Landslides in Canada
Accompanying Notes to “The Land Is Moving!”

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Modified from text that can be seen on the Atlas of Canada website
http://atlas.nrcan.gc.ca/site/english/maps/environment/naturalhazards/landslides/1

Slide 2
Landslides in Canada

- Landslides can be found in any part of Canada, even in areas with very little relief. They happen in bedrock or in loose sediment; on land or under water; may be large or small, rapid or slow, and generally occur without warning. There are a wide variety of failure mechanisms and triggering causes, and local geological and topographical conditions determine which type of landslide may happen in a specific region. Some regions are particularly susceptible to landsliding: steep slopes in the mountains; weak cretaceous bedrock along valleys in the Prairies; and valleys eroded into fine-grained sediments in areas once covered by glacial lakes and glacial seas.
- Impact is greatest where landslide occurrence coincides with human activity. In the historical period (taken to be post-1840), landslides in Canada have resulted in over 600 fatalities, including the destruction of several communities, and caused billions of dollars in damage. The hazard presented by landslides involves not only failure of ground beneath a structure and impact or burial by moving debris, but also secondary effects such as landslide-dammed floods and landslide-generated waves. However, although landslides will continue to occur annually, landslide risk in our lives can be reduced or eliminated with proper planning and mitigation action.

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What are landslides made of?

- The geological material forming the landslide can be either rock or loose sediment, and may involve both. ‘Sediment’ describes any geological material that is not solid rock, and includes clay, silt, sand, gravel, cobbles and boulders, or a mixture of these. In addition, sediment includes both natural and man-made deposits. For example, landslides can occur in artificial fill embankments. Along its path, a landslide may also incorporate geological material that has different characteristics than the source material, as well as additional water and trees. This mixture of displaced materials is called debris.

How big are landslides?

- The size of a landslide can range from a single boulder that fell off a cliff to a large area encompassing tens of square kilometres and millions of cubic metres of debris. The largest Canadian landslide known to have occurred in historical times, the 1894 earthflow at Saint-Alban, Quebec, involved 185 million cubic metres of material and created a 40 metre deep scar that covered an area of 4.62 million square metres (roughly the size of 80 city blocks).

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How fast are landslides?

- The speed of movement can range from extremely slow to extremely rapid. The slowest movement, ‘creep’, is on the order of a few centimetres to a few tens of centimetres per year. Tilted trees and telephone poles, and deformed fences bear witness to this slow ground movement. Rockfalls may attain velocities of 35 to 40 metres per second, three times faster than the fastest runner. In the rapid earthflows of the St. Lawrence Lowlands, the speed of flowing clay may vary from a ‘fast walk’ to an ‘Olympic sprint’. For example, flow at Saint-Jean-Vianney, Quebec, was estimated at 7 metres per second (25 kilometres per hour). In addition, in the case of these rapid earthflows, retrogression (headward erosion) of the scarp may exceed 5 metres per second and, in some cases, has exceeded a normal running speed. In mountainous regions, the fastest type of landslide, the rock avalanche, may reach velocities of up to 100 metres per second (360 kilometres per hour), which exceeds the speed of a race car. Witnesses reported that the 1903 rock avalanche at Frank, Alberta, lasted about 100 seconds, indicating an average velocity of 31.2 metres per second (112 kilometres per hour).

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How do landslides move?

- Landslides move downslope under the influence of gravity; although, if the geological material is particularly weak or sensitive or is saturated with water, gravity is less important. How the slope will fail and how the material will move is dependent on the specific geology and topography of the region. Landslides display a range of movement modes, ranging from free fall and end-over-end toppling movements, through sliding in relatively intact masses, to the flow of completely disintegrated materials, sometimes in a fluid-like state. For a complete description, see 'Landslide Types' section, below.) Many landslides incorporate more than one mode of movement, evolving from one to another depending on the amount of disintegration and saturation to which the moving mass is subjected. Some landslides move only a short distance, coming to a stop near the base of the slope; others can travel several kilometres from the source. Some landslides will trigger sequential failures, retrogressing the headscarp back into the slope.

Slide 13
Map of regions that are vulnerable to landsliding in Canada and locations of historic deadly landslides in Canada.
Landslides happen annually in all parts of Canada, even in areas without mountains.
Four areas are particularly prone to landslides:

- Steep slopes in mountainous terrain of western Canada (green shading). Landslides occur in both solid bedrock and soil and may be initiated by natural factors or human activity.
- Areas of fine-grained soil in regions once covered by glacial lakes (orange shading) and glacial seas (purple shading). This includes Leda clay, the silty marine clay of eastern Canada. It has high water content and if disturbed (by river erosion, earthquake, snowmelt, construction, etc.) may turn into liquid mud and form catastrophic landslides.
- Valley sides in the Prairies where rivers have cut down into the Cretaceous bedrock. This rock, deposited 65 to 114 million years ago, contains clay-rich layers that are structurally weak (yellow shading).
- Ice-rich, fine-grained soils in permanently frozen ground (permafrost) in Canada's northern regions (north of dashed black line).

Although generally not deadly, landslides in the Prairies or in permafrost terrain are responsible for considerable damage to houses, roads and pipelines.

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Some regions are particularly susceptible to landsliding. These are the Canadian Cordillera (green area), Cretaceous bedrock in the Prairies (yellow area), areas of fine-grained sediment in areas once covered by glacial lakes (orange area) and glacial seas (purple area), and ice-rich permafrost terrain in the north.

Canadian Cordillera: Landslides constitute a significant hazard, not only to communities in the Canadian Cordillera, but also to transportation, communication, and utilities corridors through the mountains. The high, steep slopes are extremely vulnerable to all types of landslides, including rockfalls, large slides and flows, and rapid, often catastrophic, rock avalanches and water-saturated debris avalanches and debris flows. Twenty-nine high-velocity rock avalanches are known to have occurred in the Cordillera since 1855, including the 1915 Jane Camp disaster in British Columbia and 1903 Frank Slide in Alberta. River banks incised deeply into thick deposits of unconsolidated sediments in the valleys are also vulnerable to landslides. For example, January 19, 2005, a rapid debris flow in a North Vancouver subdivision destroyed houses, resulting in one fatality.

Cretaceous bedrock: Landslides can also occur in areas of low relief. In these cases, slope stability is dependent on critical geological conditions. East of the Rocky Mountains, the sides of Prairie valleys are susceptible to sliding movements along planes of weakness, commonly bentonitic in weak, soft, shale bedrock of Cretaceous age. The slide mass may also involve harder bedrock lithologies (limestone, sandstone) that are carried on the underlying weaker shales. The slides are generally slow moving. This tendency to slide poses a particular problem for transportation routes at valley crossings. For example, a slide in Cretaceous shales in the north abutment destroyed the Alaska Highway suspension bridge over the Peace River, near Fort St. John, British Columbia, in October 1957. More recently (1997), a landslide reactivation severed a natural gas pipeline on the north side of the Peace River valley, near Fort St. John.

Glaciomarine sediments: Perhaps the geological material most sensitive to landsliding are the glaciomarine clays and silts that were deposited in short-lived glacial seas which flooded low coastal areas at the end of the last Ice Age. Even on very low slopes (smaller than 30 metres), if disturbed, this sensitive material may suddenly loose its physical strength and liquefy, causing the slope to collapse and materials to move as a rapid earthflow. These failures are highly destructive, as the headscarp will retrogress, even on very gentle slopes, destroying large areas of flat land behind the initial riverbank and the debris may flow for several kilometres from the scar. Best known of these glaciomarine areas is the Champlain Sea, which occupied the St. Lawrence and Ottawa valleys and is characterized by thick deposits of geotechnically sensitive material informally known as Leda Clay. Leda Clay earthflows have caused about 100 deaths in historic times, including destruction of two towns in Quebec, – Notre-Dame-de-la-Salette in 1908 and Saint-Jean-Vianney in 1971. Rapid slides and earthflows have also occurred in the less well known, sensitive glaciomarine sediments of northwestern British Columbia. For example, a rapid earthflow along the Khyex River severed a pipeline on November 28, 2003, cutting the gas supply to Prince Rupert for 10 days.

Glaciolacustrine sediments: Other vulnerable regions of low relief are areas that are covered with extensive deposits of fine-grained glaciolacustrine sediment. These are clays and silts that were deposited on the bottom of temporary glacial lakes near the end of the last Ice Age. Slides, generally slow moving although rapid slides may also occur, are the most common type of slope failure affecting the sides of valleys incised down into these sediments. Many urban centres in the Prairie Provinces and British Columbia are built on glaciolacustrine sediments. Winnipeg, for example, is built on the former floor of Glacial Lake Agassiz and numerous slope stability problems have been encountered along the Red and Assiniboine rivers in the history of the city. As these slides move, the outer part of the slide mass may develop into a slow earthflow. Less commonly, glaciolacustrine sediment may fail as a rapid earthflow. In 1905 at Spences Bridge, British Columbia, a rapid earthflow in silty sediments in the Thompson River valley buried part of a First Nations village, killing 15 people. At Duparquet, Quebec, in 1946, clay around the rim of the open-pit at Beattie Mine became fluid enough to flow into the underground mine where 4 miners were killed.

Permafrost: Northern Canada, while subject to the types of landslide common to southern Canada, also is characterized by unique landslides that occur only in permafrost regions. Active layer flows and the deeper, retrogressive thaw flows develop in ice-rich, fine-grained sediments and result from the thawing and subsequent flow of water-saturated ground. These failures can occur on very gentle slopes and hundreds of these features line the river banks and tundra lakes in the northern Mackenzie valley. They are common where forest and tundra fires have destroyed the insulating vegetation cover. These landslides are relatively small, but may have a significant impact on pipelines in the north.

The region least likely to produce large landslides is the hard bedrock and low relief of the Canadian Shield, yet even this region experiences rockfalls and small rockslides on cliffs and road cuts, as well as landslides in areas where loose sediments thickly cover the Precambrian bedrock.

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Disastrous landslides occur where landslides impact human life. In this context, the two most significant areas of landsliding in Canada are the southern Cordillera of British Columbia and Alberta and the St. Lawrence Lowlands of Quebec and Ontario.

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Frank, Alberta
At 4:30 am on April 29, 1903, 30 million cubic meters of limestone detached from the east side of Turtle Mountain and crashed into the small mining town of Frank, Alberta, burying part of the town under 82 million tonnes of rock. The primary cause of the Frank Slide was the unstable structure of Turtle Mountain. A thrust fault running through it, and eroding sandstone and shale beneath older limestone, plus deeply eroded cracks in the limestone on the top, would have caused the rock to fall eventually. Secondary causes include coal mining inside the mountain and dramatic changes in weather conditions - a quick freeze - that night. The Frank Slide, which moved at an average velocity of 31.2 m/sec, is a debris avalanche, – a term coined by geologists of the Geological Survey of Canada to describe the event. In about 100 seconds, a thick layer of rock rubble covered homes, roads, the Canadian Pacific railway and the Oldman River. The Frank Slide was Canada's worst landslide disaster, killing at least 70 people. More fatalities are suspected due to the potential presence of unregistered migrant workers in Frank at the time of the slide. Coal miners, trapped in the mine, were able to dig themselves out.

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Case study: The Lemieux Landslide, May 20 1993
Engineering studies, initiated following a large landslide on the South Nation River in 1971, concluded that the town of Lemieux, Ontario, lay within a zone of sensitive glaciomarine clay (Leda Clay) susceptible to large rapid earthflows. As a result, the town site was abandoned in 1991 and residents were relocated at the expense of the provincial government. Only two years later, on June 20, 1993, a rapid earthflow consumed 17 hectares of farmland adjacent to the former town site. Through progressive headward failure, the landslide scarp retreated 680 metres from the riverbank in less than an hour, most in the first 15 minutes. About 2.8 million cubic metres of sand, silt and liquefied clay traveled 1.7 kilometres upstream and 1.6 kilometres downstream, completely blocking the river for several days. The direct and indirect costs related to this event were estimated at $12 500 000. However, because of evacuation of the former residents, no lives were lost.

- Dammed the river for 4 days (Picture taken 4 days after landslide as the flooded river begins to flood the landslide scar.)
- Flooded 18 km upstream, raised water levels 12 m at the bridge, maintained high river levels for >1 year.
- Cost: $4 M direct; $9 M indirect
- 1 injury

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Leda clay: the silty marine clay of the Champlain Sea (blue shading), which flooded the St Lawrence Lowlands at the end of the last Ice Age.

- The clay has a high water content and if disturbed (by river erosion, earthquake, snowmelt, construction, etc.) may turn into liquid mud and form catastrophic landslides.
- Even on very low slopes (smaller than 30 metres), if disturbed, this sensitive material may suddenly loose its physical strength and liquefy, causing the slope to collapse and materials to move as a rapid earthflow. These failures are highly destructive, as the headscarp will retrogress, even on very gentle slopes, destroying large areas of flat land behind the initial riverbank and the debris may flow for several kilometres from the scar.

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Leda clay is composed of clay- and silt-sized particles of bedrock that were finely ground by glaciers and washed into the Champlain Sea. As the particles settled through the salty water, they were attracted to one another and formed loose clusters that fell to the seafloor. The resulting sediment had a loose but strong framework that was capable of retaining a large amount of water. Following the retreat of the sea, the salts that originally contributed to the bonding of the particles were slowly removed (leached) by fresh water filtering through the ground. If sufficiently disturbed, the leached Leda clay, a weak but water-rich sediment, may liquefy and become a 'quick clay'. Trigger disturbances include river erosion, increases in pore-water pressure (especially during periods of high rainfall or rapid snowmelt), earthquakes, and human activities such as excavation and construction. (Geoscape Ottawa-Gatineau)

Slide 21
Aerial view of the 1971 landslide headscarp area. A few displaced houses can be seen in the debris below the scarp. Remaining homes were permanently evacuated.

- **Saint-Jean-Vianney, Quebec**
  At about 11 pm on May 4, 1971, a major earthflow in sensitive glaciomarine clay (Leda Clay) destroyed part of the community of Saint-Jean-Vianney, Quebec. The 1971 failure lies within the scar of a much larger earthflow, thought to have been triggered by the great 1663 Charlevoix earthquake. Saturated ground conditions following a record winter snow accumulation and a lengthy rainstorm have been cited as the trigger mechanism for the 1971 earthflow. Forty homes lying above the initial failure were engulfed during the retrogression phase and 31 people died. Fatalities might have been greater had not it not been for the absence of many workers enroute to shift change at the ALCAN plant in Arvida. The landslide retrogressed 550 metres from the initial failure, consuming 26.8 hectares of flat land. A man running to escape the rapidly retrogressing failure reported having to run on what seemed like moving stairs, indicating that the final stages of the retrogression matched his running speed. Meanwhile, the rapidly flowing mud traveled at a velocity of about 7 metres per second (25 kilometres per hour) through the narrow valley of Rivière des Vases, destroying a bridge in its path and carrying the concrete piers into the Saguenay River, a distance of over 3 kilometres.

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Impact

- Landslides in Canada have resulted in over 600 fatalities in historic times (post-1840). This number is a minimum value, based on the definition of a landslide disaster as 3 or more deaths in a single event. In some of these disasters the death can be attributed to secondary effects (flood waves and tsunamis) triggered by the landslide. Events with 1 to 2 fatalities are difficult to trace.
- Costs associated with landsliding are difficult to compile, but it is estimated that landslides have cost Canadians billions of dollars over time and annual costs may approximate $100 to 400 million. In addition to major losses and reconstruction costs associated with large landslides in populated areas, the accumulated expenses of more frequent small failures tax our economy (that is closures and repairs along transportation routes; individual property damage or loss, etc.).

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Landslides have impacted or destroyed several communities: For example:

- **Notre-Dame-de-la-Salette, Quebec**
  In the early morning hours of April 26, 1908, a landslide in Leda Clay occurred suddenly on the west bank of the Lièvre River which at the time was frozen with about 0.5 metre of ice on its surface. Three houses on the west bank were immediately engulfed, resulting in 6 deaths. On entering the river, the landslide generated a highly destructive wave that overwhelmed part of the village of Notre-Dame-de-la-Salette, located on a low terrace on the opposite bank. Large blocks of river ice carried by the wave crushed buildings. Twelve buildings were completely destroyed by the wave and an additional 27 people were killed. Debris was found up to 15 metres above river level. Muddy water from this event was noticed as far away as Montréal.

This landslide occurred within the scar of a much larger, older earthflow. The town was later re-established on a higher terrace.

- **Frank, Alberta**
- **St. Jean Vianney, Quebec**

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Impact on roads: For example, the August 1999 debris flow at Five Mile Creek in Banff National Park buried the Trans-Canada Highway for 24 hours with significant impact on flow of goods from Calgary warehouses to Vancouver businesses. It is estimated that a 1 hour of closure of this highway is equivalent to $1 million in economic loss.

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Canada's most expensive landslide:
1957: Taylor, BC - On October 16th a landslide of weak Cretaceous rock at the north end of a suspension bridge across the Peace River on the Alaska Highway caused the spectacular collapse of the bridge. The cost of dismantling and replacing the bridge was $60 million, and is probably Canada's most expensive single cost resulting from a landslide, to date. No deaths.

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Although landslides will continue to occur annually, landslide risk in our lives can be reduced or eliminated with proper planning and mitigation action.
How can we protect ourselves from landslides?

1. Landslide risk can be controlled. The first method of reducing risk is simply **avoidance of the hazard**. With expert input and careful planning, communities can identify unstable slopes and restrict or control development in the hazard zone or move people away. For example, the town of Lemieux was abandoned in recognition of a landslide risk prior to the 1993 earthflow.
2. If unstable slopes can not be avoided, there are numerous **engineered methods** of reducing risk.

- Many methods have been developed to reduce the possibility of a slope failure by **alleviating unstable ground conditions**. Methods include improving surface or subsurface drainage, reducing the angle of the slope, excavating to unload the top of the slope, building protective berms to reduce erosion at the base of the slope, revegetation of the slope, and geotechnical nailing or artificial hard covers on disintegrating cliff faces. On some slopes, stability may be achieved if the proper method is applied, but these measures carry considerable financial and/or environmental cost.
- Where landslides can neither be prevented nor avoided, a number of **physical containment or diversion structures** have been designed to protect communities and critical infrastructure. Some common techniques include retention structures (catchment dams) to stop and de-water debris in containment basins above critical sites, artificial channels or chutes to confine debris movement to a specific route, deflection berms or dykes to divert debris movement away from critical sites, and nets and artificial walls to prevent falling or bouncing rock from reaching highways. Again, as in the case of slope stabilization methods, artificial controls are expensive and must be carefully designed and maintained.
- Innovative mitigation techniques include active slope monitoring and early warning systems.

What can you do? Although landslides usually occur without warning, understanding this natural hazard and following some sensible rules can help to protect yourself and your family.

- Learn about your local geology and the potential for landslides in your area.
- Avoid actions that would increase instability. For example, do not undercut a steep bank; do not build near the top or base of steep slopes; do not place fill on steep slopes; do not drain pools or otherwise increase water flow down steep slopes.
- Learn how to recognize signs of potential failure in your locality. Examples include slope cracks, slope bulges, unusual seepage of water on the slope, and small rock or sediment falls.