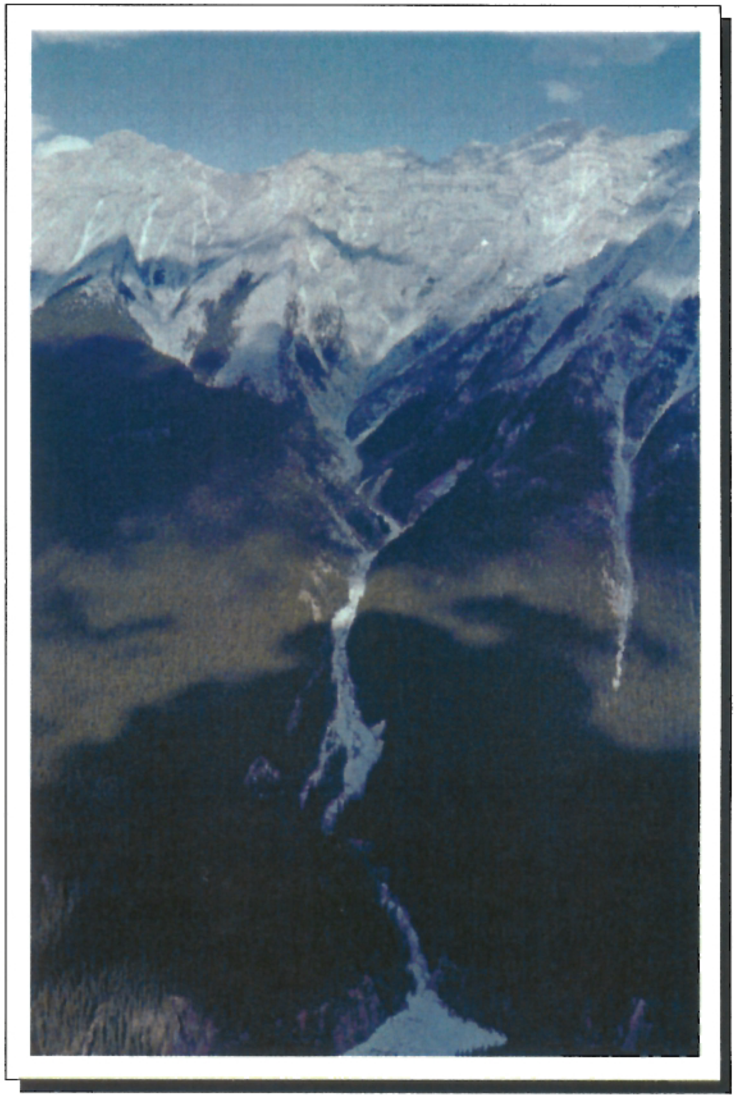


Figure 4.21 Oblique aerial view of the one of the two debris flows that occurred on July 31st, 1998 in the Spray River valley. Note the large fan deposit that blocked the Spray River and impounding a lake upstream. This site is identified by a green star on Figure 1.1.

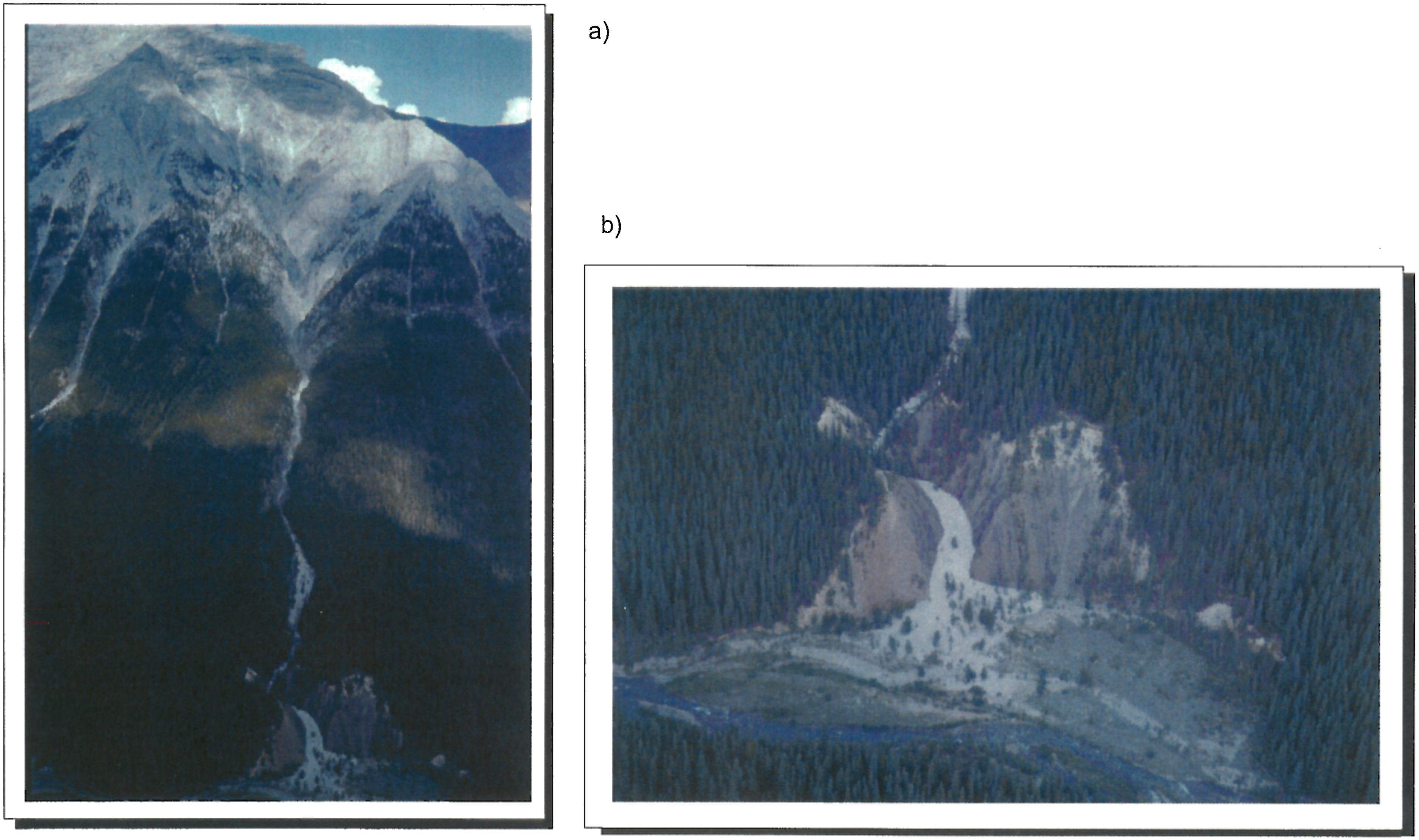


Figure 4.22 a) Oblique view of the second debris flow that occurred on July 31st, 1998 in the Spray River valley. This debris flow is located about 1300 m upstream the debris flow shown on Figure 4.21.
b) Close-up on the fan deposit, which is mostly formed by very coarse particles. The volume of the fan deposit appears to be smaller than the debris flow located 1300 m downstream (see Figure 4.21).

Appendix 1

Article in the
Globe and Mail,
Friday, August 6, 1999

and

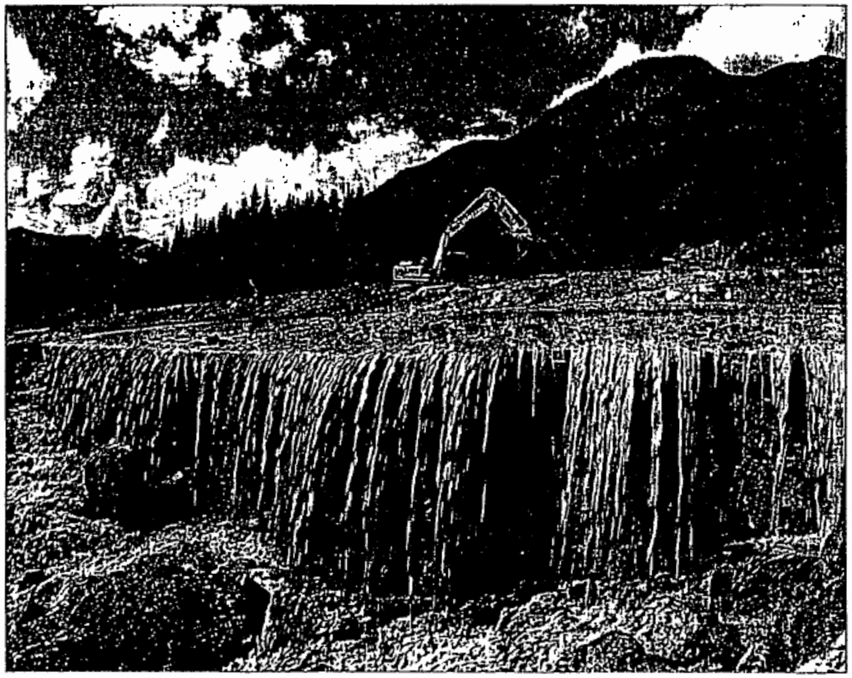
Photograph of the debris flow published in the
National Post,
Friday, August 6, 1999

CANADA

WORD: WHALE SOUNDS

of whales from the wild, picked up by a listening
waters of B.C.'s Johnstone Strait and broadcast on
M (ORCAO FM), are being converted into digital for-
to promote increased understanding of wild killer
se habitats are being threatened. The Vancouver Aquarium, along with several other corporations and environmental groups, is sponsoring the project — but this is not their first foray into whale awareness. For several years the groups have been holding sleepovers with the whales inside the aquarium. It is hard to get much closer to whales than curling up with a sleeping bag and a flashlight while they play in their tanks behind the glass in front of you. *Christopher Michael, National Post*

Mudslide makes highway driving impossible



CHRIS WOOD / CALGARY HERALD

Road crews were busy cleaning up a mudslide that closed a portion of the Trans-Canada Highway eight kilometres west of Banff yesterday morning. A track hoe was clearing a path to drain some water and reopen a blocked drain pipe under the highway.

THE GLOBE AND MAIL • FRIDAY, AUGUST 6, 1999

ALBERTA: Mudslides cause traffic chaos, close highway

BANFF. Thousands of motorists turned away by mudslides that closed a portion of the Trans-Canada Highway took alternative routes yesterday or simply waited out the sunny day by sightseeing in the Rocky Mountains.

A wall of brown mud laden with tree limbs and boulders tumbled down a mountain at 6:45 p.m. Wednesday, covering about 100 metres of highway and washing out all four lanes just west of Banff. By 4 p.m. yesterday, crews had managed to open one lane each way. It will take two days to a week for normal traffic to resume.

Officials said severe rain and an already-swollen creek caused the mud to cascade. "We're very lucky no one was hurt," said Bill Leonard, executive service manager of Banff National Park. "If it had happened earlier in the day when traffic was heavier, it might have been a catastrophe." *CP*

Appendix 2

List of air photos used for the investigation of the Five-Mile Creek debris flow

Line Number	Photo Number	Scale	Date	Source
A11709	226	N/A	1948	NAPL
A10932	143, 166, 204	N/A	1947	NAPL
A18441	3	N/A	1963	NAPL
A19847	63	N/A	1966	NAPL
A20157	4, 5	N/A	1967	NAPL
A20146	104	N/A	1967	NAPL
A20148	27	N/A	1967	NAPL
A22534	36	N/A	1971	NAPL
A22443	16	N/A	1971	NAPL
A23861	20	1 :24,000	1974	NAPL
A23011	14	1 :66,000	1977	NAPL
A24776	140	1 :50,000	1977	NAPL
A27987	116, 117	1 :50,000	1993	NAPL
A27988	59, 60	1 :50,000	1993	NAPL
A22275	167	N/A	1971	NAPL
A25671	52	1 :10,000	1981	NAPL
A26217	112	1 :5,000	1983	NAPL
A26217	117	1 :8,000	1983	NAPL
A26259	39, 40	1 :5,000	1983	NAPL
FF99043 – L2	6, 7, 8, 9, 10	1 :30,000	1999	FOTO-FLIGHT

N/A : Not available
NAPL : National Air Photo Library, Natural Resources Canada

Appendix 3

Morphometric parameters relative to Five-Mile Creek drainage basin.

Parameter	Symbol	Value
Total Basin Area	A_T	4.5 km^2
Total Basin Relief	$Z_T = Z_{max} - Z_{min}$	1.31 km
Elevation Relief Ratio	$Z_R = \frac{Zaver. - Zmin}{Zmax - Zmin}$	0.5
Total length of channels and debris chutes	L_c	13.98 km
Drainage Density	$D_d = L_c / A_T$	3.1 km^{-1}
Melton's Ruggedness Number	$N_M = D_d / (A_T)^{0.5}$	1.46 km^{-2}
Fan Slope Angle at Five-Mile Creek	β	6°
Mean Basin Slope	S	16°