Canada

The East Gate Landslide, Beaver Valley, Glacier National Park, Columbia Mountains, British Columbia

Report to

Mount Revelstoke and Glacier National Park
Revelstoke, British Columbia

OPEN FILE # 3877

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CONTENTS

Figures

<u>Appendix</u>

Executive Summary

As requested by Glacier National Park authorities, a GSC party under the direction of Dr. Réjean Couture and accompanied by a park warden, investigated a rockslide-debris flow that has taken place since January 30, 1997. In late May 1999, mudflow debris covered the Trans-Canada Highway 1.5 km north of the East Gate of Glacier National Park in the Beaver Valley, Columbia Mountains, British Columbia. The debris originated from disintegrating rockslide debris high above the highway in an area of active rock slope failure. Field investigation and analysis were carried out and lead to recommendations relative to security and monitoring.

1. INTRODUCTION

1.1 In late May 1999, mudslide debris covered the Trans-Canada Highway 1.5 km north of the East Gate of Glacier National Park in the Beaver Valley, Columbia Mountains, British Columbia (Fig. 1). The debris originated from disintegrating rockslide debris high above the highway in an area of active rock slope failure. On July 15, 1999, Glacier National Park contacted the Geological Survey of Canada (GSC) requesting assistance in the analysis of the landslide and in the development of a monitoring/mitigation program for the geotechnical instability.

1.2 On August 24, 1999, a GSC party, under the direction of Dr. Réjean Couture and accompanied by National Park Warden, J.P. Kors, visited the landslide area and made a ground traverse from the headscarp down to valley bottom. A helicopter reconnaissance was undertaken immediately before the ground traverse.

1.3 Following the site visit, vertical airphotos of the east side of the Beaver Valley in the vicinity of the landslide were taken on September 8th, 1999, by Foto-Flight of Calgary (Alberta) under contract to the GSC. Available airphotos were also examined (Appendix 1).

1.4 This report summarizes the field observations made on August 24, explores the complex mechanism of failure at the East Gate landslide, and suggests measures for monitoring and hazard mitigation, with emphasis on the important consequences of such a landslide along a lifeline corridor.

2. BACKGROUND

2.1 The East Gate landslide first came to the attention of Glacier National Park officials after a large failure event in January 1997. Geotechnical assessments of the landslide were subsequently undertaken by EBA Engineering Consultants Ltd (EBA, 1997a,b; EBA 1999).

2.2 Ancient and recent slope failures (e.g., Pritchard et al., 1989; Pritchard and Savigny, 1991) are well documented in the Beaver Valley. Most of the landslides in the Beaver Valley have occurred on its eastern slopes. Many landslides are visible on aerial photographs and are outlined on the 1999 airphoto and topographic map in Fig. 2. Some of the landslides have been previously identified (Fig. 2, e.g., « Soup Kitchen », « Beaver Berms », and « Heather Hill »). It is evident that the East Gate landslide takes place on a mountain slope that exhibits extensive evidence of slope deformation and failure (Fig. 2).

2.3 The Beaver Valley is situated between the Prairies Hills of the Purcell Mountains on the east and the Hermit and Sir Donald Ranges of the Selkirk Mountains. The highest summit in the Prairies Hills is at about 2480 m elevation and located just above the East Gate landslide. The valley floor is at elevation 820 m. The natural slope angles in the valley vary from 23 to 40 degrees.

2.4 Airphotos taken in 1949 show clear indications of slope deformation in the East Gate landslide area (Figure 3). A failure plane that generated relatively small rock falls and debris flows is seen at about 1950 m above the valley bottom. However, over a period of 29 years, as seen on 1978 airphotos, the slope did not show any obvious further degradation (Fig. 3). Marked degradation did not take place until noted in January 1997. Photos taken on January 30, 1997 (shown in EBA, 1999) show that the headscarp had retreated to a identified structural lineament (indicated by arrow on earlier photos, Fig. 3) parallel to the slope and two large debris flows had moved downslope to about 1450 m elevation (Fig. 4a).

3. GEOLOGY OF THE BEAVER VALLEY

3.1.1 The east side of the Beaver Valley is formed in rocks of Hadrynian (Late Precambrian) Horsethief Creek Group (Fig. 5; Wheeler, 1963). The Horsethief Creek Group consists of a Lower Grit Division (GR) successively overlain by a Middle Slate Division (SL), an Upper Carbonate Division, and an Upper Slate Division (Poulton & Simony, 1980). Only the first two divisions (GR and SL) are of concern in the study area (Fig. 5). The Middle Slate Division (SL) is divided into a Semipelite Amphibolite Unit in the Beaver Valley. The East Gate landslide occurs in the Lower Grit Division (GR), which consists "dominantly of coarse- and fine-grained gritty, feldspathic and micaceous sandstone with slate interbeds" (Simony & Wind, 1970). More details concerning the description of rock assemblages are given in Poulton & Simony (1980).

3.1.2 The east slope of the valley consists of a series of imbricated thrust sheets. The upper eastern slope of the valley is affected by two overturned thrust faults (Fig. 5). The Hadrynian rocks are complexly folded and exhibiting bedding (So) trending northwestward throughout the valley, dipping steeply east. The penetrative foliation or schistosity (S1), corresponding to a first phase of folding, is virtually obliterated by intense crenulation cleavage (S2), striking northwest to northeast and dipping more steeply than So bedding (Pritchard et al., 1989). The rocks show a phyllitic to schistose texture. The rocks in the landslide have a soapy feel due to the presence of talc (R. Herd, personal communication) which helps to reduce the friction angle of failure planes.

4. FIELD OBSERVATIONS AND DATA ANALYSIS

4.1 Initial rock slope failure – conditions at the headscarp

4.1.1. The failing rock mass is a talc-rich mica schist that has a fair intact shear strength. However, the rock disintegrates easily on wetting.

4.1.2. Structural measurements were taken at the south side of the headscarp (Fig. 6). The rock mass is strongly affected by schistosity planes, probably corresponding to the S2 of Poulton & Simony (1980), that dip SSW with an angle between 22° and 50°. The average strike and dip of schistosity is N284°/29°. A joint set sub-vertical and parallel to the slope creates vertical scar and rock faces in the detachment zone (Fig. 4b). In fact, this joint set can be divided into 2 joint sets which are N168°/80° (JS1) and N001°/80° (JS2). Finally, a third joint jet (JS3), sub-vertical and perpendicular to the slope, makes a saw tooth-pattern on the headscarp (N072°/68°). The rock mass is very fractured, the average spacing of schistosity planes is about 0.05 to 0.20 m. The joint sets parallel to the slope are well developed, however, the third joint set is less frequent and less developed.

4.1.3. Field measurements and a kinematics analysis indicate that the initial rock failure is associated with a toppling mechanism (Fig. 6). The joint sets JS1 and JS2, oriented more or less parallel to the slope, cut the rock mass into blocks, which are subject to toppling (Fig. 6). Although the schistosity planes daylight in the slope, since they dip at a lower angle than the slope angle, they are more or less perpendicular to the slope face, and thus schistosity planes are not prone to rock-sliding. However, because the rock is so fractured, pseudo-rotational landslide occurs and the headscarp retrogresses by the failure of large blocks.

4.1.4. The south side of the headscarp is more affected by slope deformation since it shows a large concentration of structural lineaments. These structural lineaments, shown in Fig. 4b, are expressed in the field by cracks and opened fissures located on the south side of the headscarp (Fig. 7). These cracks define blocks within the slope; some of them show fresh displacements (Fig. 7). Once a block has failed, it disintegrates completely after less than few hundred meters of sliding, due to the high degree of fracturing and poor discontinuity cohesion.

4.1.5. Some of those blocks failed during the summer 1999 (Photos in 1999 EBA report). We believe that further displacements and eventually rock mass failures, mostly located in the south side of the current headscarp, are to be considered for the spring and summer 2000 if climate conditions are unfavorable. A large amount of water coming from snow melting in the upper section of the slope and from unusual heavy rainfall could certainly cause further block failures and enhance the debris flow activity in the flow path.

4.2 Rock mass disintegration – the formation and morphology of the debris flow.

4.2.1 From the air, it is clearly seen that debris accumulates in the upper part of the failed slope forming an unstable pile of disintegrated rock (Fig. 8). Tongues of saturated debris extend downslope from this pile. Although the debris mass has moved down the slope by about 1 km (Fig.9) since January 1997, it has not yet reached the valley bottom. Only a small amount of debris, essentially mud, that flowed down a stream channel in May 1999, has reached the highway. From May 1999, the morphology of the flow path has changed considerably. A forested area, located at about elevation 1300 m, has been washed out by debris mass in motion and has now completely disappeared.

4.2.2 After a block fails and starts to slide down, it rapidly disintegrates and thus it transforms into a debris spread, then into a debris flow, and ends in a mud flow. Debris is now accumulating at different elevations on flatter, bench-like, parts of the slope. Three benches are identified and these debris accumulations, which can be clearly seen on Figure 8b, show a lower angle upslope and a very steep slope angle downslope. These benches are also associated with the mountain slope morphology (Figure 8b). The thickness of debris in the flow in the upper section is estimated to be at least 4 to 5 m and may be higher at the level of benches. On both sides of the flow path, levees up to 3 to 4 m high were noted. In many places on the upper section of these benches, fissures perpendicular to the flow direction indicate downslope displacement of debris (Fig. 10). Such a type of deformation is indicative of retrogressive failures within the accumulated debris that then can generate larger debris spreads and flows descending the mountain slope.

4.2.3 Because the rock mass material is already extremely fractured, the occurrence of large boulders is rare in the debris. A few large boulders, identified by a circle on Fig. 8b, can be seen on the north side of the debris flow. However, there is a very low risk that large boulders resulting from rock falls on the main head scarp could affect the highway.

4.2.4 The debris is essentially composed of small rocks (average diameter = 0.30 m) with a matrix, which corresponds to 50% of the debris, composed of pebbles, gravel, and fine particles (Fig. 11). Organic matter is also incorporated into the debris. Grain size distribution curves of debris sampled at two locations are shown in Fig. 12. Sample #1, which was taken at about elevation 1350 m in the debris flow (Fig. 8), consists of 71.4% gravel, 17.6% sand, and 11% silt and clay. The debris that reached the highway was also sampled (Fig. 8). The material is much finer, consisting of 33% gravel, 22.7% sand, and 44.3% silt and clay (sample #2 on Figure 12). All along the debris flow path, the debris has a high moisture content.

4.2.5 At least two springs daylight at the base of the headscarp. Runoff water enters the debris at the uppermost bench (bench #1) and disappears lower in the flow path through the debris. Groundwater originates from rainfall and snow melting in a zone above the top of the main headscarp. Water runs off from the debris path down to the highway. On the North side of the flow path, a gully drains the water, while on the South side, a creek runs down to the valley bottom about 500 m off the flow path. Because of the large proportion of fines, and also because the debris is highly erodible, a large amount of material can be entrained down the slope, devastating forested areas.

4.2.6 At least, three lobes are now formed by the debris flow (Fig. 8a). In September 1999, only one seems to follow the clearly defined stream channel, which descends directly down to the valley bottom. In their movement downslope, the debris flow lobes bulldoze trees, pushing them ahead until they form a plug. Then debris accumulates behind the plug which forms material for a downslope surge (Fig. 13). While the timber plugs slow down the velocity of debris flow, the release of the plugs forms a more rapid surge, which moves downslope bulldozing more trees and thus forming a new plug.

4.3 Deposition area and valley bottom

4.3.1 As mentioned above, only a small amount of debris (Estimation by National Park officials: 15,000 m^3), which were mainly fines (Fig. 12), reached the highway and forced highway maintenance workers to clean off the debris. However, an important amount of material remains in the slope (EBA estimation: 385,000 m^3), and because the rock mass is still active and because debris is still moving down the slope, other debris flows affecting the highway are anticipated. If debris continues to flow down the slope, the flow path will be mainly controlled by the configuration of the stream channel crossing the fan deposits. However, debris flows could come out anywhere along the 1 km-road section contouring the fan deposits.

4.3.2 The base of the slope is formed by a large fan that the road is contouring for about 1 km (Figure 2). Upstream of the highway, the slope angle is about 20°, while downstream of the highway the slope becomes flat. The Beaver River flows from North to South and meanders through a 1 km wide flat area forming the valley bottom. At East Gate landslide area, the river makes a large meander towards the west and moves about 400 m away from the highway.

5. SUMMARY OF LANDSLIDE MECHANISM

5.1 In January 1997, a reactivation of a very large post-glacial landslide was brought to the attention of Glacier National Park authorities. The current landslide involves retrogressive bedrock failures on an over-steepened headscarp. During a relatively short period of time, about 28 months, debris generated by disintegration of bedrock slumps has moved down the mountain slope about 3.4 km. A very small amount of debris reached the highway in late May 1999, but fortunately without any disastrous consequences. Due to the presence of continuous retrogressive failures of the headscarp and clear indication of slope deformation on a forested area south of the main headscarp, more debris is expected to be added to the current debris in the upper section of the flow path.

5.2 Because of the considerable amount of groundwater seepage in the slope and continuous displacement of debris, Glacier National Park authority must consider the possibility of a catastrophic landslide at East Gate landslide area. Other deep-seated landslides were recognized in the Beaver Valley (Pritchard et al., 1989), implying that a larger than expected volume of rock might be involved in a potential future slope failure. Based on the distance traveled by debris since the recognition of the slope failure on January 30, 1997, the average displacement rate of debris is 1.5 m/day. The relationship of time *versus* distance of the debris flow front is shown in Fig. 14.

The worst scenario anticipated indicates that the debris front would reach the highway by the end of December 1999. Winter months will certainly reduce the rate of displacement, but the motion of the debris flow front is closely dependent on spring 2000 climate conditions. General trend from January 30, 1997 indicates that debris flow front will hit the highway by late September 2000 (Fig. 14). Therefore, this landslide must be closely investigated and monitored to understand the failure mechanism(s) and potential impacts on the Beaver Valley sector and as well on the consequences to Glacier National Park activities, as well as wildlife, transportation activity and municipal economy. Based on field investigation and analysis of available documents, we propose the following recommendations.

6. STRATEGIES FOR FUTURE ACTIONS

6.1 Immediate warning measures

6.1.2 Landslide warning signs should be posted as soon as possible, instructing travelers to not stop at the East Gate area. Traffic fences and lights could also be installed on the highway, and perhaps designated stopping points be provided a few kilometers of the East Gate area to prevent traffic stopping in the problematic area.

6.1.3 It is the GSC's understanding that Park authority was planning to install a weather station at the top of the mountain during autumn 1999. This climate station should be linked to the Park warden office in order to get the weather conditions in real time. This would allow the Park to control traffic on the highway and to limit the disastrous consequences. As proposed by EBA, we also recommend an analysis of past climatic conditions over the last two and a half years in order to correlate debris flow displacements and rainfall and temperature variations. Thus a model can be developed to, at least, verify and eventually understand the relationship between displacement and rainfall and temperature.

6.1.4 It is strongly recommended that an "alert network" that will include all authorities concerned by this hazard and the associated risk be installed. These authorities could, for instance, all Glacier National Park sectors (Warden office, Road Maintenance Service, etc.), local municipalities, Canadian Pacific Railway Company, Government agencies (e.g. Geological Survey of Canada, RCMP, Emergency Preparedness Canada, etc.), consultants involved in landslide assessment, and others if necessary.

6.2 Further studies

6.2.1 Frequent aerial reconnaissance should be carried out during the next year (2000), especially during the spring. Photos of the landslide should be taken periodically from the same observatory in order to evaluate the rate of displacement. Professional aerial photos of the landslide area, with scale varying between 1:10,000 to 1:30,000, should be taken at least once a year.

6.2.2 The East Gate landslide can be divided in two zones. The first zone is the headscarp area, which is affected by rock toppling and pseudo-rotational rock sliding and shows important slope deformation and continuous failures. Slope indicators, installed on a landslide located on the west side of the valley, showed deformations up to 30 mm during one month (Thurber Consultant Ltd., 1979 *in* Pritchard et al., 1989), indicating that displacement could be important and rapid. Although flexural toppling seems the main mechanism at the headscarp, deep-seated chevron (such as the LaClapière landslide, France; Follacci, 1987) and deep-seated block-flexure toppling mechanism must be anticipated. These certainly involve a larger volume of rock than already defined. The second zone consists of the debris flow from the base of the headscarp to the most downslope end of debris. The first zone has a low impact on the highway, but it continues to supply debris to the second zone, which may have a strong impact on the Beaver Valley activity.

6.2.3 EBA has already proposed a series of studies concerning numerical analysis for both zones (EBA, 1999). GSC agrees with EBA's suggestions, but GSC has reticence with the relevance of the rock fall analysis. As mentioned above, the highly fractured state of the rock mass won't create large boulders, and only a few large boulders are mapped in the flow trail. The bench-shape morphology of the flow path limits considerably the run-out distance of boulders. Similar numerical modeling can be achieved as it was carried out for Heather Hill (Pritchard & Savigny, 1990).

6.3 Monitoring

6.3.1 Many types of monitoring system could be considered here, including those mentioned by EBA. Photogrammetry (Fraser & Gruendig, 1985), interferometry and satellite images are among those available techniques. However, GSC believes that a simple and low-cost warning system should be installed between the actual front of debris and the highway early next spring or earlier if possible. The goal aimed is to reduce the risk if a debris flow reaches the highway, and to warn Park authorities (and its partners) and travelers that a debris flow is moving down towards the highway.

6.3.2 The system must, in the same time, indicate the location of the advance of the debris flow and must be electrically linked to traffic lights to stop the travelers, and be connected to a station permanently under human supervision. For instance, a series of vertical anchored posts should be installed along the channel (between the debris front and the highway) and along any potential debris flow travel path. The posts should be able to break or hinge once the debris flow front hits the posts and then trigger an electrical signal to the park office and turn the warning lights on. This system would warn Park authorities and its partners of the presence of debris flow in motion and the need to limit the traffic along the hazardous 1 km-highway section at the base of the fan.

6.3.3 Despite the proposed passive protection systems, and even the most sophisticated considered, these protection measures will not slow down the displacement of debris and will not reduce the slope deformation. Active protection actions should be considered.

6.4 Active Measures involving slope engineering

6.4.1 As seen in many other landslides, gravity and water are the power-driven factors for the instability of both zones in the East Gate landslide. Since we have no control on gravity, water remains the only factor that humans may control. Thus, it is recommended to "catch" as much as possible runoff water daylighting at the base of the headscarp and to divert water sources away from the landslide area. The installation of a drainage system for runoff in the flow path should be considered.

6.4.2 The debris is moving forward down the slope by progression of lobes. The farthest lobes have reached a point on the fan where they can take any direction, north side, south side, or in the middle of the fan. Thus, the road can be blocked at any point along its 1 km-long section on the fan. The actual stream channel should be widened and channeled to lead the debris to only one location.

6.4.3 The establishment of a deposition basin for debris should be considered. The slope morphology above the highway does not allow many possibilities to install such as basin. However, the flat area between the fan and the river can be used as a deposition basin. In a 250 m x 250 m basin by 2 meters deep, about 125,000 m^3 of debris could be collected. The relocation of the road can become problematic. Either the road can be diverted towards the river, making a larger bend than it does now, or the Park authority can consider the option of a construction work allowing the traffic to pass over the area at risk.

6.5 Measures involving relocation or protection of Trans-Canada-Highway

6.5.1 In a long-term perspective, the Park authority could consider the following option:

6.5.2 Move the highway at the base of the western slope of the valley (beside CPR tracks) for a distance about 8 km from Mountain Creek Campsite to Beaver Picnic Site (Figure 2b). This option avoids the entire section of the valley affected by ancient and current large slope deformations.

6.5.3 Although the tunnel option could be considered, due to a low cost road maintenance, this option should be avoid because of the poor quality of the rock mass and the exceptional length of the tunnel. In addition, tunneling would be required not only for the East Gate landslide area, but also for all the Beaver Valley section affected by deep-seated landslides.

The Geological Survey of Canada understands that the assessment of the landslide risk and proposed passive and active protection actions involve a lot of effort in terms of knowledge, technical practice, as well as financial input. Glacier National Park authority should be aware that the risk is eminent and impacts could be disastrous. The Geological Survey of Canada hopes this report will help the Glacier National Park authority in their decisions regarding the East Gate landslide assessment. The Geological Survey of Canada remains available for any questions or comments regarding this report or any future assistance.

Yours truly,

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FIGURES

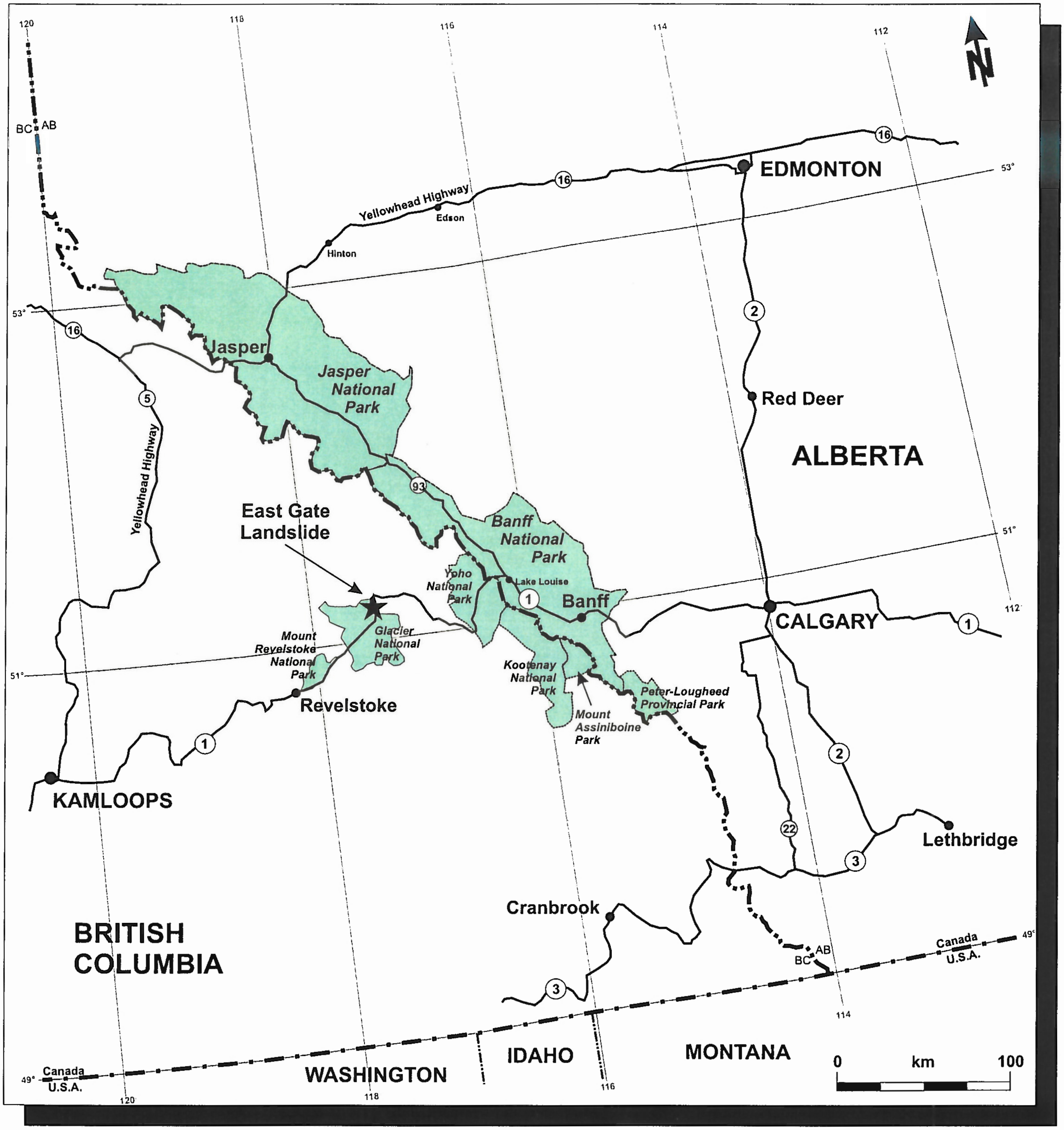

Figure 1. Location of the East Gate landslide, Beaver River valley, Glacier National Park, British Columbia.

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a)

1:50000 scale topographic map 82/N-6

b)

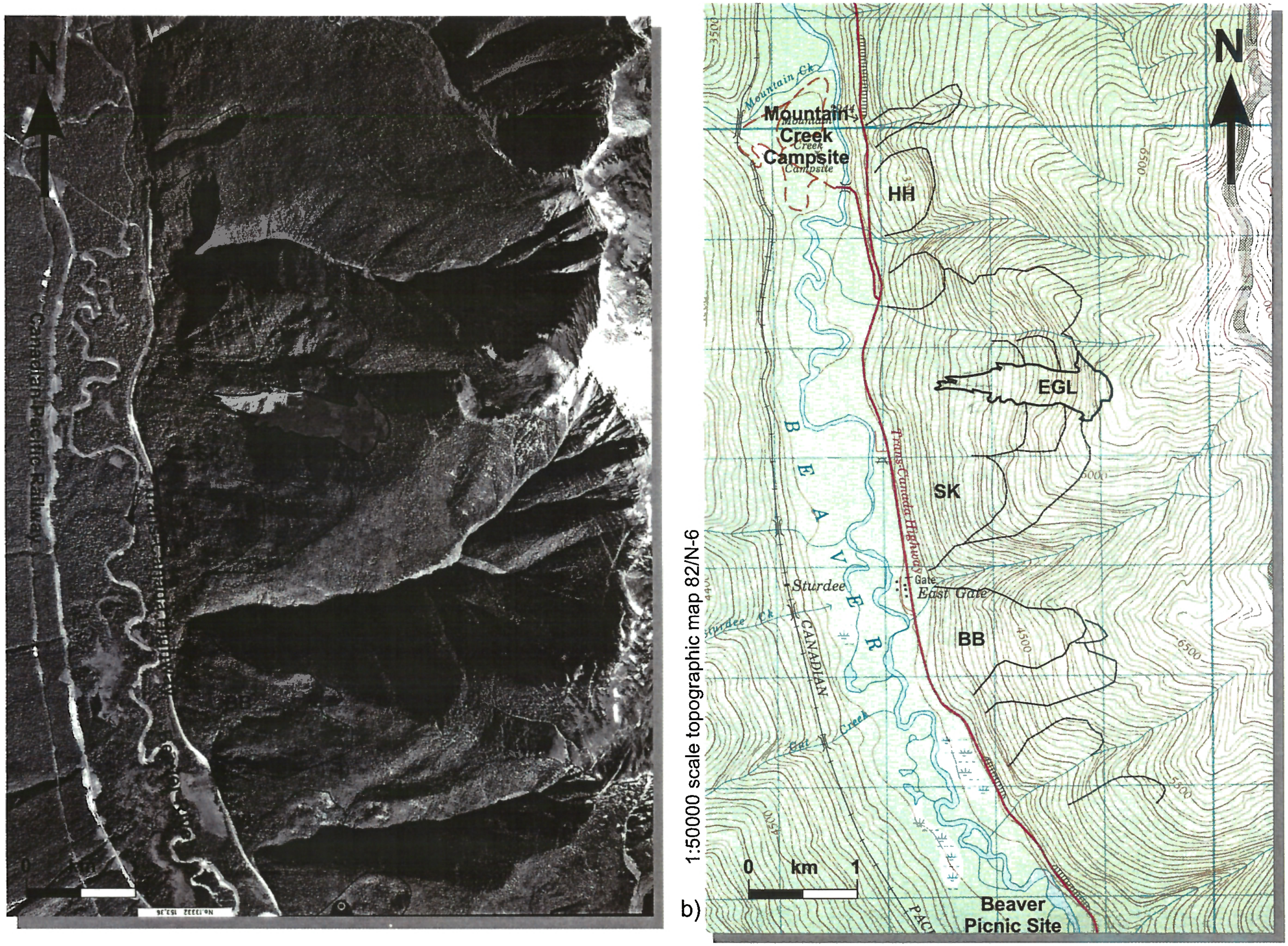


Figure 2. a) 1: 30,000 scale air photo (8 September, 1999) and b) 1:50,000 scale topographic map of the Beaver River valley in the vicinity of the East Gate landslide. Location of ancient and present slope failures in the vicinity of East Gate landslide. BB: Beaver Berms debris flows area; EGL: East Gate landslide; HH: Heather Hill landslide; SK: Soup Kitchen debris flow area.

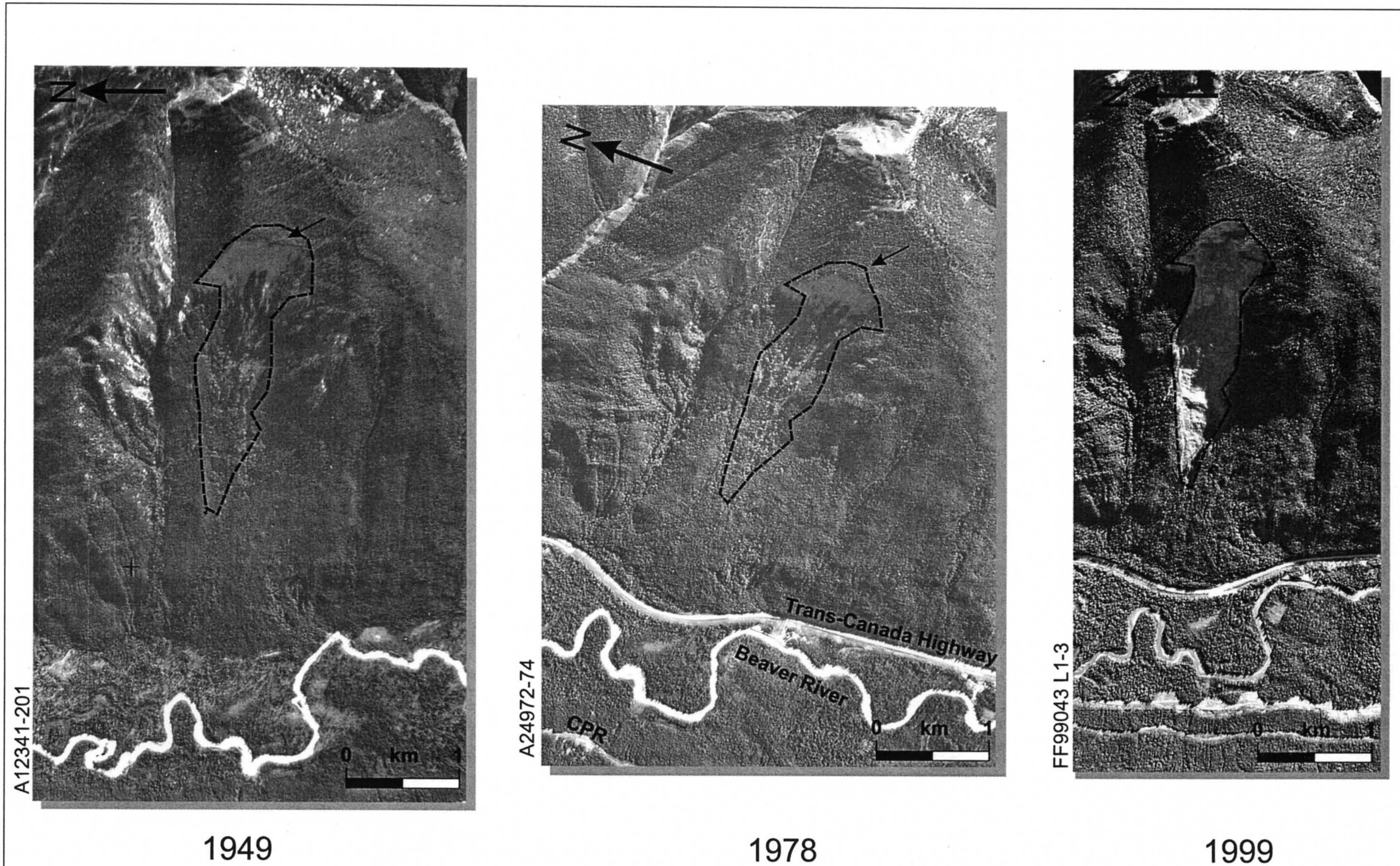


Figure 3. Evolution of the East Gate landslide from 1949 to 1999 and approximate location of September 1999 limits of landslide. Before 1978, the upper slope was affected by limited slope failures including rockfalls, small debris flows and slow deformation above the headscarp (pointed by arrows). The size of the exposed headscarp is similar in 1949 and 1978. In mid nineties, the segment limited by the lineaments indicated by the arrow has failed (EBA, 1999). In 1999, this segment has been completely transformed into debris. In the last two years, the headscarp has extended towards the south, generating new debris.

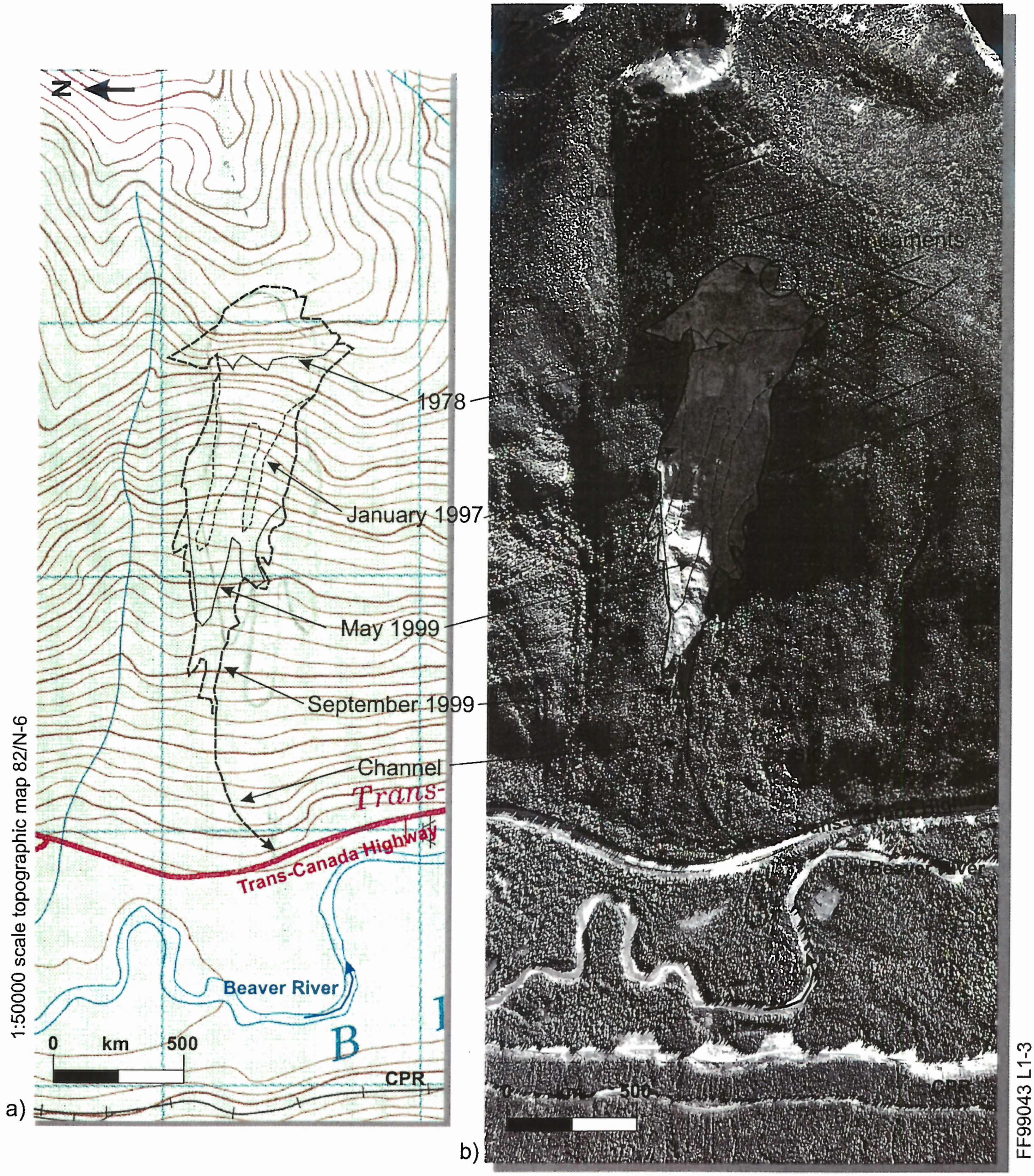


Figure 4. Location of the East Gate landslide and evolution of the debris flow front on a) 1:50,000 scale topographic map and b) 8 September,1999 airphoto. Joint sets are well represented at the headscarp. Structural lineaments are occasionally seen as opened cracks on the field. SK: Soup Kitchen debris flow area.

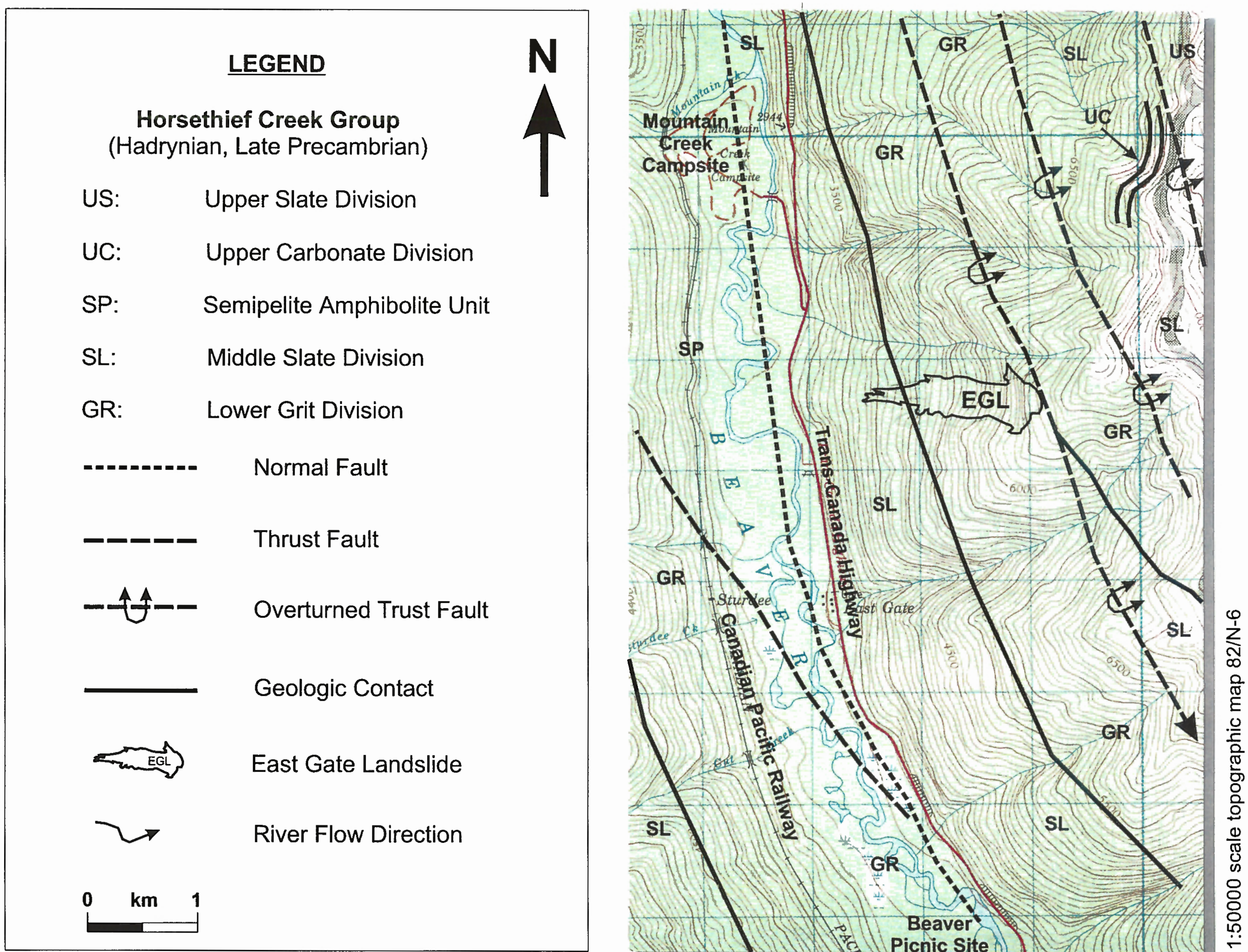


Figure 5. Regional geology map of the Beaver Valley, Glacier National Park, British Columbia (after Simony & Wind, 1970; and Poulton & Simony, 1980).

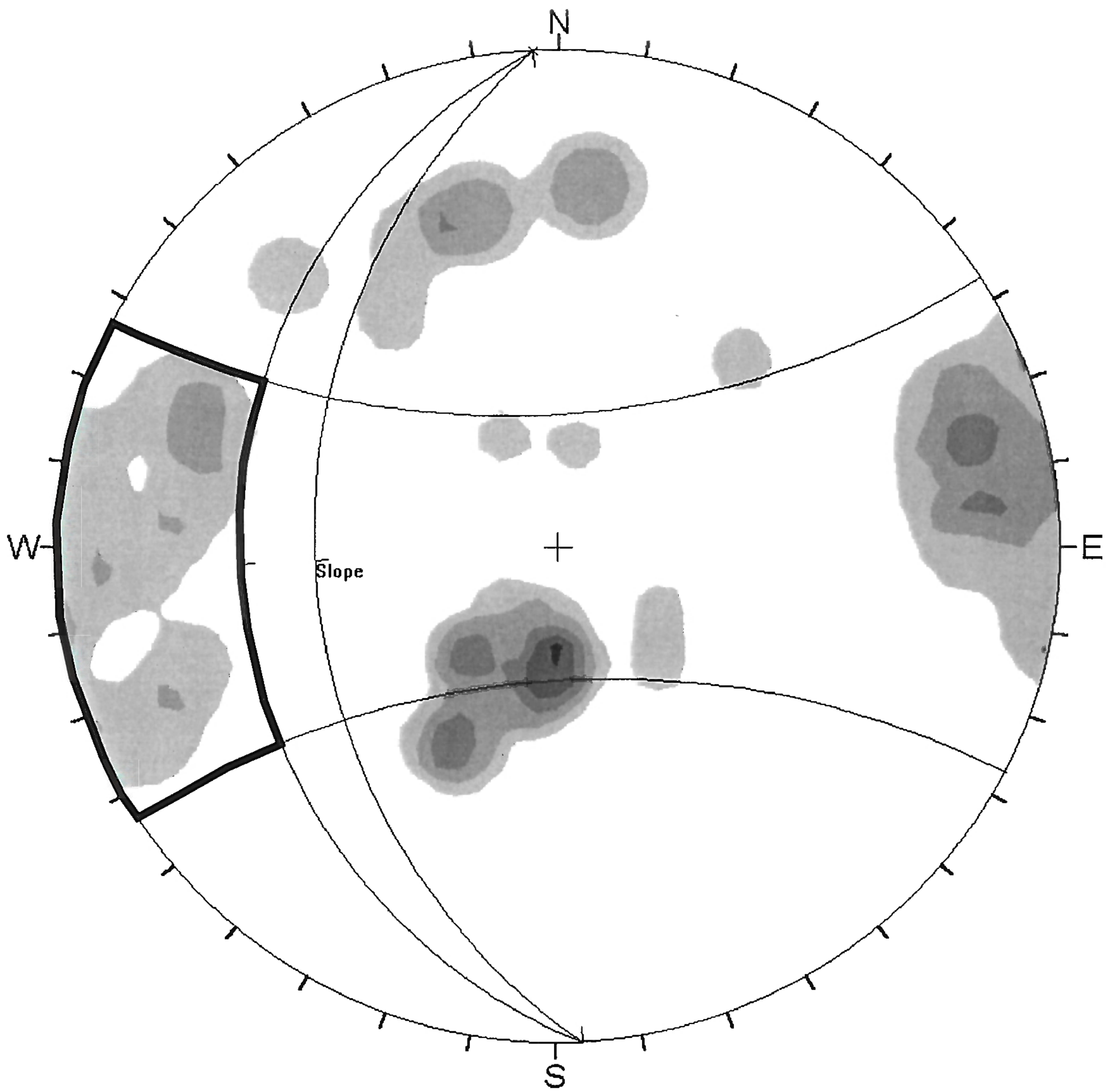


Figure 6. Lower hemisphere projection of contour plot for discontinuities measured at the headscarp of East Gate landslide. Kinematic analysis indicates that toppling is the main mechanism responsible for the slope instability. Pole of joint sets falling in zone limited by bold line show toppling mechanism. Slope strike and dip is 177°/30°, while friction angle assumed for foliated sandstone is 25°.

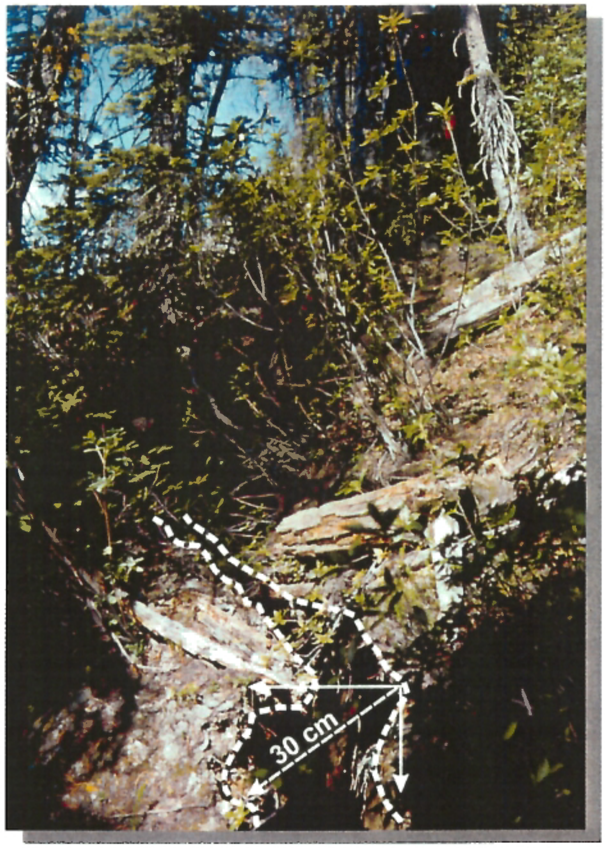


Figure 7. View towards north of an opened fissure located on the southern slope of the East Gate landslide at elevation about 1950 m (see Figure 8 for exact location). The fissure shows aperture up to 25 cm with relative displacement downslope. Note tilted trees above the fissure (August 24, 1999).

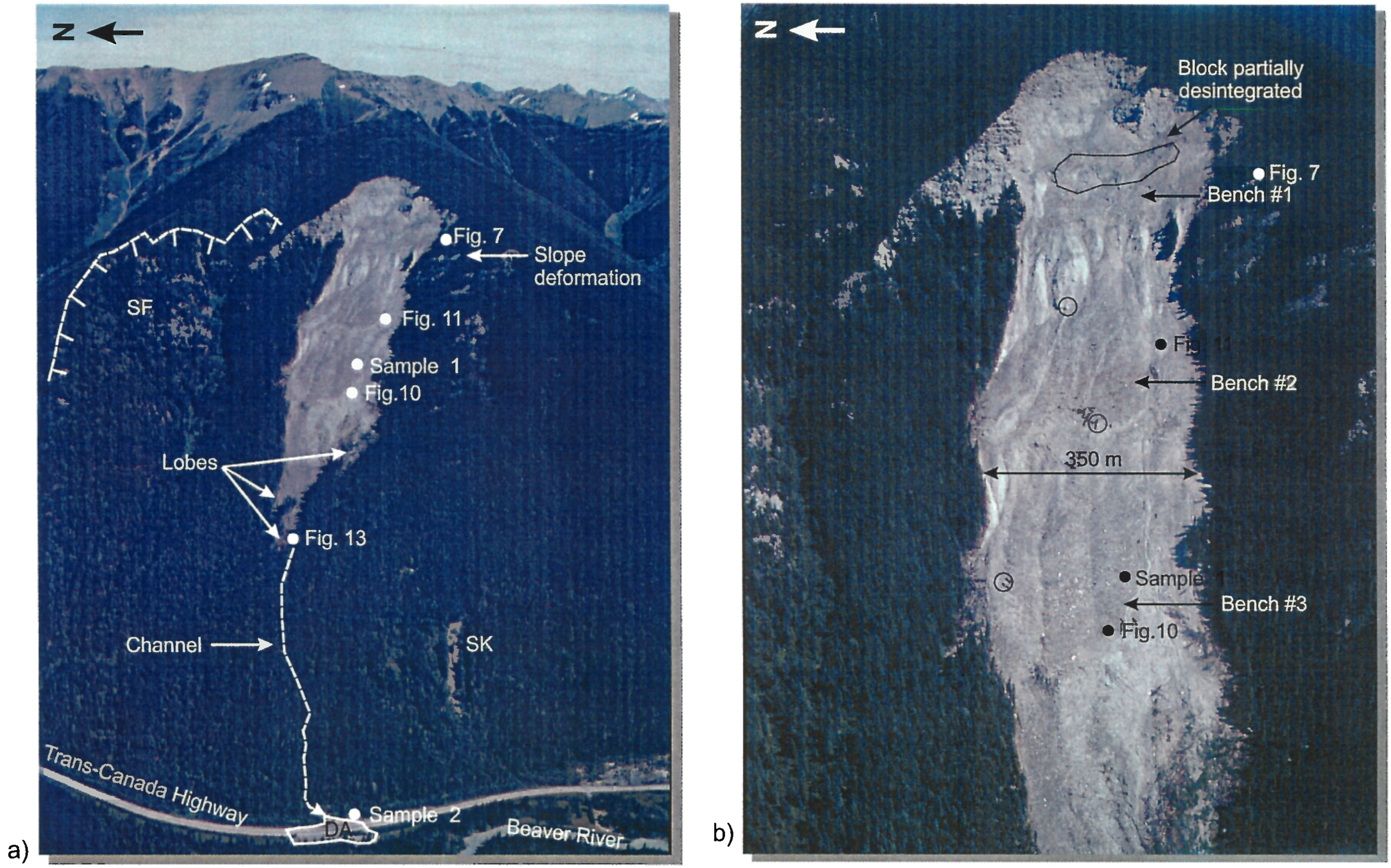
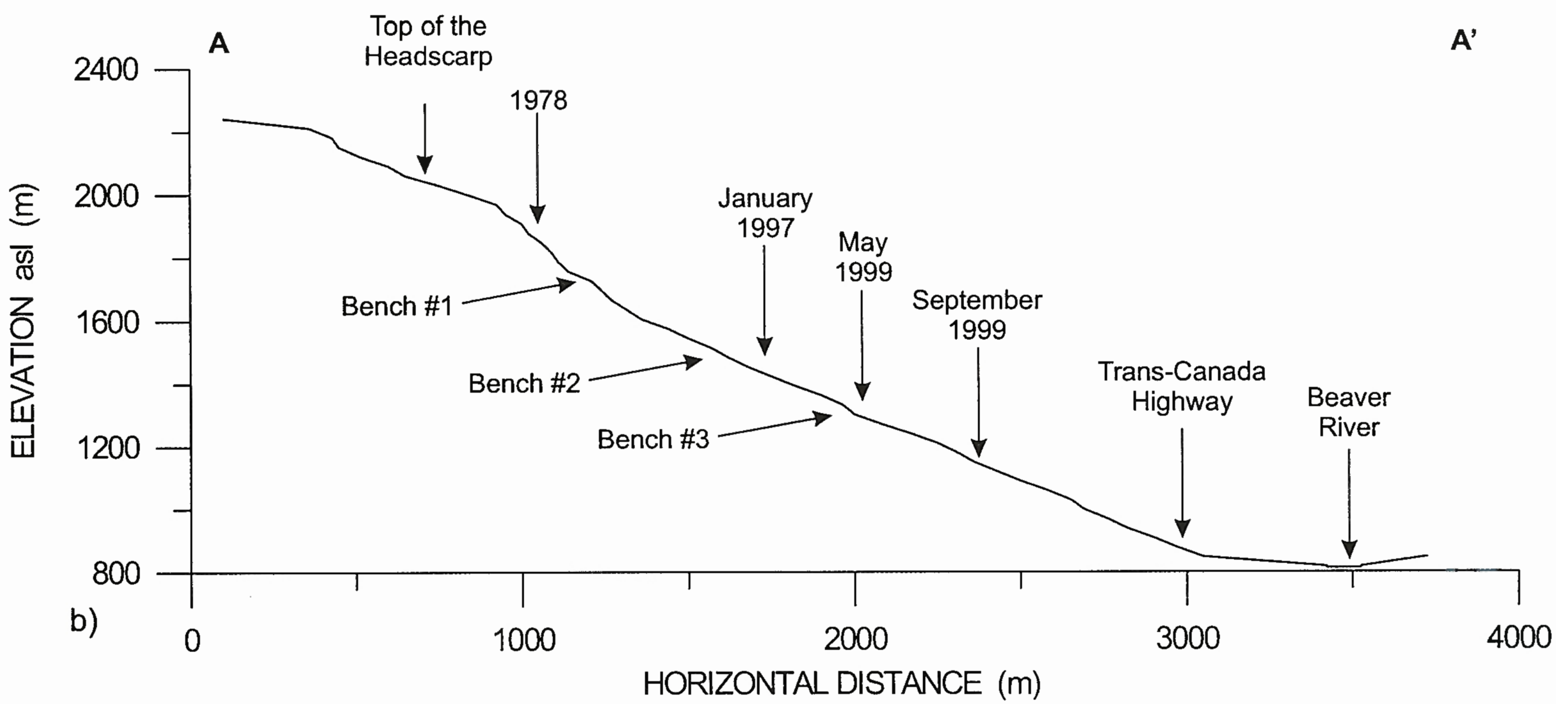
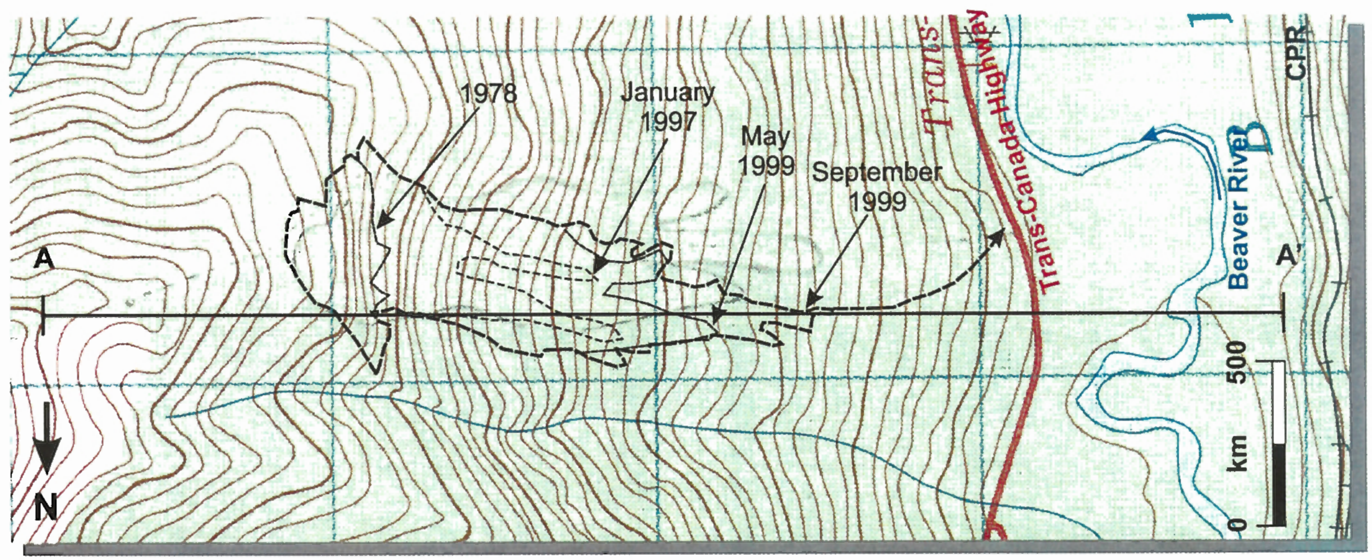


Figure 8. a) Oblique aerial view of the East Gate landslide. Slope deformation is identified on the southern slope of landslide headscarp. DA: Deposition area of 1999 debris flow; SF: Slope failure; SK: Soup Kitchen debris flow area. Location of Figures 7, 10, 11, and 13, and samples 1 and 2 (August 24, 1999).

b) Close-up on the upper slope of the East Gate landslide. Three zones of debris accumulation, known as benches #1 to #3, show permanent and slow downslope displacements. A few large blocks can be identified at the level of bench #2 and bench #3 (encircled) (August 24, 1999).



b)



a)

1:50000 scale topographic map NTS 82/N-6

Figure 9. a) Location of East Gate landslide and evolution of debris flow front.
b) Profile through the East Gate landslide with locations of the debris flow front.

Figure 10. View towards north-west fn opened fissures (indicated by arrows) in the debris located on bench #3 at elevation 1500 m (see Fig. 8). Fissures are perpendicular to flow direction and indicate downslope displacement of the debris. Such deformation involves a retrogressive failure within the debris accumulated at bench #3. Similar fissures are also seen on benches #1 and #2 (August 24, 1999).

Figure 11. The debris is essentially composed of small rocks (diameter = 0.30 m) with a matrix, which corresponds to 50% of debris, composed of pebbles, gravels and fine particles. The fine material, which corresponds to about 40% to 50% of the matrix material, shows a high percentage of water. Organic matter is also incorporated into the debris. Grain size distribution of the matrix is shown by sample #1 on Figure 12. A field book gives the scale. See Fig. 8 for exact location of photograph (August 24, 1999).

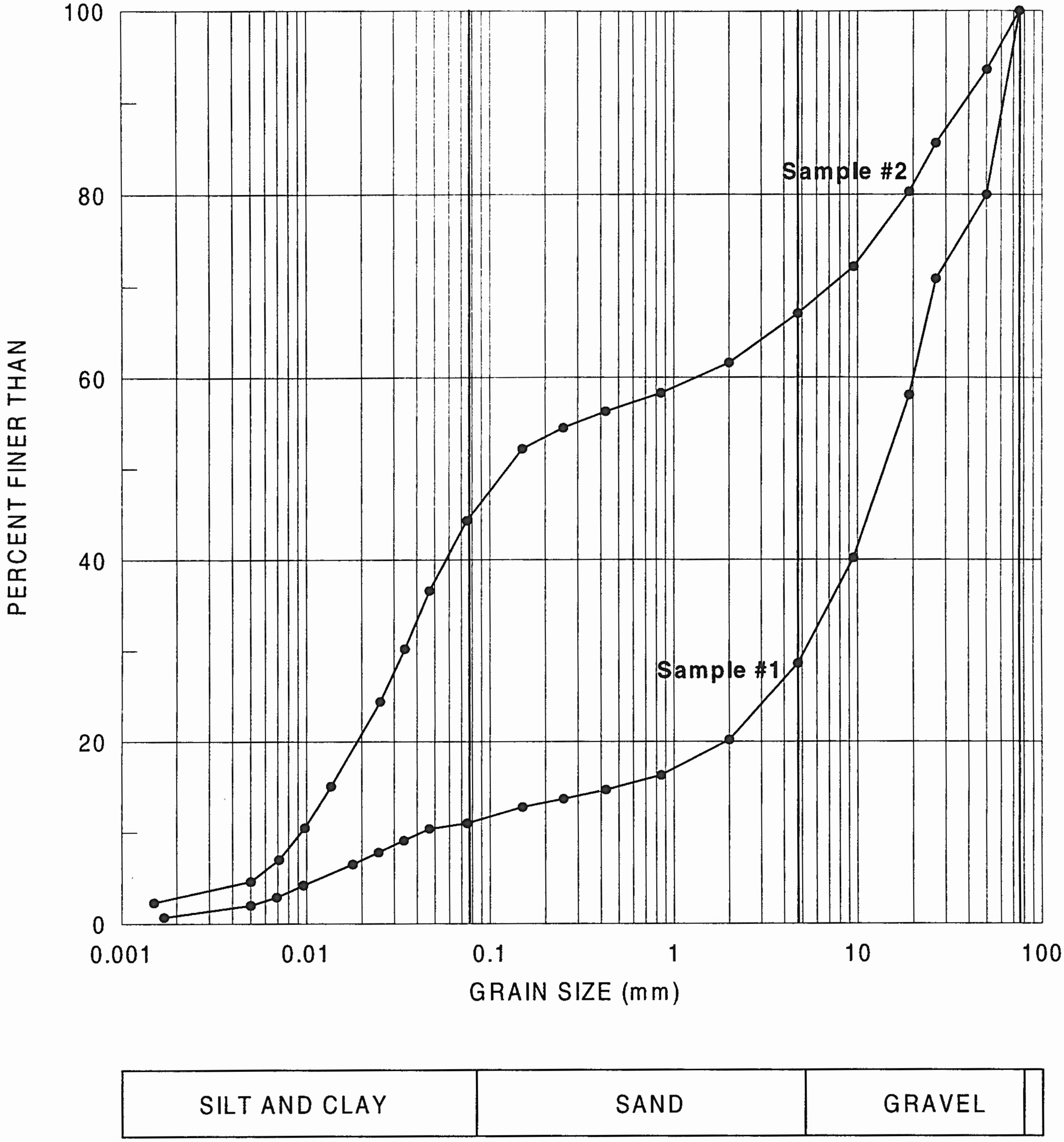


Figure 12. Particle size distribution of the East Gate landslide debris sampled at mid-slope (Sample #1) and at the Trans-Canada Highway level (Sample #2) on August 24th, 1999.

Figure 13. Typical example of timber plug that blocks debris flow in the channel downstream of the debris flow front. Arrow indicates the direction of flow. Persons show the scale of fallen trees slowing down the debris flow. Once the dam breaks, debris and trees surge further downstream until another temporary dam forms. See Fig. 8 for exact location of photograph (August 24, 1999).

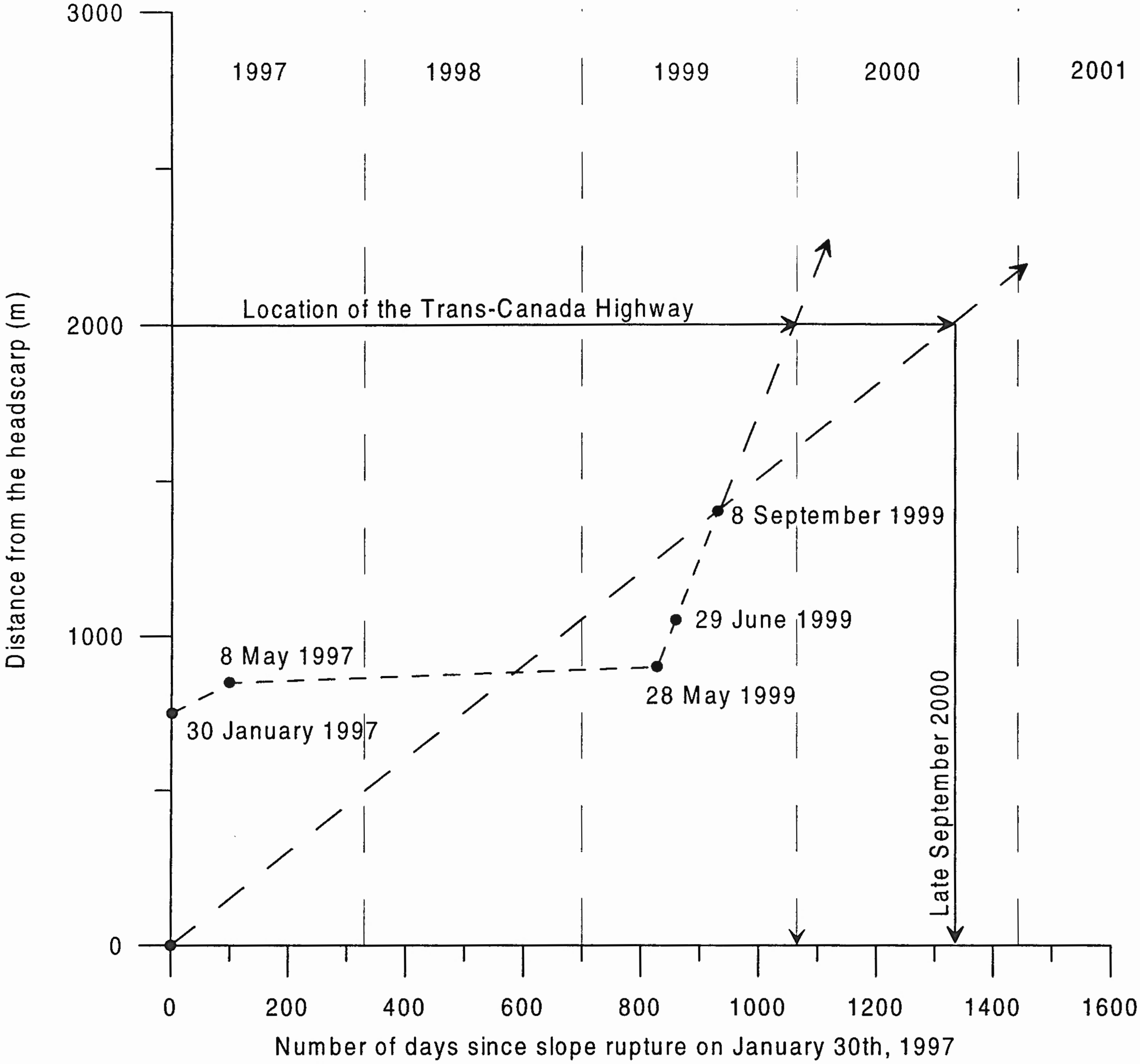


Figure 14: Time *versus* distance relationship of the East Gate debris flow front displacement since the observed slope rupture on January 30, 1997. According to extrapolation of summer 1999 rate of displacement, the debris would reach the Trans-Canada Highway at the end of December 1999. This is the worst scenario anticipated. Winter months will certainly reduce the rate of displacement, but the motion of the debris flow front is closely dependent on spring 2000 climate conditions. The general trend of displacement from January 30, 1997 to September 8, 1999 indicates that late September 2000 would be the date when the debris flow front will hit the highway.

Appendix 1

Table of airphotos referenced in text

Line Number	Photo Number	Scale	Date	Source
A12341	201, 202	1:34000	1949	NAPL
A24972	73, 74	1: 34000	1978	NAPL
A27180	102, 103, 104	1:10000	1987	NAPL
FF99043 L1	1, 2, 3, 4, 5	1: 30000	1999	Foto-Flight

NAPL: National Airphoto Library, Natural Resources Canada