

# LANDSLIDE HAZARDS AND THEIR MITIGATION ALONG THE SEA TO SKY CORRIDOR, BRITISH COLUMBIA

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## RÉSUMÉ

L'autoroute Sea to Sky s'étend sur une distance de 110 km de Horseshoe Bay à Pemberton, C.-B. Historiquement, ce corridor de transport a été et reste exposé aux glissements de terrain. Plus de 18% du total d'accidents mortels au Canada reliés aux glissements de terrain (>600) ont eu lieu dans ce corridor. Selon un inventaire effectué à partir d'articles de journaux et de rapports géotechniques ou scientifiques, des centaines de glissements de terrains se sont produits depuis les 150 dernières années. Le nombre de glissements de terrain a augmenté durant les années 1980 et 1990, avec environ 40 événements par décennies. Cependant, la période antérieure aux années 1980 est très fortement influencée par l'incomplétude des données. La tendance observée pour la période postérieure aux années 1990 indique que les mesures d'atténuation du risque ont eu un effet positif. L'inventaire réalisé documente la distribution spatiale, le type, et l'impact des glissements de terrain. Les types de glissements les plus nombreux sont les éboulements rocheux et les coulées de débris, surtout concentrés dans la partie sud du corridor. Certains événements catastrophiques ont incité les autorités à mettre en place des mesures d'atténuation. Des structures de protection actives ont été construites et des mesures de sécurité routière ont été implantées. De plus, des mesures systématiques de contrôle des éboulements rocheux ont été mises en place, et le Système d'Évaluation des Aléas d'Éboulement Rocheux (Rockfall Hazard Rating System) a été utilisé par le Ministère des transports de la C.-B. Depuis le début des années 1970, l'intégration des mesures d'atténuation à la gestion du corridor a ainsi augmenté la sécurité de la population. Aucun accident mortel provoqué par des glissements de terrain n'a été rapporté depuis le début des années 1990. Suite à l'accroissement de la densité de population le long du corridor, il serait toutefois opportun de considérer les risques associés à la survenance de glissements de terrain de magnitude forte et de faible occurrence.

## ABSTRACT

The Sea to Sky Highway stretches 110 km from Horseshoe Bay to Pemberton, BC. Historically, the highway corridor has been vulnerable to landslides. More than 18% of Canada's total landslide related deaths (>600) have occurred along this corridor. Over the last 150 years, hundreds of landslide events have been reported. A landslide inventory from newspaper articles, geotechnical reports, and scientific articles has been compiled. The observed trend in landslide frequency has a peak period during the 1980's and 1990's at approximately 40 events per decade. The early part of the trend is heavily influenced by data censoring, due to an incomplete record prior to the 1980's. In recent decades, the observed trend indicates the positive effects of improved slope maintenance and landslide mitigation measures. This inventory documents the geographical distribution, the types, and the impacts of landslides. The most abundant types of landslides are debris flows and rock falls, which are highly concentrated in the southern part of the corridor. Certain individual landslide disasters led to implementation of mitigation measures. Active protection structures were built and road safety measures were introduced. Moreover, systematic mitigation of rock falls and the adoption of the Rockfall Hazard Rating System were implemented by the B.C. Ministry of Transportation and Highways. Thus, evolving mitigative measures since the 1970's have increased the safety of the population. There have been no reported fatal accidents caused by landslides in the corridor since the early 1990's. With increasing population density in the corridor, more attention should be paid to the potential for high-magnitude low frequency landslide hazards.

## 1. INTRODUCTION

The Sea to Sky Corridor, which includes Highway 99 and surrounding communities, is located in the southern Coast Mountains of British Columbia. The highway stretches 110 km from Horseshoe Bay to Pemberton (Figure 1). Historically, the Sea to Sky Corridor witnessed the 2<sup>nd</sup> worst Canadian landslide disaster in terms of casualties in 1915 losing 54 people in one single rock avalanche at Jane Camp. This was a mining camp owned by Britannia Mines, which was in operation from 1902-1974. In addition to great loss of life with more than 18% of the total number of

Canada's landslide related deaths (>600) occurring in the Sea to Sky Corridor, costs to infrastructure and resources have been estimated in millions of dollars (Figure 1). Recently, the Sea to Sky Highway has become the focus of attention for southern BC because it is being widened to accommodate traffic and development related to the 2010 Winter Olympics, to be held in Whistler and Vancouver. Thus, landslide hazards and risk in the corridor are at the forefront of discussion.

The first objective of the paper is to present a summary of historical landslide events based primarily on archived newspaper accounts, geotechnical consultant reports, and scientific articles. A total of 154 reported events were counted from 1855-56 to 2007 (Blais-Stevens and Septer, 2006; 2008; Blais-Stevens, 2007; Blais-Stevens and Hungr, 2007). The second objective is to describe specific historical landslide events that led to implementing mitigation measures in order to adapt to landslide risk in the corridor. The third and final objective is to discuss the landslide hazard potential in the corridor.

## 2. PHYSIOGRAPHIC SETTING

The southern Coast Mountains are a northwest-southeast trending mountain chain, part of the Canadian Cordillera. In the south, components of the Coast Mountains range in age from Upper Triassic to Recent. They are composed of volcanic, volcanoclastic, sedimentary as well as plutonic rocks (Monger and Journeay, 1994). Peaks are high, reaching elevations of 2500-3000 m. The area has experienced several glaciations and deglaciations over the last 2.5 million years. The most recent glaciation took place ca. 25,000-10,000 years BP (Clague, 1989).

The fall winter and spring climate of the corridor is dominated by the incursion of moist air masses from the North Pacific Ocean. The corridor receives up to 3000 mm of precipitation per year, making it one of the wettest parts of Canada. Thick snow packs accumulate during winter in mountains bordering the corridor. In summer, the coastal region comes under the influence of a large anticyclone, and there are spells of fair weather with infrequent convective storms. Air temperatures are moderated by maritime air masses and vary much less on the coast than farther inland. Mean January temperatures range from 1E-5EC. Topography produces strong local differences in microclimate. Precipitation increases and temperature decreases, with elevation (Hare and Hay, 1974; Ryder, 1989).

## 3. LANDSLIDE TYPES AND DISTRIBUTION

Historical landslide events were compiled from all the available documentation that could be found in archives, libraries, and government offices. The quality of the data was variable. Landslides were categorized according to type based on the definitions from Cruden and Varnes (1996). However, some interpretation had to be made because of the available descriptions. From the 154 events compiled, six types of landslides were observed (Figures 2a and b). These were: rock fall, rock avalanche, rock slide, debris slide, debris flow, and submarine landslide. As a first step in assessing the landslide hazard of historical events, we plotted the locations of the landslides as well as the relative frequencies at each site (Figures 2a, b). The landslide distribution maps clearly indicate that there have been more landslides historically in the southern part of the corridor between Horseshoe Bay and Porteau Cove. It is

important to note that in the southern part of the corridor, the highway is just metres away from very steep bedrock slopes unlike in the northern part of the highway where the valley is wider; thus, creating greater chances of slope failures reaching the highway and settlements than if farther away. The most abundant types of landslides have been rock falls and debris flows (Figures 2a, b, and 3). For about two thirds of these landslide events, the trigger/cause, when reported, was identified as either climate (54%) or construction (6%; Blais-Stevens, 2007; Blais-Stevens and Septer, 2008).

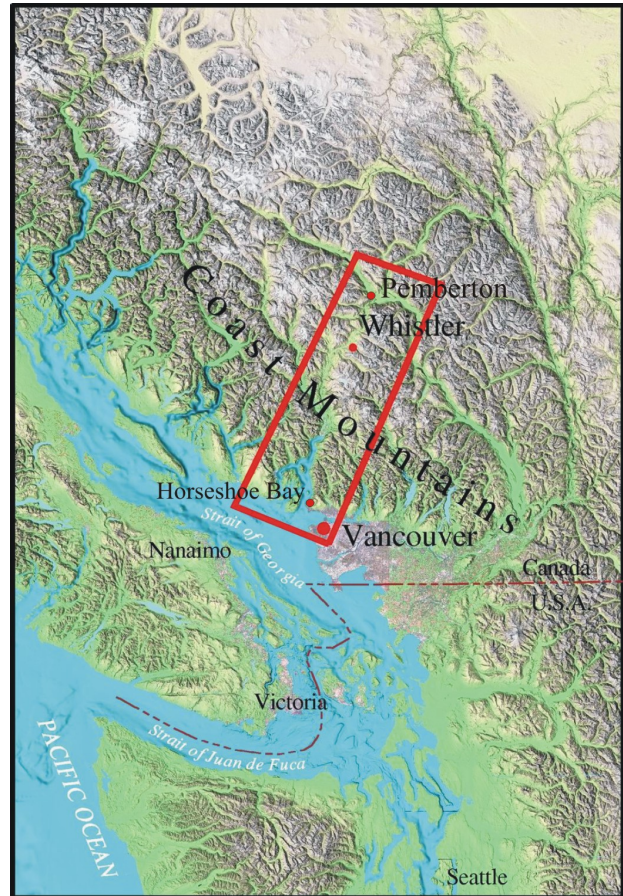


Figure 1. Location map of the Sea to Sky corridor shown within the red rectangle.

A histogram showing the frequency of historical events per decade (Figure 4) indicates that the number of events showed a dramatic increase on the 1950s (30 events). This likely is related to the construction associated with the opening of the southern extension of the Pacific Great Eastern railway (now owned by CN Rail) between Horseshoe Bay and Squamish in 1956 (Blais-Stevens and Septer, 2008). The 1980's (35 events) and 1990's (43 events) saw a peak in number of events. This is most likely due to a greater increase in development of the corridor, *i.e.*, more people, more infrastructure development, more awareness of landslide hazard, thus more reporting. Furthermore, most mitigation measures (*e.g.*, such as

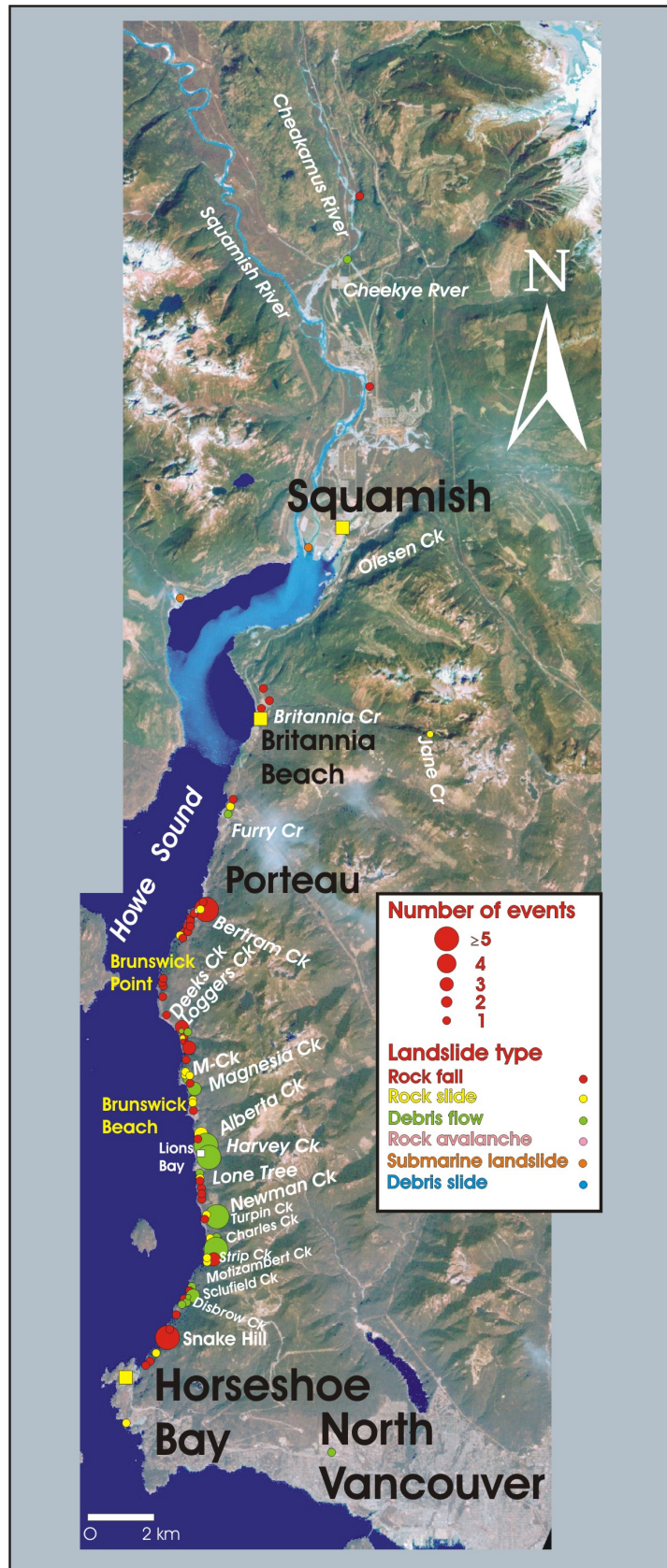


Figure 2a. Distribution of landslides along the southern part of the Sea to Sky Corridor from Horseshoe Bay to Cheakamus River. Landslide events are by divided (colour coded) by type (Cruden and Varnes, 1996) and according to number of events.

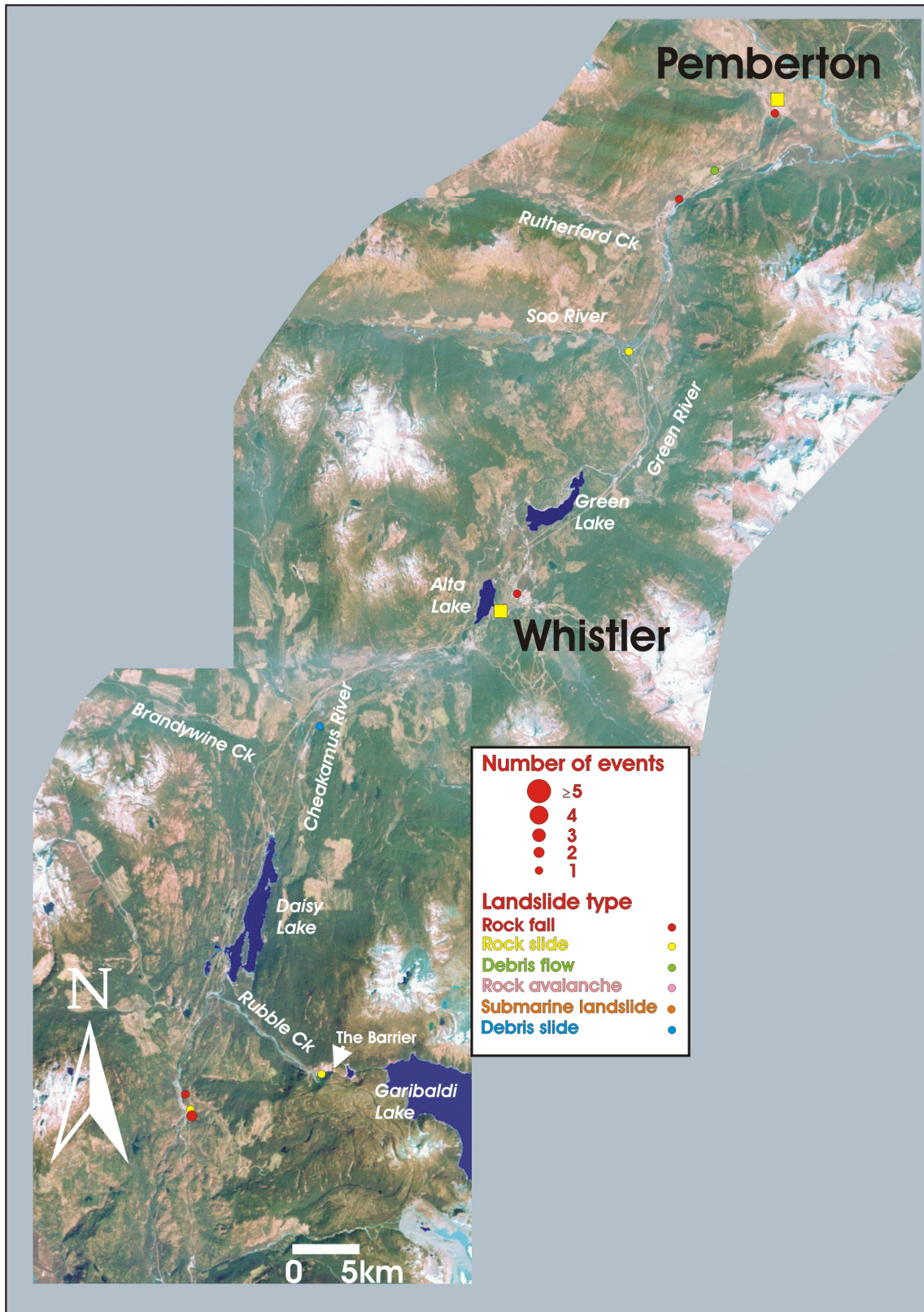


Figure 2b. Distribution of landslides along the northern part of the Sea to Sky Corridor from from Garibaldi Lake toPemberton. Landslide events are by divided (colour coded) by type (Cruden and Varnes, 1996) and according to number of events.

shotcrete, channel stabilization, debris basins, rock bolting, etc.) to alleviate the impacts of such landslide events were constructed only during or after the 1990's.

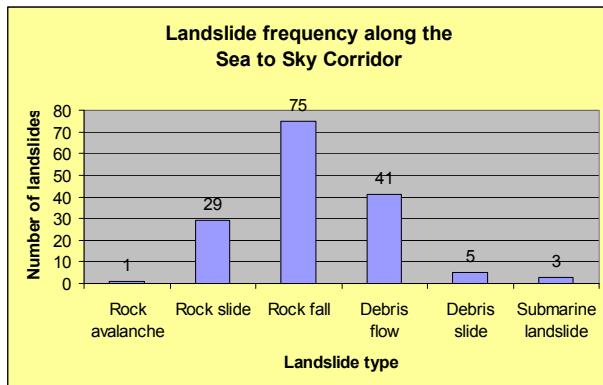


Figure 3. Number of landslides compiled from 1855-56 to 2007 divided by type.

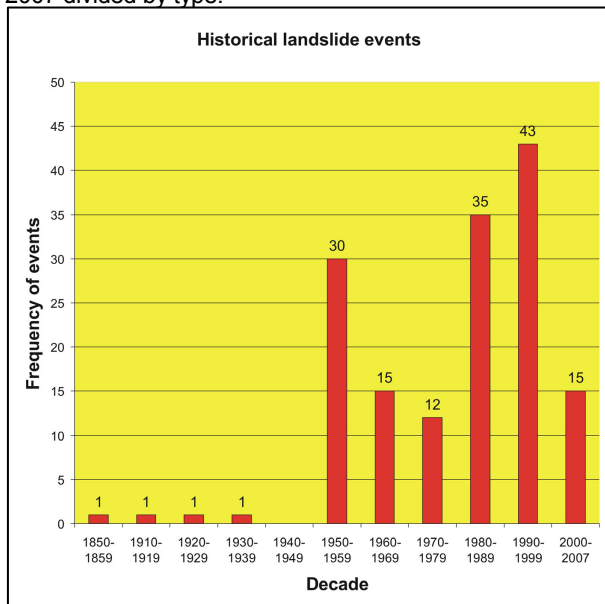


Figure 4. Number of reported landslide events per decade, from 1855-56 to 2007.

#### 4. MAJOR LANDSLIDE EVENTS IN THE HISTORY OF THE SEA TO SKY CORRIDOR

##### 4.1 Jane Camp

On March 22, 1915, at 12:05 a.m., a “snow and landslide” (a small rock slide) struck several bunkhouses at the Jane Mining Camp, part of the Britannia Mine complex (Figure 2). The amount of rock displaced by the Jane Camp rock slide was estimated at 200,000 m<sup>3</sup>. A total of 54 people were killed. The slide was probably caused by elevation of pore pressures within the slope caused by infiltration of water from rapidly melting snow during warm weather of the preceding 48 hours. Furthermore, it is thought that ground subsidence due to tunneling and stoping in fractured

Mesozoic volcanoclastic rocks at Jane Camp in 1914 may have contributed to a progressive deterioration of an unstable bedrock ridge approximately 300 m above the camp. A near-vertical crack on the ridge crest above Jane Camp was observed and photographed before the disaster struck (Eisbacher, 1983; Evans and Gardner, 1989). This was Canada’s second worst landslide disaster after Frank slide which killed 76 people in 1903.

##### 4.2 M-Creek debris flow

Around midnight on October 27, 1981, a small debris flow descended the steep channel (48%) of M-Creek, 2 km north of Lions Bay (Figure 2a). The debris flow consisted of surficial debris and fractured bedrock. It initiated along a steep tributary on the margin of an old clear-cut at an elevation of 1,500 m. The destruction of an old logging bridge on Brunswick Mountain, 650 m upstream of the M-Creek bridge on Highway 99, may have caused debris to pile up before releasing as a torrent of approximately 20,000 m<sup>3</sup> (Thurber Consultants Ltd, 1983; Church and Miles, 1987). The flow knocked out the central wooden support columns of the bridge and the 18-m long and 8-m wide centre span of the old two-lane wooden trestle highway bridge and cut an 18-m gap across the roadbed. The slide wall roared by, sweeping away 70 m of BC Rail track and a small house built on the beach near the creek’s mouth. The bridge, a timber trestle structure built in 1957, was demolished in less than 30 seconds. The fatal spot was about 70 m north of a curve, and for northbound drivers on a bad night, the gap would have been difficult to spot immediately. Five cars approaching the bridge in the rain-swept darkness plunged into the chasm and disappeared in the debris streaming to the sea. The accidents claimed nine lives (Eisbacher, 1983; VanDine, 1985). As a result of the accident, safety measures were introduced including a tape-recorded highway status broadcasting system, a series of roadside emergency telephones and 24-hour road patrols at a cost of almost \$5 million.

##### 4.3 The Just rock fall case

Early on January 16, 1982, heavy snowfall brought traffic on Highway 99 to a standstill at Brunswick Point (Figure 2a). A single boulder fell from natural rock slope above Argillite Cut, a badly sheared rock face above the highway that was known for frequent rock slide and rock falls. The boulder was thrown into a trajectory by a natural bench in the slope, landed on top of a car, killing a 28-year old woman. The victim’s father, also a passenger in the car, was seriously injured (Eisbacher, 1983). The father, Mr. Just, successfully sued the provincial Ministry of Transportation and Highways (MoTH) for \$1M in damages, which took nine years to resolve with the final decision being delivered by the Supreme Court of Canada. Subsequently, MoTH developed a comparative method of ranking areas by hazard. Since 1993, MoTH has adopted the Rock Fall Hazard Rating System based on the Oregon system (Bunce *et al.*, 1997).

##### 4.4 Debris flows along Howe Sound

The frequent occurrences and heavy damage caused by debris flows in steep creeks along Howe Sound, such as Alberta, Harvey, Charles, Turpin, Newman, Disbrow, Sculfield M- Creek, and Magnesia creeks, led to very detailed geotechnical studies carried out by Thurber Consultants (1983), on debris flow and flooding hazard (Figure 2a). These led to construction of several structures to control extreme stream discharges debris flows during periods of heavy precipitation. At Harvey Creek in the village of Lions Bay and two other creeks, debris basins were built to catch excess debris (Thurber Consultants, 1983; Eisbacher, 1983; Hungr *et al.*, 1987; Hungr and Skermer, 1998; VanDine, 2002; Couture and VanDine, 2003). These basins were built with a retention capacity which exceeds the estimated volume of debris available to form debris flows in their respective basins. Other structures, such as a concrete-lined “shooting channel” were built to control Alberta Creek also located in Lions Bay (Figure 2a).

#### 4.5 Rock fall and rock slides between Brunswick Point and Porteau Bluffs

Rock fall and rock slide incidences have been the most damaging along a five kilometre stretch between Brunswick Point and Porteau Bluffs. The bedrock in parts of this segment is intensely fractured consisting of meta-sedimentary, igneous, and volcanic rocks, with stress relief joints steeply dipping towards the Sea to Sky Highway. Several adaptation measures were undertaken to minimize the effects of rock falls and rock slides in this area and elsewhere along the corridor. These were blanket wire mesh, shotcrete, scaling, rock bolts, and horizontal drainage holes (Eisbacher, 1983; Bunce *et al.*, 1997; Hungr and Skermer, 1998).

### 4. LANDSLIDE HAZARD MITIGATION AND POTENTIAL

#### 5.1 Charles Creek

Landslides continue to be a threat in this mountainous corridor, but mitigation measures against landslide hazards and risk seem to have been successful so far, with no reported casualties since the 1990s.

As an example, Charles Creek is one of the creeks with a historical record of high frequency debris flows with at least 7 disastrous events. The worst event took place on 18 September 1969 when a debris flow destroyed a wooden trestle bridge and thus created chasm in the highway. Two cars then plunged into the gaping hole, but the four occupants survived. One other car and its driver disappeared along this stretch of road, and were presumably carried to sea by the debris flow (Eisbacher, 1983). The driver and the car were never recovered.

As a consequence, a catchment basin was built at this high gradient creek as well. Thus, in November 2006, a debris flow of 20,000 m<sup>3</sup>, which could have affected the highway, the railway, and the homes built on the fan of Charles Creek, was controlled by the debris basin (Figure 5). What could have been a disastrous event at Charles Creek did

not even make the news because the debris basin worked so efficiently.



Figure 5. Charles Creek debris basin at work. Notice the debris basin is stopping the debris flow deposit and protecting the Sea to Sky Highway, railway, and homes built on the alluvial fan.

#### 5.2 Jane Creek landslide hazard

Although mitigation measures have worked in some areas along the corridor, the threat of high magnitude, low frequency landslides is still present.

One of the present concerns is the Britannia Creek basin. Subsidence and tension cracks caused by underground mining in mid-1900's are apparent along the opposite wall of the where the 1915 Jane Camp rockslide took place (Figure 6), involving a rock volume in the order of 20 million m<sup>3</sup>. Preliminary observations by several specialists, including the second author, indicate that the heavily fractured volcaniclastic bedrock could fail catastrophically. However, more detailed research and monitoring are needed to confirm the hazard. If there is potential for slope failure, Britannia Beach, which is a town under expansion, and the Sea to Sky Highway could be at risk.

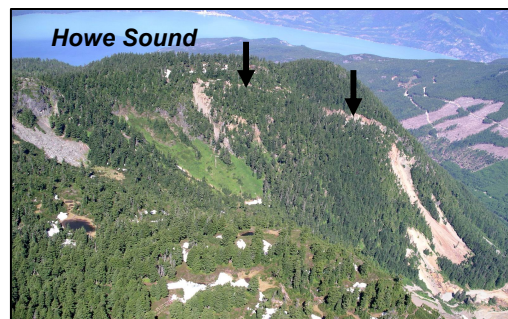


Figure 6. Subsiding rock wall at Jane Creek (arrows indicate major tension crack), east of Britannia Beach. Picture taken from the head scarp area of the 1915 catastrophic landslide site mentioned above.

#### 5.3 Mount Garibaldi

Mount Garibaldi is a 2600 m Quaternary volcano situated at the head of Howe Sound, north-east of the town of Squamish (Figure 2a). A large part of the present stratovolcanic edifice was built by mixed explosive and effusive activity in contact with ice, during the final stages of Pleistocene glaciation (Matthews, 1958). During and following the retreat of ice, the valley of the Cheekye River deeply incised the volcano and the underlying metamorphic basement. At present, the drainage of the Cheekye River is about 10 km long, with a vertical relief of more than 2.5 km. It culminates in a 1.5 km near-vertical headwall, cut in altered and weak metamorphic basement rocks, capped by a complex assemblage of unwelded volcanic breccias and dacitic lava flows (Figure 7).



Figure 7. The headwall of Cheekye River valley. Scars of large rock slides can be recognized on the slopes. The interface between Quaternary volcanic rocks and the metamorphic basement coincides approximately with the tree line.

The erosion products from the Cheekye Valley accumulate in a large fan, covering the valley floor at the confluence of the Squamish and Cheakamus Rivers. The surrounding area has been the subject of rapid development due to the expansion of the Squamish community to the north during the last three decades. However, perception of hazards has so far kept the Cheekye Fan under development restrictions. In early nineteen-eighties, the presence of a large debris flow deposit was identified on the fan surface (Friele and Clague, 2005). The stratigraphic record of the fan gives clear evidence that volcanic debris flows of up to several million m<sup>3</sup>, sourced in the Cheekye headwaters, have reached the corridor periodically during the Holocene. The largest of these covered the surface of the fan with deposits up to 5 m thick approximately 1100 years ago. Studies aiming at quantifying the debris flow hazard at this site in order to allow development within tolerable risk limits are continuing.

The second recognized hazard source related to the Garibaldi volcanic centre is the valley of Rubble Creek, half-way between Squamish and Whistler. Here, the corridor crosses the deposits of the 1855-56 rock avalanche (Moore and Matthews, 1978). Its source is the Barrier, a 500 m high cliff created by damming of basaltic lava flows against retreating Pleistocene ice, filling the

Cheakamus Valley. (Figure 8) The history of the Rubble Creek drainage also includes large debris flows, which likely originated by major overflows of Barrier Lake, sending catastrophic discharges down the creek channel and re-mobilizing talus and rock avalanche deposits in the valley. Again, important development restrictions exist within the corridor on account of potential renewal of landslide activity in the valley.



Figure 8. The Barrier, a lava cliff at the head of Rubble Creek drainage and source of the 1855-56 rock avalanche that reached the Squamish-Whistler corridor.

## 6. CONCLUSIONS

In the last 150 years, a total 154 historical landslide events were reported in newspapers, scientific and geotechnical reports. The highest concentration of landslide events is located in the southern part between Horseshoe Bay and Porteau Cove. The most abundant types of landslides are rock falls (75) and debris flows (41). In about two thirds of the events, the cause/trigger is mentioned as either climate or construction.

The 1980s and 1990s saw an increase in reported events due to increase in development, greater population, and greater awareness of landslide risk.

Some of the major historical landslide events such as, Jane Camp, M-Creek debris flow, the Just rock fall, the abundant rock falls and debris flows influenced the responsible authorities to mitigate against landslide risk. Evolving mitigative measures undertaken since the 1970's have increased the safety of the population with no reported casualties since the early 1990's.

Nevertheless, there is still a landslide hazard potential. Of special concern are high magnitude, low frequency landslides at locations such as Jane Creek, Cheekye Fan and Rubble Creek. Appropriate management of these risks represents an important challenge for the geoscience and engineering professions in the region. Overestimation of the risks and the use of development restrictions are extremely expensive, as it estranges developable land which is rare and extremely valuable in this mountainous terrain. Underestimation of the risk could, of course, lead to major disasters. Professionals charged with outlining

risk zones in this area, as well as developers and government officials face very difficult decisions.

## 7. ACKNOWLEDGEMENTS

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