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G. H. Eisbacher

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Article abstract

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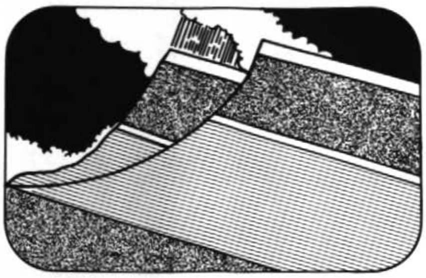


# First-Order Regionalization of Landslide Characteristics in the Canadian Cordillera

G.H. Eisbacher
*Geological Survey of Canada*
*100 West Pender Street*
*Vancouver, B.C. V6B 1R8*

**Abstract**
Landslide modes in the Canadian Cordillera are regionalized into eight zones according to the dominance of specific types of failure and mass transport. The Coast-Insular Zone is dominated by rock falls, rock avalanches, debris and earth flows; the St. Elias Zone by rock slumps and debris flows; the Plateau Zone by earth flows and rock slumps; the Skeena Zone by rock slumps; the Yukon-Selwyn Basin Zone by rock slumps; the Cassiar-Columbia Zone by deep-seated slope-sagging and gravitational spreading; the Eastern Carbonate Zone by rock avalanches and debris flows; the Foothills Zone by soft-rock slumps and earth flows. Landslide abundance in the Canadian Cordillera is related to the complex interaction of local geology on the one hand and regional factors such as relief, intensity of precipitation, and seismicity on the other. The landslide hazard deserves special attention in the recreational hinterland of Vancouver and Calgary.

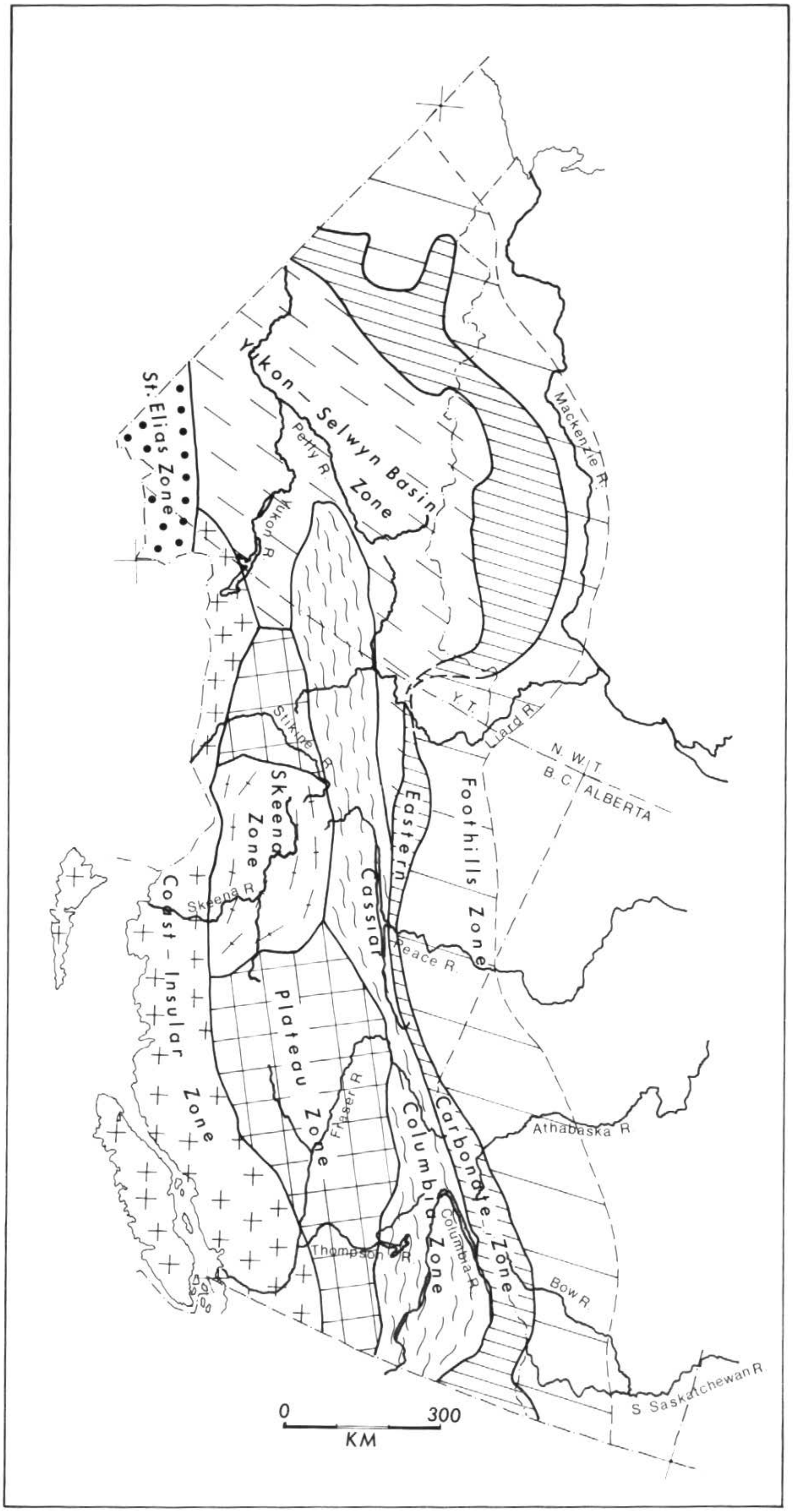
**Introduction**
It is widely recognized that landslides occur in areas of high rainfall, seismic activity and strong relief. A large and rapidly growing literature identifies these as the three most important parameters contributing to landslide hazard (Zaruba and Mencl, 1970; Radbruch-Hall and Varnes, 1976; Voight, 1978). However, it is also being realised that the *type* of failure found in any region is strongly controlled by the local geology, and that specific geologic conditions such as permafrost or sensitive clays, if disturbed, can create serious landslide problems anywhere. The art of dealing with the special geologic conditions has recently led to the notion of landslide 'behaviour belts' (see Cotecchia, 1978, for an excellent review of the state of the art). This notion is based on the intuitive feeling that a certain geology expresses itself in very special types of slope failure. As an example, it may be helpful to recall that the old Swiss term 'flysch', which is now widely accepted as a geological facies term, originally meant no more than that rock slopes in this geological formation 'flowed'. Landslide behaviour can be defined as the interplay between the *internal fabric* of bedrock slopes, the *erosional history* of unconsolidated drift deposits, and *gravity* during Holocene time. Mapping of landslide behaviour is most useful on large-scale maps (1:50,000 and larger). However, a first-order characterization of landslides can often be carried out for regions larger than those covered by maps of the indicated scale. For example, Mollard (1977) has recently presented an overview of the principal landslide types found in Canada, providing a most stimulating introduction to the problems encountered in this country.

In the Canadian Cordillera, economic considerations, environmental awareness and court litigations have created a growing demand for landslide information (Farquharson, 1976). In general, this information cannot be extracted from existing geological reconnaissance maps and the bewildering complexities of physiography and geology have, so far, precluded meaningful generalizations concerning the distribution of landslide types in the mountainous part of western Canada. During the last ten years, while engaged in geological work in the Canadian Cordillera, the author has been impressed by how much the regional geologic framework influences landslide behaviour. Figure 1 attempts to illustrate this geologic-physiographic control. The first-order distribution of landslide behaviour in eight zones obviously cannot differentiate between areas of high and low landslide incidence and is not suitable for local planning decisions. It can, however, serve as a guide to the dominant slide types within broad belts, and, more importantly, help to focus further work. For example, the techniques for appraising earth flows in the Plateau Zone differ greatly from those required to assess the hazard of deep-seated slope sagging in the Cassiar-Columbia zone, and thus specialized knowledge can be utilised according to the landslide zones. Transitions from one zone to another do not always coincide with physiographic boundaries proposed for the Canadian Cordillera by Bostock (1948) and Holland (1964) although physiography and geology are the most important regional parameters affecting the distribution of landslides.

In practical terms, landslides are dealt with on two scales: large, deep-seated slides (sagging rock slopes, rock avalanches, and rock slumps) when known to be a threat to permanent structures such as mine sites, settlements, dams and reservoirs may justify large expenditures in order to assure safety within a relatively small area; small, shallow slides (debris flows, earth flows, rock falls) when known to be common along a planned transportation corridor or logging zone may justify a detailed regional map from which the cumulative cost of maintenance or environmental impact can be estimated.

No area in the Canadian Cordillera can be considered entirely free of the landslide hazard although in many places it is very low. The principle that early recognition may avoid costly later treatment is probably the most worthwhile point to remember, although (as in medical practice!) much credit will always go to the spectacular, last minute cures.

In the following sections landslide characteristics of the eight zones will be described using historical and prehistorical examples where available. The landslide terms applied in this review are illustrated in Figure 2. A subsequent section attempts to delimit broad regions in the Cordillera where external factors such as precipitation, relief and seismicity favour landslide activity.




## Coast-Insular Zone

This zone comprises high granitic massifs and more subdued volcanic-metamorphic complexes, overlain by younger volcanics and glacial deposits. Surface-parallel jointing in massive granitic rocks and shear zones in metamorphic terrain are the most important discontinuities with respect to bedrock slides. Locally, flatlying lavas or Pleistocene drift resting on glacially polished bedrock create potentially unstable situations. A dense mantle of vegetation has hampered study of rock falls, rock avalanches, debris flows and earth flows which contribute to the great variety of landslides found in the Coast-Insular Zone.

*Rock falls* are a hazard along high bedrock slopes, particularly those which are undercut by roads or railroad tracks (Fig. 3). Historically rock falls have contributed considerably to the cost of highway and railroad maintenance along the lower Fraser River and other transportation routes in the Coast-Insular Zone.

In the Fraser Canyon an early spectacular rock fall, caused by excavation for the Canadian National Railroad (1913-14) at Hells Gate, blocked the Fraser River and prevented the upstream migration of Pacific salmon. In spite of the subsequent installation of fish ladders over the fallen rock mass the salmon runs have not regained their pre-slide magnitude (Barker, 1977, Fig. 81). Rock falls in the Fraser Canyon have continued since then, and their incidence is generally highest during the wet autumn and winter months (Piteau, 1977). Some rock falls are preceded by slow movement or creep of the rock mass during the wet season (October to March) thus permitting a timely recognition of the hazard and application of remedial measures (Peckover and Kerr, 1977). Seismicity is also a factor in triggering rock falls: for example numerous rock falls occurred during the 1946

**Figure 1**

*Map showing the eight first-order landslide behaviour zones of the Canadian Cordillera proposed in this review. Each zone is characterized by the predominance of specific, geologically controlled, slide characteristics seen in historical and pre-historical examples of slope failures.*

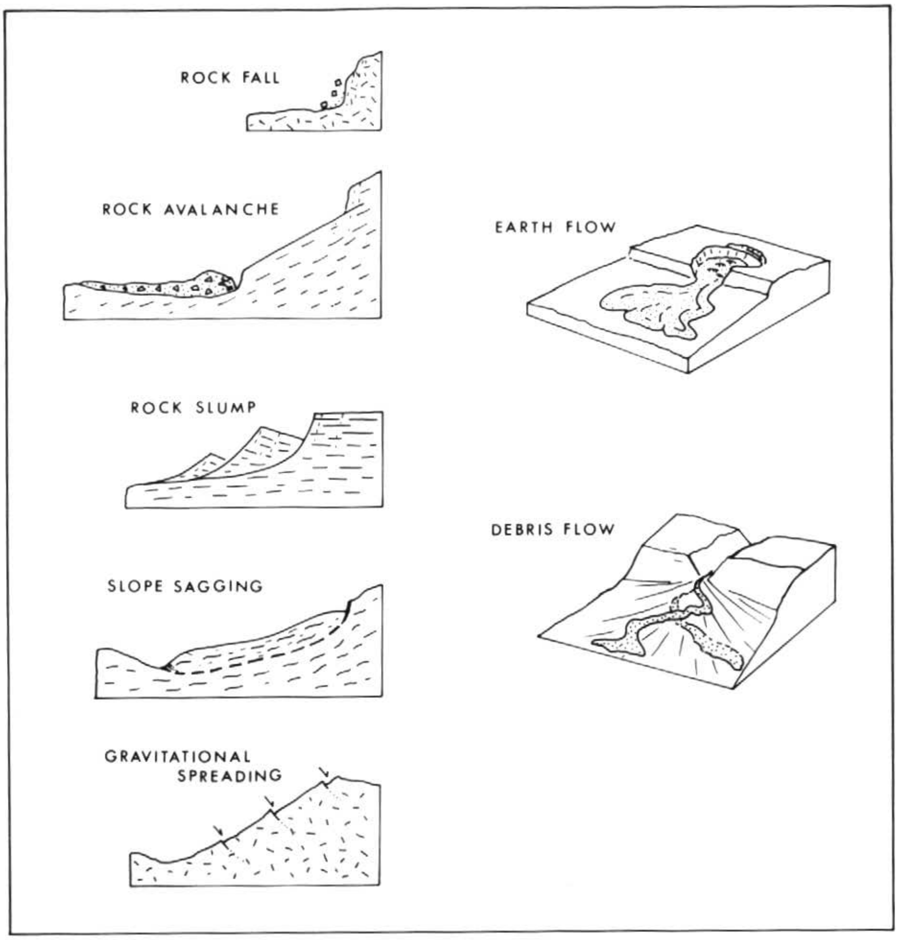



**Figure 2**
*Simplified landslide terminology used in this paper.* Rock fall *is the free or tumbling motion of bedrock fragments;* rock avalanche *(or* sturzstrom*) is the extremely rapid downhill motion of large internally disintegrating rock masses;* rock slump *is the rotational failure of rock slopes ( - if outward translation is dominant the term* lateral spread *is used);* slope sagging *is the deep-seated slow movement involving high slopes of internally broken rock masses;* gravitational spreading *is expressed by enigmatic uphill-facing scarplets in bedrock;* earth flow *is the predominantly translational movement of large quantities of unconsolidated deposits;* debris flow *is the rapid movement of poorly sorted water-saturated materials. There are numerous landslide types transitional between those illustrated above, but limitations on space prohibit further subdivision for the present purpose.*

Vancouver Island earthquake (Mathews, 1979).

*Rock avalanches* in this zone are found near glacially oversteepened valley walls which display prominent discontinuities dipping towards the valley floors (Fig. 4). Slides may be triggered by seismic shaking or excessive piezometric pressures in the rock slopes. If the rock avalanche incorporates water-saturated sediments, snow or ice, an initially dry rock avalanche may change into a debris flow of great destructive power.

Four major historical rock avalanches, some associated with debris flows, have been documented, and in addition a number of prehistoric rock avalanche deposits are known from the Coast-Insular Zone. The historical slides are the Rubble Creek Slide in 1855-56 (Moore and Mathews, 1978), the Hope Slide in 1965 (Mathews and McTaggart, 1969 and1978), Devastation Glacier Slide in 1975 (Mokievsky-Zubok, 1977; Patton, 1976; Read, 1977), and the failure of a cliff near the Britannia Mine

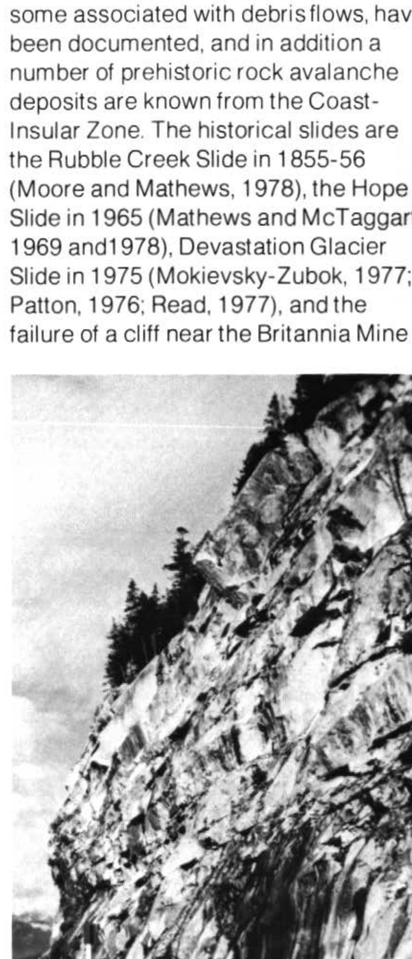


**Figure 3**
*A high rock slope in granitic rocks north of Vancouver which has been undercut by a transportation route. Many joints are parallel to the original surface and individual blocks occasionally break loose in rock falls.*

**Figure 4**
*View of the composite discontinuity which served as a rupture surface for the 1965 rock avalanche near Hope, B.C. in the Coast-Insular Zone.*

(Jane Camp) in 1915 (Ramsey, 1967, p. 39-44). The Jane Camp Slide is particularly interesting because only two days before the disaster occurred open cracks in the mountainside above were inspected by company geologists and the mountain 'appeared to be solid to these experts' (Ramsey, 1967, p. 34). Shortly thereafter about 60 people lost their lives when a rock avalanche mixed with snow buried Jane Camp.

*Debris flows* in the Coast-Insular Zone are common along steep slopes and gullies. Although fundamentally related to high seasonal rainfall they often tend to be triggered by logging activity in the uplands (O'Loughlin, 1972; Alley and Thomson, 1978; Clague, 1978). Debris flows seriously damaged the town of Port Alice (northern Vancouver Island) after excessive rainstorms in 1973 and 1975.

*Earth flows* in this zone are associated with subaerial bluffs and submarine slopes composed of fine-grained unconsolidated deposits. Several earth flows have been caused by excavation activity in glaciomarine surficial deposits in the greater Vancouver area (Armstrong, 1957 and in press), and a large destructive flow of similar materials occurred near Terrace in 1962 (Clague, 1978). Submarine earthflows inflicted considerable damage to an industrial installation in Howe Sound near Vancouver in 1955 (Skermer, 1976) and caused a damaging seawave in Douglas Channel near Kitimat in 1975 (Luternauer and Swan, 1978).

In the Coast-Insular Zone the scenario for serious landslide activity would embody a period of high-intensity rainfall (or meltwater runoff) combined with occurrence of a strong earthquake.

### St. Elias Zone

The St. Elias Mountains consist of a great variety of sedimentary and igneous rocks which, in the course of geological history, have been intensely faulted and fractured. The granitic massifs of the western St. Elias Zone rise above large ice fields and glaciers which cover most of the land surface. Landslides are ubiquitous in the nonglaciated eastern part of the zone and include rock slumps, rock avalanches, gravitational spreading, and debris flows.

Mixed *rock-earth slumps* are common along erosional plateau rims composed of flat-lying sedimentary and volcanic rocks. Active slumps commonly force vigorous mountain streams against opposite valley walls where erosional undercutting generally initiates other slumps. Such continued undercutting and progressive failure can be observed along most narrow creeks transecting fractured bedrock or unconsolidated drift deposits of the eastern St. Elias Mountains.

*Debris flows* can be a direct outcome of the slumping process when slides form temporary dams across steep creek beds and, in a sudden burst, discharge the stored water onto soft materials below the breached dam. Other debris flows originate by rapid discharge of glacial lakes. The numerous alluvial fans in the St. Elias Zone are the depositional record of debris flow activity (Broscoe and Thomson, 1969).

*Rock avalanche* deposits of prehistoric age have been reported from several places (Rampton, in press). During and after the great 1964 Alaska earthquake many rock and ice avalanches were dislodged along high cliffs above glaciated terrain in Alaska, a short distance west of the Canadian St. Elias Mountains (Post, 1967). The high seismicity of the whole region would indicate that rock avalanches are also a potential hazard along the high cliffs of the glaciated portion of the St. Elias Zone.

*Gravitational spreading* of mountain sides (Fig. 5), possibly related to prehistoric earthquakes along the Denali Fault, is common near the northeastern boundary of the St. Elias Zone (Clague, 1979). Individual uphill-facing scarplets are generally less than six kilometres long. At present, it is not clear whether the scarps are due to shaking and sinking of a shattered mountain core or whether they are due to extension and minor normal faulting within a broad zone of tectonic shear.

The area encompassed by the St. Elias Zone is relatively small but is one of the geologically most hazardous regions in Canada.

### Plateau Zone

The Plateau Zone is characterized by intensely fractured and faulted bedrock formations which are commonly overlain by flat-lying volcanic strata and glacial drift (e.g., lacustrine silts). Rivers flow in deep, glacially modified valleys cut into the rolling uplands. The two dominant landslide types in the Plateau Zone are earth flows and rock slumps.

*Rapid earth flows* occur where large amounts of water penetrate the benches of lacustrine silt which are perched against many of the valley sides in this zone. In a dry state, these 'white' silts stand in vertical walls, and natural

**Figure 5**
*Uphill-facing scarplet in bedrock south of Granite Creek, eastern St. Elias Zone. The bedrock here is offset by about 1.5 metres.*

surface runoff creates only deeply incised gullies and 'pipes' (Evans and Buchanan, 1976). However, irrigation water (in the dry south) or excessive rainfall (farther northwest) may cause liquefaction which converts initially stable siltbanks into earth flows whose consistence has been likened to thick pea soup.

Historically, the most important earth flows occurred in the Thompson River valley. In the 1870s, after the excitement of the Caribou gold rush had subsided somewhat, farmers moved into the dry Thompson valley where they began to work small plots of bench land which they irrigated with water diverted from upland creeks and lakes. As a result several of the silt benches failed, generally three to six years after irrigation had been initiated. The largest of these earth flows occurred in 1881 south of Ashcroft, where a slide about 600 metres wide blocked the Thompson River and formed a lake 18 kilometres long. After a few days this dam broke and the water rushing through the gap "caused a terrific flood in the valley below" (Stanton, 1898). The Canadian Pacific Railroad laid its track over deposits of this slide but the company was plagued by new earth movements of the same nature which shifted the tracks relentlessly towards the river. At one point a train-load of tea was said to have derailed and disappeared into the river - a great setback to the march of civilization on the prairies! A thorough study by Stanton (1898) recognized the causal relationship between irrigation and earth flows (Fig. 6) and a court injunction was granted in 1899 which stopped irrigation along the benches above the railroad track. However, only six years later (1905) another rapid earth flow, also caused by irrigation, killed 15 people near Spences Bridge (Drysdale, 1912, p. 126-127). This slide happened in a place where a previous earth flow had overridden the local Indian burial grounds.

Slow earth flows are known from various parts of the Plateau Zone. One of them crosses the Transcanada Highway near Drynock and therefore has a long history of investigation. Prior to stabilization attempts movement rates exceeding 50 cm/year were registered (VanDine, 1974). More recently, small segments of the densely populated silt banks in Kamloops have been set in slow motion by garden sprinklers!

Earth flows similar to those along the benches of the Thompson River are also known from the Fraser and Chilcotin drainage systems.

*Rock slumps* are found along the steep walls of valleys cut into the upland plateaus. They are especially conspicuous where flat-lying lava flows rest on less resistant strata. Commonly, the lower slopes show the ominous signs of outward bulging. These rim-slumps can exceed 100 x $10^6 m^3$ in volume. In the dry southern Plateau Zone most of the incipient rock slumps are not moving at present and are relicts of a wetter past, but slight changes in the hydrology of the slopes probably would re-initiate movement.

In the northern segment of the Plateau Zone (upper Stikine region) fresh head scarps and debris lobes indicate current movement of rock slumps along the edge of volcanic and sedimentary plateaus, (e.g. Souther, 1971, p. 5).

## Skeena Zone

The Skeena Zone covers a mountainous terrain composed of folded and faulted Mesozoic sandstone, shale, conglomerate, and volcanics. Within a large part of the Skeena Mountains clastic strata strike northwesterly and dip to the southwest. Landslide hazard exists in the form of rock slumps, (Alley and Young, 1978).

Large *rock slumps* are common in high slopes of conglomerate, sandstone and volcanics. Failure begins generally

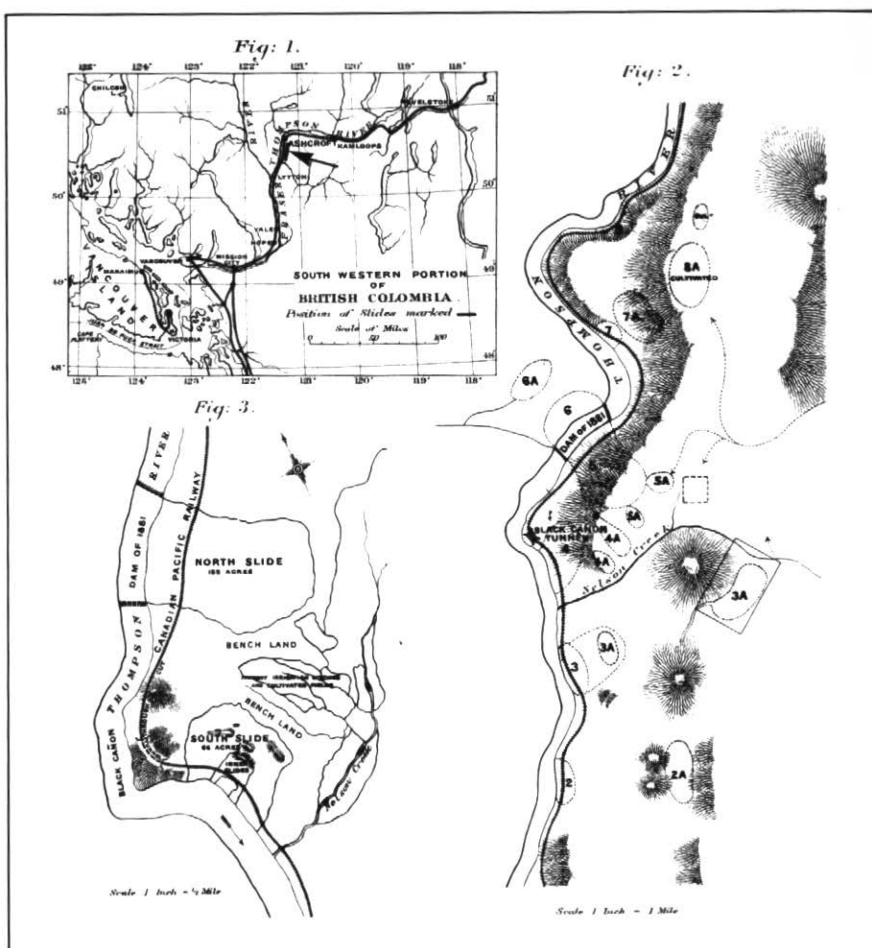



**Figure 6**

*This illustration is a reproduction of the original documentation by Stanton (1898) of the relationship between irrigation on silt-benches above the C.P.R. railway tracks (oval plots suffixed with A) and the resulting earth flows below (plain numerals) south of Ashcroft, B.C. This convincing cartographic presentation led to the subsequent court order which prevented further irrigation of the land plots directly above the C.P.R. track.*

with slow rotational movement but can develop into rapid avalanching along inclined bedding planes (Eisbacher, 1971). Southwest facing dip-slopes are most prone to rock slides. Recognition of landslide problems in this region is difficult on account of dense vegetation in the low valleys and solifluction at higher elevations. Undercutting of rock benches along the deeply incised rivers poses a continuing problem of slumping.

Probably the earliest known historical slide in the Cordillera was of this type. Morice (1904) relates how at the beginning of the nineteenth century the Kitksan (Tsimshian) and Western Babine tribes supported themselves from the abundant salmon runs on the Skeena River and Bulkley River, respectively. Life seems to have been peaceful" . . . until the year 1820, or thereabouts, when a large piece of rocky cliff overhanging the same river (Bulkley) at the place now called Ackwilgate . . . having fallen across the stream, barred it so completely that it formed a cataract of sufficient height to prevent the fish from getting up to the Moricetown falls. Threatened with starvation the Western Babines went in a body, armed cap-a-pie, and forcibly took the new terminus from its owners of Tsimshian parentage. In the course of time, the rock, which was to give a name to the new place - Rocher Deboule - wore away to such an extent that salmon could return to their former haunts up the river . . ."(Morice, 1904, p. 8). The Kitksans, however, did not regain their ancient fishing grounds.

## Yukon-Selwyn Basin Zone

This zone includes a large area of subdued relief. A variety of igneous and sedimentary rocks are exposed in upland plateaus which rise above broad, drift covered river valleys. However, where granitic plutons pierce soft shale and sandstone along the southwestern margin of the Selwyn Basin considerable local relief exists. Rock slumps are the principal slide type particularly in the deformed sedimentary strata of the Selwyn Basin but, because of extensive surficial solifluction lobes, slumped bedrock terrain is often difficult to recognize. Rock falls are common along steep granitic bedrock walls, and minor earth slumps occur on drift covered valley bottoms.

## Cassiar-Columbia Zone

This zone is underlain mainly by metamorphic rocks. Smooth densely vegetated slopes are commonly parallel to gently dipping foliation or schistosity in the bedrock. Deep longitudinal valleys such as the Rocky Mountain Trench are filled with glacial drift which has been sculptured into terraces by Holocene fluviatile erosion. The principal landslide hazards in the Columbia-Cassiar Zone are deep-seated slope sagging and gravitational spreading.

Deep-seated *slope sagging* in this zone is poorly understood but seems to occur preferably in areas where foliation and shear-zones in the metamorphic bedrock dip towards the axis of the adjacent valleys (Fig. 2). Under such circumstances it is possible that thick broken slabs and veneers of rock (up to 2,000 x $10^6 m^3$) move slowly downslope, leaving a distinct scarp at the head of the slope which stands out on air photographs (Mollard, 1977). A basal slide surface is generally difficult to define because movement occurs along numerous internal zones of dislocation akin to those in the tongue of a glacier. In most instances it is likely that movement began thousands of years ago and has been maintained by fluvial undercutting of the toe and by the annual downward percolation of water during the spring melt. The rate of down-slope movement rarely exceeds a few centimetres per year.

The Downie Slide (Fig. 7) along the Columbia River, north of Revelstoke, B.C., has recently received intensive study (Piteau *et al.*, 1978; Gardner *et al.*, 1976) and is a dramatic example of large scale slope sagging. Many other slopes in the Columbia-Cassiar Zone exhibit sagging although generally on a smaller scale than that of Downie. Sagging slopes have been studied widely in the Central Austrian Alps in conjunction with engineering projects. There the terms "Sackung" (= sag), "Bergzerreissung" (= mountain rupture) and "Talzuschub" (= valley closure) have been applied to the slow and deep disintegration of mountain slopes (Ampferer, 1939; Zischinsky, 1969 a, b).

The central and tantalizing question concerning large sagging rock slopes is whether or not the slow creeping motion can change into rapid and therefore potentially catastrophic rock avalanches. Rock avalanche deposits are known from some steep-walled valleys of the Columbia Mountains and a minor rock avalanche fell into Upper Arrow Lake in 1903 (Brock, 1904), but it is not known whether these rockslides were

**Figure 7**

*The Downie Slide in the Columbia River valley (Cassiar-Columbia Zone). The snow covered band which runs across the mountainside indicates the headscarp of the sagging slope. The sagging involves about 2000 x $10^6 m^3$ of metamorphic rocks.*

preceded by long continued slope sagging.

*Gravitational spreading* of mountain slopes is another poorly understood phenomenon of the Cassiar-Columbia Zone. It is indicated by rock scarps facing up-slope and trending parallel to the valleys. A general discussion of this phenomenon has recently been given by Radbruch-Hall *et al.* (1976) and Radbruch-Hall (1978). Scarplets such as those observed on Nagle Mountain along the Columbia River may have originated by expansion of mountain massifs following deglaciation (Mollard, 1977). In the northern part of the Cassiar-Columbia Zone up-hill scarps are parallel with faults which follow the northern Rocky Mountain Trench.

Parts of the Cassiar-Columbia Zone are also subject to debris flows (e.g., Nasmith, 1972, p. 20-21). Settings with active debris flows are characterized by sparsely vegetated alluvial fans at the mouth of steep gullies. Siltbanks along the major rivers and lakes of this zone tend to fail in small slumps.

**Eastern Carbonate Zone**

This zone includes high ranges composed of southwestward dipping strata of massive limestone, dolomite and quartzite in the Rocky Mountains, Mackenzie mountains, Wernecke Mountains, and Ogilvie Mountains. These bedded formations of Proterozoic and Paleozoic age are broken by southwest-dipping thrust faults which are commonly hidden along the bottom of forest covered valleys. The white carbonate cliffs soaring above have invoked images of fortresses, castles, steamboats and cathedrals. The principal landslide types are rock avalanches and debris flows.

*Rock avalanches* (or 'sturzstroms') in the Eastern Carbonate Zone have left deposits of angular debris on many valley floors. They bear witness to extensive post-glacial cliff failure along the whole length of the zone. Rock avalanches are especially common in the southern Rocky Mountains and the Mackenzie Mountains (Fig. 8A). There, all major rock avalanches originated by failure of carbonate and quartzite formations which dip towards the adjacent valley floors (Cruden, 1976; Eisbacher, 1977 and in press). In the Rocky Mountains bedding-plane failure affected slopes with strata dipping more than 25°. In the Mackenzie and Wernecke Mountains, which are located within a significant intra-plate earthquake belt, seismically-induced collapse also occurred above bedding planes dipping less than 15°. Failure of as much as 400 to 500 x $10^6 m^3$ of rock can be documented locally (Cruden, 1976; Eisbacher, 1977). The shape of the runout zone of these most dangerous landslides depends on the topography of the adjacent valley floor (Eisbacher, 1978 and in press). If impeded in their course, rock avalanches can climb slopes several hundreds of metres high (Fig. 8B), and no man-made structure could withstand the force of direct impact.

The most disastrous historical rock avalanche in western Canada, probably triggered by coal mining, resulted from

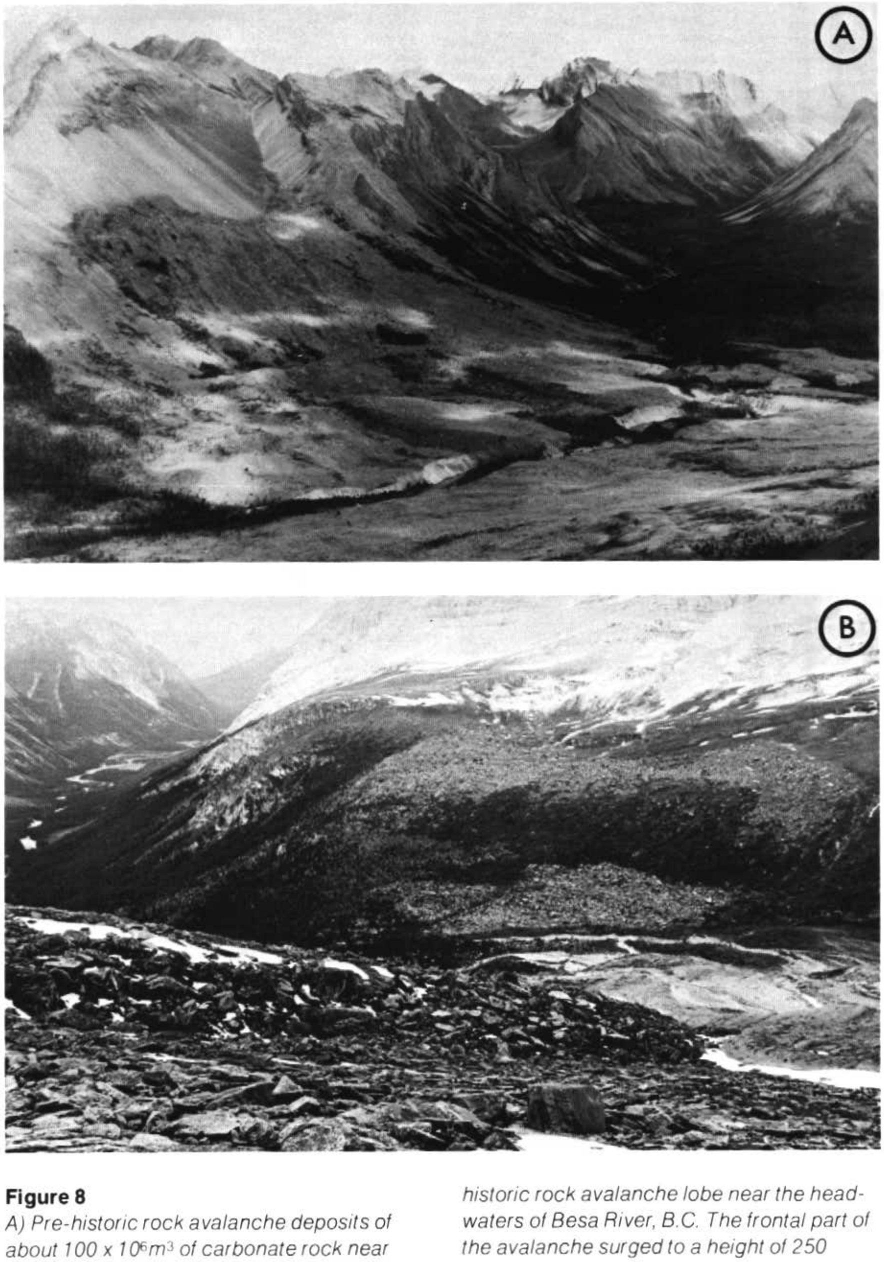



**Figure 8**
*A) Pre-historic rock avalanche deposits of about 100 x $10^6 m^3$ of carbonate rock near Bonnet Plume Lake, Yukon Territory. Failure occurred on a wedge defined by a bedding plane and a fracture surface. The Bonnet Plume River has cut a canyon 50 m deep through the slide material. B) View of a pre-historic rock avalanche lobe near the headwaters of Besa River, B.C. The frontal part of the avalanche surged to a height of 250 metres above the bottom of the tributary valley; the remainder of the material continued to stream several kilometres down the main valley. The dip of the rupture surface in the foreground is 29°.*

the failure of a carbonate cliff on Turtle Mountain above the town of Frank, Alberta, in 1903 (McConnell and Brock, 1904; Daly *et al.*, 1911; Cruden and Krahn, 1973). It is interesting to speculate on whether the name Turtle Mountain implied only the shape of the mountain behind the town-site or whether it also signified slow movement of the ridge top, possibly noticed by the locals long before the catastrophy!

Another manifestation of a large rock avalanche in the Eastern Carbonate Zone may be the enigmatic Foothills Erratics Train. This regionally extensive band of angular rock slabs of Rocky Mountain lithology in the outer Foothills of Alberta has fired the imagination of many a geological visitor. The blocks are now thought to have originated by a late-Pleistocene rock avalanche onto a glacier in the central Rocky Mountains from where they were transported piggy-back on the surface of the piedmont ice sheet as far as 600 kilometres to the southeast (Stalker, 1972).

*Debris flows* of the Eastern Carbonate Zone are related to excessive autumn rains, springtime runoff, or glacial melt-water. The large input of water necessary to initiate debris flows often originates step-by-step from temporary ponds and saturated ground, and a growing plug of wet debris, incorporating loose material in its path can reach the lower part of its course with devastating force (Fig. 9). Historical debris flows are known along all major transportation routes through the Carbonate Zone (e.g., near Field, B.C. and Muncho Lake, B.C.).

**Foothills Zone**

The Foothills Zone is the transitional belt between the strongly-titled formations of the Eastern Carbonate Zone and the flatlying strata of the Interior Platform. There is no sharp boundary of the Foothills Zone in either direction. In general, the geology of the Foothills Zone is dominated by gently dipping Mesozoic and Tertiary sandstone, mudstone, shale, coal and bentonitic clays. The most important landslides are rock slumps in the south and earth flows in permafrost terrain of the north.

*Rock slumps* occur mostly along high river banks made up of the fine-grained and poorly cemented mudstone, siltstone and shale (Fig. 10). They are commonly triggered by high piezometric pressures during spring runoff and occur preferably on slopes whose microclimate favours accumulation and retention of snow (Beaty, 1972). Slope stability is greatly influenced by the low residual shearing resistance of clay-rich stratigraphic horizons and the swelling properties of bentonite beds. Many riverbanks in this zone show retrogressive slump scars and overlapping slide deposits of variable age and size. As in the Interior Plains region (Scott and Brooker, 1968; Thomson and Morgenstern, 1977; Mollard, 1977, p. 38-46) many failures are translational towards the rivers and slide surfaces are distinctly non-circular (e.g., Thomson and Hayley, 1975). Where strata are folded and better indurated the slide surfaces

**Figure 9**
*Track of a recent debris flow near Field, B.C., in the Eastern Carbonate Zone. This area has been subject to repeated historical debris flow activity probably related to build-up of water in the glaciated upland area.*

**Figure 10**
*Soft-rock slump along the banks of Peace River, B.C. A strong translational sliding component forced the toe of the slide across the river. The mounds, seen in the foreground, suggest forceful injection of water trapped below the slide mass.*

tend to be even more controlled by bedding planes. The rotational component of failure may be small compared to that of outward translation. The term 'lateral spreads' is then applied to these slope failures (Locat and Cruden, 1978, p. 188-191).

*Earth flows* occur along silt and clay slopes especially in the region of discontinuous permafrost. If frozen silt, clay or shale are exposed to seasonal thawing, retrogressive flow slides or active-layer detachment is a common mode of slope failure along the northern river banks (Rutter *et al.*, 1973).

**Precipitation, Relief, and Seismicity**

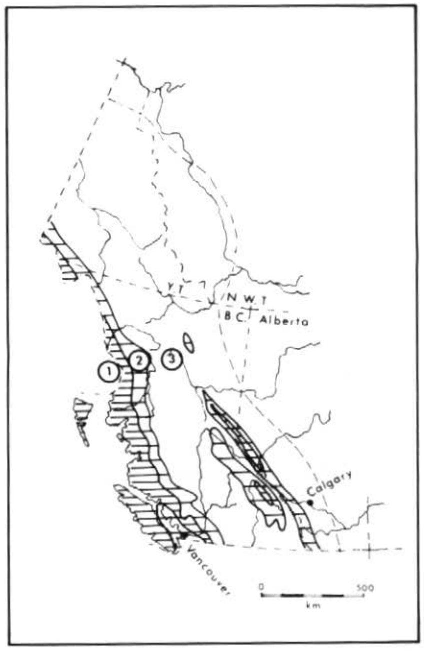
Total annual precipitation, intensity of precipitation, local relief, and seismic risk in the Canadian Cordillera are unevenly distributed and therefore affect the intensity of landsliding differently from zone to zone. In Figure 11 a, b, c annual precipitation, local relief, and seismic risk respectively have been subdivided into three somewhat arbitrary classes. Unfortunately, information on duration and intensity of precipitation is not available for most of the Cordillera.

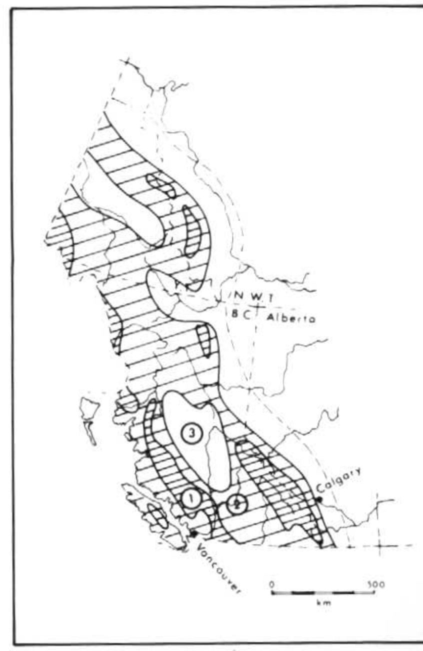
*Total precipitation* (Fig. 11 a) is shown for areas with more than 1600 mm per year (Class 1), more than 800 mm but less than 1600 mm per year (Class 2), and less than 800 mm per year (Class 3).

*Local relief* (Fig. 11 b) is generalized into areas with relief exceeding locally 1000 m (Class 1), areas with relief exceeding locally 500 m but not 1000 m (Class 2), and areas with relief of generally less than 500 m (Class 3).

*Seismicity* (Fig. 11 c) is shown by the three seismic risk zones discussed in Whitham (1975). They are based on three classes of annual seismic acceleration probabilities.

The areas of Class 1 for precipitation, relief, and seismic risk have been superimposed on one map (Fig. 12) to convey a feeling for the relative landslide intensity that might be expected if intrinsic local geology is ignored. The map suggests that natural landslide hazard should be high in the Coast-Insular Zone, St. Elias Zone and some areas of the southern Cassiar-Columbia Zone and the Eastern Carbonate Zone. Observational material at hand does indeed bear out that most of these areas are characterized by high natural landslide activity. In particular, the narrow



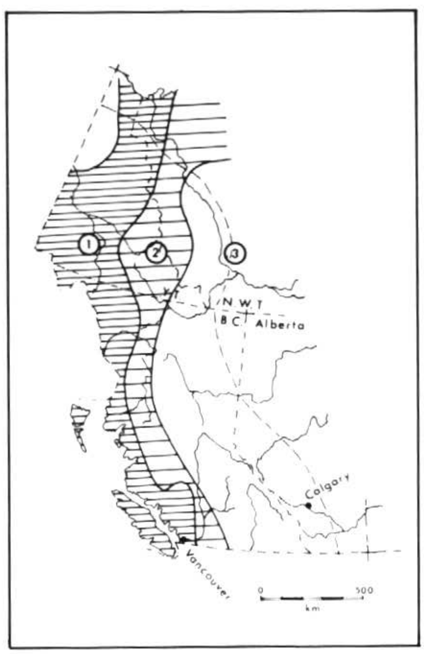




**Figure 11**

*A) Three classes of total annual precipitation in the Canadian Cordillera; B) three classes of local relief; C) three zones of relative seismic risk. See text for discussion.*

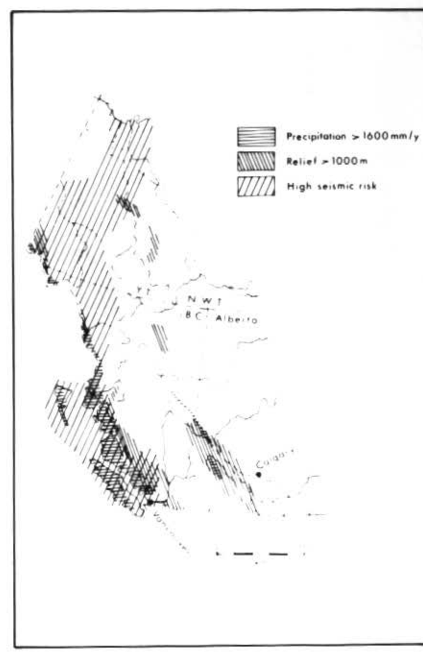



**Figure 12**

*Superimposition of the areas of relative high precipitation, relief and seismic risk on a map of the Canadian Cordillera. It illustrates that, ignoring geological detail, high natural landslide activity is to be expected in the Coast-Insular Zone, the St. Elias Zone, and along several bands in the southeastern Cordillera.*

valleys in the vicinity of Vancouver and steep slopes along a broad belt near the B.C.-Alberta border are notable for their abundant landslides. The map (Fig. 12), however, cannot account for special geological conditions such as those of the Foothills Zone, or for the impact of regional hydrologic and climatic change (e.g., reservoirs).

## Outlook

To date, approximately 160 to 170 people have lost their lives in landslide-related accidents in the Cordilleran region. Total damage to structures, roadbeds, fisheries, etc. probably exceeds 100 million dollars. This may not seem much compared to death damage resulting from traffic accidents. However, two points must be considered: first, most of the deaths resulted from slides that probably were triggered by man's activity (Frank - 70, Britannia Mining Camp - 60, Spences Bridge - 15); secondly, human activity in the Cordillera, so far, has been largely restricted to 'landslide-safe' areas.

The high cost of building and maintaining large reservoirs and roadbeds in more remote parts of the Cordillera and the increasing use of landslide-prone terrain in the recreational hinterland of Calgary and Vancouver certainly require that landslide hazard be appraised promptly during planning of transportation routes, dam sites, and recreational developments. Geotechnical practice, with a good track record in *overcoming* trouble, can always be improved by *avoiding* trouble.

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### References

Alley, N F and B Thompson, 1978, Aspects of environmental geology, parts of Graham Island, Queen Charlotte Islands B.C Ministry of Environment, Bulletin 2, 64 p

Alley N F and G K Young, 1978, North central British Columbia environmental significance of geomorphic processes: B C Ministry of Environment, RAB Bulletin 3, 83 p

Ampferer, O , 1939, Uber einige Formen der Bergzerreissung: Sitzungsberichte der Akademie der Wissenschaften in Wien, math -naturw Kl Abt. 1, v 148, Ht/2, p. 1-14

Armstrong, J.E., 1957, Surficial geology of New Westminster map-area, British Columbia, Geol. Survey Canada, Paper 57-5, 25 p.

Armstrong, J E , in press, Environmental and engineering applications of the surficial geology of the Fraser Lowlands, B.C Geol Survey Canada, Bulletin.

Barker M.L., 1977, Natural Resources of British Columbia and the Yukon, Vancouver, Douglas, David and Charles, 155 p

Beaty, C.B., 1972, Geographical distribution of post-glacial slumping in southern Alberta: Can Geotechn. Jour , v. 9, p. 219-224.

Bostock, H.S., 1948, Physiography of the Canadian Cordillera, with special reference to the area north of the fifty-fifth parallel: Geol Survey Canada, Memoir 247, 106 p.

Brock R.W , 1904, The Lardeau District, B C , Geological Survey of Canada, Summary Rept. 1903, p. 42-57

Broscoe, A J. and S Thomson, 1969, Observations on an alpine mudflow, Steele Creek, Yukon Can. Jour Earth Sci , v 6, p 219 229

Clague, J J , 1978, Terrain hazards in the Skeena and Kitimat River basins, British Columbia: Geol. Surv Canada, Paper 78-1A, p. 183-188.

Clague J J , 1979, The Denali Fault System in southwest Yukon Territory - a geologic hazard Geol Surv Canada, Paper 79-1A, p. 169-178

Cotecchia, V., 1978, Systematic reconnaissance mapping and registration of slope movements Bull Internatl Assoc Engin Geol No 17, p 5-37

Cruden, D M., 1976, Major rock slides in the Rockies Canadian Geotech Jour v 13, p 8-20

Cruden, D M and J. Krahn, 1973, A reexamination of the geology of the Frank Slide Canadian Geotechnical Jour v 10, p 581-591

Daly, R A , W G Miller, and G S Rice 1911 Turtle Mountain Frank, Alberta, Geol. Survey Canada, Memoir 27, 34 p

Drysdale, C W , 1912, Geology of the Thompson River Valley below Kamloops Lake, B C : Geol Surv Canada, Summary Rept 1912, p 115-150

Eisbacher, G H , 1971, Natural Slope failure, northeastern Skeena Mountains, Canadian Geotech Jour , v. 8, p 384 390

Eisbacher, G H , 1977, Rockslides in the Mackenzie Mountains, District of Mackenzie Report of Activities, Pt. A, Geol Survey Canada, Paper 77-1A, p 235-241

Eisbacher, G H , 1978, Observations on the streaming mechanism of large rock slides, Northern Cordillera Current Research, Pt A Geol. Survey Canada, Paper 78-1A, p 49-52

Eisbacher, G. H., in press, Cliff collapse and rock avalanches (sturzstroms) in the Mackenzie Mountains, northwestern Canada: Canadian Geotech Jour

Evans, S. G., and R. G Buchanan, 1976, Some aspects of natural slope stability in silt deposits near Kamloops, British Columbia. 29th Canadian Geotechnical Conference on Slope Stability, Proceedings, Section 4, p. 1-57.

Gardner, W I , D H MacDonald and F D. Patton, 1976, Report of the Downie Slide Review Panel (August 15, 1976): British Columbia Hydro and Power Authority, Internal Report, 74 p

Farquharson, K G , 1976, Development of a Natural Hazards Policy for B C., B.C. Professional Engineer, v 27, no. 1, p 13-14

Holland, S S., 1964, Landforms of British Columbia, A Physiographic Outline British Columbia Dept. Mines and Petrol Res Bull 48, p 138

Locat, J and D M Cruden, 1978, Major landslides on the eastern slopes of the southern Canadian Rockies Proc 15th Annual Symp Engin Geology Pocatello, Idaho, p 179-197

Luternaurer J L and D Swan, 1978, Kitimat submarine slump deposits a preliminary report Geol Surv Canada, Paper 78-1A p. 327-332

Mathews, W H 1979, Landslides of Central Vancouver Island and the 1946 earthquake Seismological Society of Amer Bull., in press.

Mathews, W H , and K C McTaggart 1969, The Hope Landslide, British Columbia: Geol Assoc Canada, Proceedings, v 20, p 65-75

Mathews, W H , and K C McTaggart, 1978 Hope Rockslides, British Columbia, *in* B Voight, ed , Rockslides and Avalanches, v 1 Elsevier, Science Publ. Co , p. 259-275

McConnell, R G and R W Brock, 1904, The great Landslide at Frank, Alberta Dept. of the Interior, Annual Rept , pt 8, 17 p

Mokievsky-Zubok, O., 1977, Glacier caused slide near Pylon Peak, British Columbia Canadian Jour Earth Sci v 14 p 2657-2662

Mollard, J D , 1977, Regional landslide types in Canada Geol Soc America, Reviews in Engineering Geology, v 3, p 29-56

Moore, D P, and W H Mathews, 1978, The Rubble Creek landslide southwestern British Columbia Canadian Jour Earth Sci., v 15, p. 1039-1052.

Morice, A. G., 1904, The history of the northern Interior of British Columbia: London, J. Lane, 368 p.

Nasmith, H, 1972, Engineering geology of the southern Cordillera of British Columbia: 24th Internatl Geological Congress, Guidebook A08, 34 p.

O'Loughlin, C. L., 1972, A preliminary study of landslides in the Coast Mountains of southwestern British Columbia: *in* O. Slaymaker and H. J. McPherson, eds., Mountain Geomorphology: B.C. Geographical Series No. 14, p. 101-112.

Patton, F. D., 1976, The Devastation Glacier Slide, Pemberton, B. C.: Geol. Assoc. Canada, Cordilleran Section, Abst., p. 26-27.

Peckover, F. L. and J. W. G. Kerr, 1977, Treatment and maintenance of rock slopes on transportation routes: Canadian Geotechn. Jour. v. 14, p. 487-507.

Piteau, D. R., 1977, Regional slope-stability controls and engineering geology of the Fraser Canyon, British Columbia: Geol. Soc. Amer. Reviews in Engin. Geol., v. 3, p. 85-111.

Piteau, D. R., F. H. Mylrea, I. G. Blown, 1978, Downie Slide, Columbia River, British Columbia, Canada: *in* B. Voight, ed. Rockslides and Avalanches, v. 1: Elsevier Sci. Publ. Co., p. 365-392.

Post. A., 1967, Effects of the March 1964 Alaska Earthquake on glaciers; The Alaska Earthquake, March 27, 1964: U.S. Geol. Survey Prof. Paper 544-D, p. D1-D42.

Radbruch-Hall, D. H. and D. J. Varnes, 1976, Landslides - Cause and effect: Bull. Internatl. Assoc. Engin. Geol., No. 14, p. 205-216.

Radbruch-Hall, D. H., D. J. Varnes and W. Z Savage, 1976, Gravitational spreading of steep-sided ridges ("Sackung") in western United States: Bull. Internatl. Assoc. Engin. Geol., No. 14, p. 23-35

Radbruch-Hall, D. H., 1978, Gravitational creep of rock masses on slopes, *in* B. Voight, ed., Rockslides and Avalanches, v. 1. Elsevier Sci Publ. Co, p 607-657.

Rampton, V. N., in press, Surficial deposits and landforms of Kluane National Park. Geol. Survey Canada, Paper.

Ramsey, B., 1967, Britannia - The Story of a mine: Vancouver, Agency Press Ltd., 177 p.

Read, P.B., 1977, Meager Creek volcanic complex, southwestern British Columbia: Geol. Survey Canada, Paper 77-1A, p. 277-281.

Rutter, N.W., A.N. Boydell, K.W. Savigny, R.O. VanEverdingen, 1973, Terrain evaluation with respect to pipeline construction, Mackenzie Transportation Corridor. Environmental Social Committee Northern Pipelines, Task Force on Northern Oil Development, Report No. 73-36, 135 p.

Scott, J.S. and E.W. Booker, 1968, Geological and engineering aspects of Upper Cretaceous shales in Western Canada: Geol. Survey Canada, Paper 66-37.

Skermer, N.A., 1976, Earthquakes, avalanches, landslides: The British Columbia Prof. Engin., v. 27, no. 1, p. 5-8.

Souther. J.G., 1971, Geology and mineral deposits of Tulsequah map-area, B.C.: Geol. Survey Canada, Memoir 362, 84 p.

Stalker, A. Macs., 1972, Foothills Erratic: *in* N.W. Rutter, and E.A. Christiansen, Quaternary geology and geomorphology between Winnipeg and the Rocky Mountains: 24th Internatl. Geol. Congress, Excursion C-22, p. 73-74.

Stanton, R.B., 1898, The great land-slides on the Canadian Pacific Railway in British Columbia: Proc. Institution Civil Engin., v. 82, pt. 2, p. 1-48.

Thomson, S. and D.W. Hayley, 1975, The Little Smoky Landslide: Canadian Geotech. Jour., v. 12, p. 379-392.

Thomson, S. and N.R. Morgenstern, 1977, Factors affecting distribution of landslides along rivers in southern Alberta: Canadian Geotech. Jour., v. 14, p. 508-523

VanDine, D F., 1974, Geotechnical and geological engineering study of Drynoch Landslide, British Columbia MSc. Thesis, Queen's University, Kingston, Ont., 122 p.

Voight, B., ed., 1978, Rockslides and Avalanches, v. 1 (Natural Phenomena): Elsevier Sci. Publ. Co., 833 p.

Whitham, K., 1975, The Estimation of seismic risk in Canada: Geosci. Canada, v. 2, p. 133-140.

Zaruba, Q and V. Mencl, 1970, Landslides and their control: Elsevier - Academia, 205 p.

Zischinsky, U., 1969a, Uber Bergzerreissung and Talzuschub: Geologische Rundschau, v. 58, p. 974-983.

Zischinski, U., 1969b, Uber Sackungen: Rock Mechanics, v. 1, p 30-52.

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