Landslides

There is a wide variety of failure mechanisms and triggering causes, and local geological and topographic conditions that determine the type of landslide 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 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 more than 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 the impact or burial of moving debris, but also such secondary effects 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.

What is a landslide?

A landslide is the downslope movement of sediment and rock. The word 'landslide' also refers to the landforms that result from this action. Canada has many different types of landslides, reflecting the many diverse landscapes in our country.

Figure 1. Frank Slide, Alberta. In 1903, more than 70 people were buried by a rock avalanche when the east side of Turtle Mountain collapsed.
Source: Photograph courtesy of Frank Interpretive Centre

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).

Figure 2. Rockfall on Trans-Canada Highway. Rockfall on Trans-Canada Highway, near Yale, British Columbia, triggered by heavy rains on November 9, 1990
Source: Photograph courtesy of Duncan Wyllie, Golder Associates

Figure 3. Zymoetz Landslide, British Columbia. A complex rock avalanche–debris flow that occurred on June 8, 2002, approximately 30 kilometres east of Terrace, British Columbia. The debris travelled for more than 4.5 kilometres, descending about 1250 metres. The landslide ruptured a gas pipeline, triggered a forest fire, dammed the Zymoetz River, flooded a Forest Service road and destroyed a bridge.
Source: Photograph courtesy of Marten Geertsema, British Columbia Ministry of Forests, 2002

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).

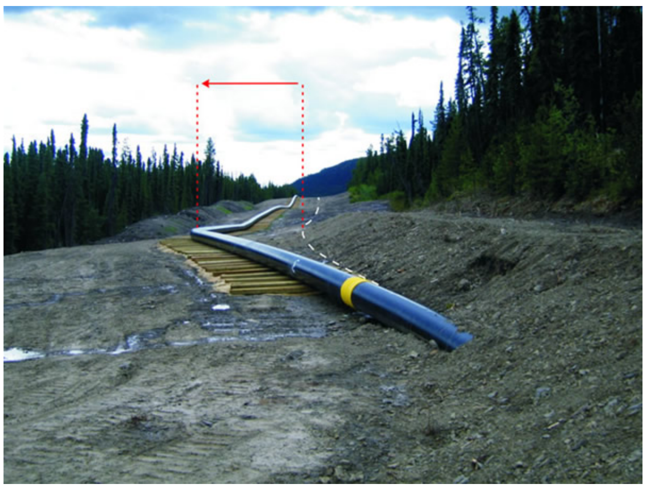

Figure 4. Creep. The slow downslope movement of erosional debris has displaced (arrow) a gas pipeline in northern British Columbia. Original position of pipeline is indicated by white dashed line. The pipeline has been placed on timbers to allow adjustment to continuing slope movement.
Source: Photographer: L.D. Dyke, 2006

Figure 5. Fast Rock Avalanche. Aerial photograph (1965) showing the path (dashed line) of the 1959 high-velocity rock avalanche at Pandemonium creek, British Columbia. Rock debris descended a steep slope from the arrow in the lower left corner and then travelled nearly 8 kilometres along a low-angle (6–9 degrees) stream valley into a lake at the upper right. Debris may have reached velocities of up to 100 metres per second.
Source: Province of British Columbia photo BC5145–163

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.

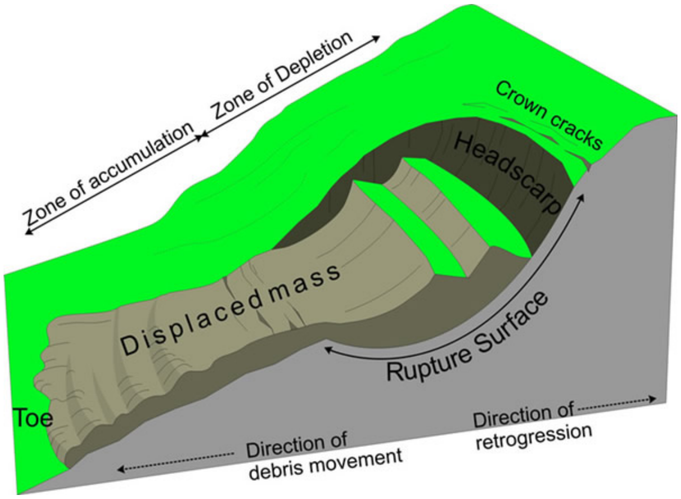

Figure 6. Parts of a landslide
Source: Geological Survey of Canada

Landslide Types

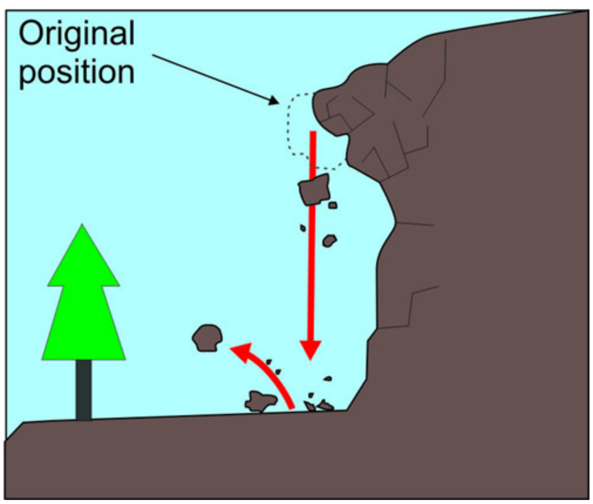

Figure 7. Fall – the free fall of rock or sediment that detached from a very steep slope, usually accompanied by bouncing or rolling movement
Source: Geological Survey of Canada

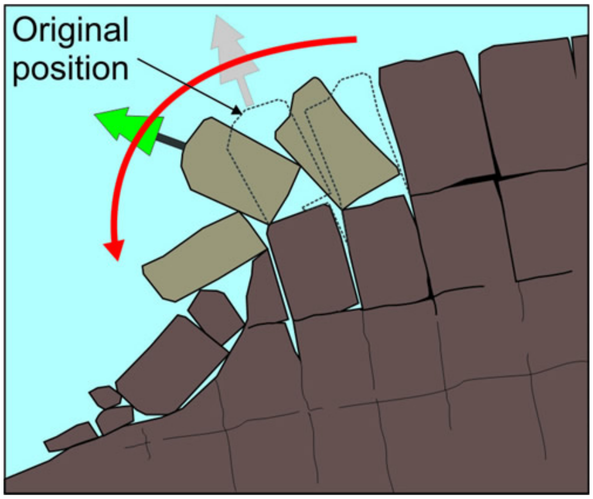

Figure 8. Topple – the forward rotation of blocks of rock or sediment resulting in an end-over-end movement
Source: Geological Survey of Canada

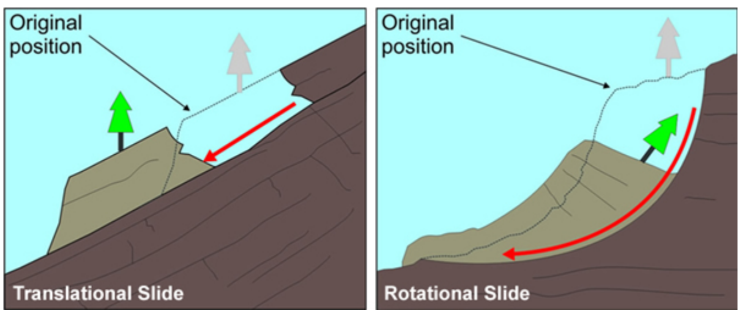

Figure 9. Slide – the downslope movement of bodies of relatively intact material along planes of weakness
Source: Geological Survey of Canada

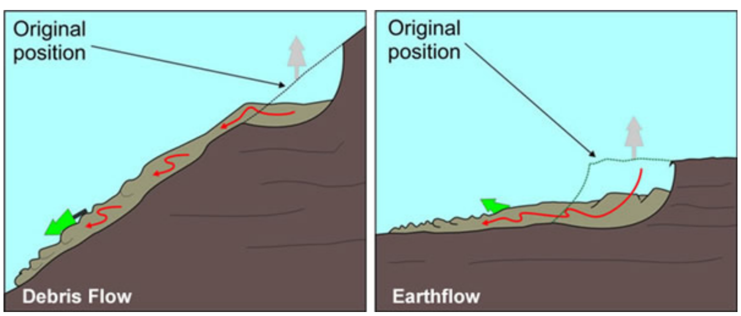

Figure 10. Flow – the downslope movement of sediment or rock in a fluid-like motion
Source: Geological Survey of Canada

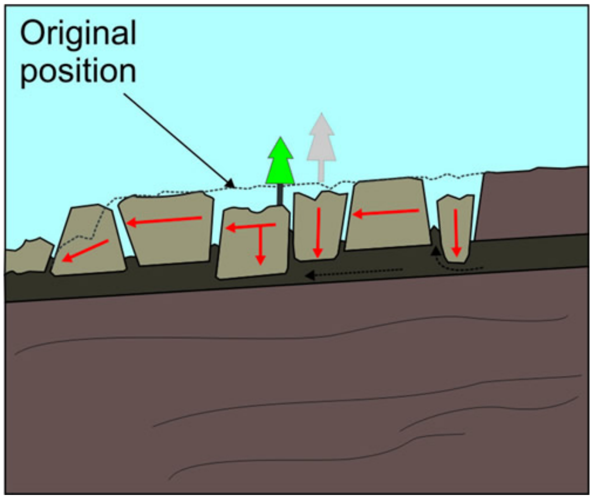

Figure 11. Spread – the extension, or spreading-out, of blocks of sediment or rock on a gentle slope
Source: Geological Survey of Canada

Where can we find landslides?

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. However, landslides happen annually in all parts of Canada. Depending on the local geology and the triggering factors, landslides can occur on any slope, whether high or low, steep or gentle, or even underwater. This said, some regions are particularly susceptible to landsliding. These are the Canadian Cordillera, Cretaceous bedrock in the Prairies, areas of fine-grained sediment in areas once covered by glacial lakes and glacial seas, and ice-rich permafrost terrain.

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.

Figure 12. Hope Slide. The 1965 Hope Slide is the largest rock avalanche in British Columbia. The southwestern slope of Johnson Peak collapsed on January 9, 1965, spreading 47 million cubic metres of debris, 85 metres thick, over a 3 kilometres stretch of the Hope-Princeton highway. Two cars were buried, resulting in 4 deaths. **Source**: Photograph courtesy of British Columbia Ministry of Environment, Lands and Parks

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.

Figure 13. Landslide in Cretaceous shales of the Bearpaw formation in Red Deer River valley, near Dorothy, Alberta. The dramatic graben structure, formed by differential vertical movement at the head of the slide, is formed by complex sliding on a horizontal sliding surface. Arrows indicate the opposing sides of the graben.
Source: Geological Survey of Canada, photo number GSC 118541; Plate III in Scott and Brooker, 1968

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.

Figure 14. 1955 Nicolet Landslide, Quebec. Air photograph of the 1955 rapid (2 to 3 minutes) earthflow in Leda Clay at Nicolet, Quebec. Three people were killed. The 147 year old Cathedral of St-Jean-Baptiste (circled), which stood on the edge of the crater, had to be demolished following the landslide.
Source: Province of Quebec 377-24

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.

Figure 15. Landslide in Glaciolacustrine Silts. Landslide in glaciolacustrine silts along Thompson River, just south of Ashcroft, British Columbia, occurred in 1897. Arrows indicate top of scarp.
Source: Geological Survey of Canada, photo number GSC 2000-184; Photographer: S.G. Evans, 2000

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.

Figure 16. Retrogressive thaw flow in ice-rich sediment near Tuktoyaktuk, Northwest Territories. The flow is a reactivation within an older retrogressive thaw flow scar (dashed line indicates older scarp.) The colour change visible in the vegetation cover reflects the moister conditions occurring within the old scar. Massive ground ice (arrow) is visible in the new scarp.
Source: Photographer: J.M. Aylsworth, 1992

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.

How often do we have landslides?

Thousands of small landslides occur every year in Canada. Larger landslides are less common. Landslides with volumes that exceed one million cubic metres are more likely to occur about every 10 years.

What causes landslides?

Landslides can be triggered by natural processes or human actions. Natural processes include erosion at the base of the slope by waves or by rivers, particularly during snow melt or heavy rainfall; increased water pressure in the ground, also resulting from excessive rainfall or snow melt; increased ground temperature in permafrost regions; freeze-thaw action on rock faces; and earthquakes. Climate change, where the projected change involves increased temperature and precipitation and more extreme storms, will probably result in an increase in landslide events. Human modification of the land is another major factor in slope instability. Common examples include changes to the drainage regime by deforestation, irrigation or stream modification; over-loading the slope or blocking drainage by artificial fills or embankments; over-steepening or under-cutting the slope by excavation and blasting.

How do landslides impact us?

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 and have not been included in the database. Descriptions of each of the 45 landslide disasters shown on the map are provided in the "List of Major Landslide Disasters" at the end of this document.

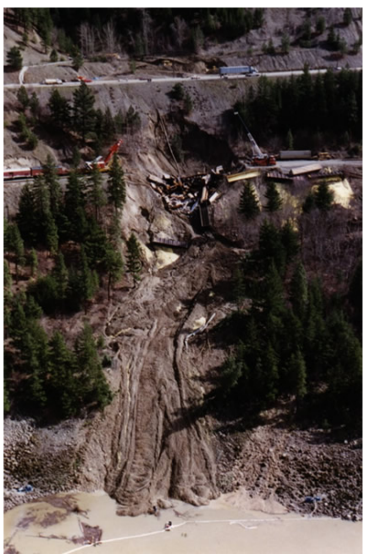

Figure 17. Railway Embankment Failure. Aerial view of a railway embankment failure which occurred at Conrad Siding, near Lytton, in the Fraser Canyon of southern British Columbia, March 1997. A freight train plunged into the pit caused by the failure, resulting in the death of two crewmen. The failure also undermined the Trans-Canada Highway, visible at the top of the photograph. The saturated fill material formed an earthflow which flowed down to the Fraser River in the foreground.
Source: Geological Survey of Canada, photo number GSC 2000-097; Photographer: S.G. Evans, 1997

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 200 million. Probably Canada's most expensive single cost resulting from landslide was a slide in Cretaceous shales at the north abutment of the Alaska Highway suspension bridge over the Peace River, near Fort St. John, British Columbia, in October 1957. Cost of dismantling and replacing the bridge was $60 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, etcetera). 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.

Figure 18. Five Mile Creek debris flow, Alberta. The August 1999 debris flow which covered the Trans-Canada Highway for 24 hours was unexpected and a result of intense rainfall.
Source: Banff National Park, 1999

Case Studies

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.

Figure 19. Notre-Dame-de-la-Salette landslide, Quebec. Contemporary photograph of destruction at Notre-Dame-de-la-Salette, western Quebec, showing effects of landslide-generated wave on wooden buildings located on east bank of Lièvre River in April 1908. Arrow indicates scarp of landslide on west bank of river.
Source: Photograph courtesy of Archives nationales du Québec

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 metres per second, 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. For more information, visit the website of the Frank Interpretive Centre, listed in the References and Links section.

Figure 20. Frank Slide, Alberta. Canada's worst landslide disaster.
Source: Geological Survey of Canada, photo number GSC 132916

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. Excellent news footage in the days following the landslide can be seen on the CBC archives listed in the References and Links section.

Figure 21. Saint-Jean-Vianney landslide, Quebec. Close-up of the scarp of the 1971 earthflow. Note cars (arrows) on scarp for scale. A few displaced houses (circled) can be seen in the debris within the scar.
Source: Unknown

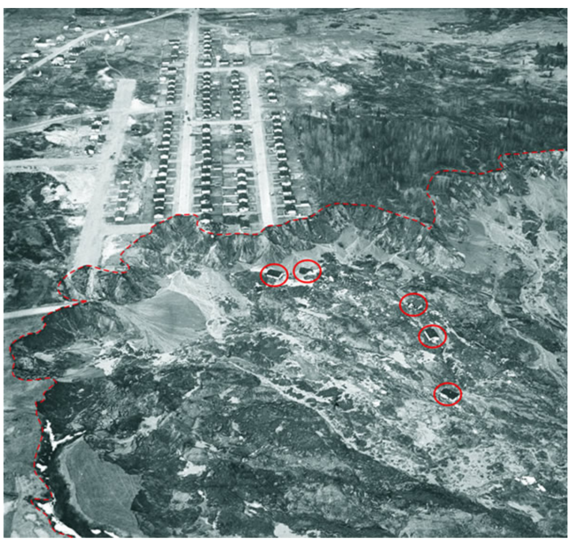

Figure 22. Saint-Jean-Vianney landslide, Quebec. Aerial view of the 1971 landslide headscarp area. Headscarp is indicated with dashed line. A few displaced houses (circled) can be seen in the debris below the scarp. Remaining homes were permanently evacuated.
Source: Photograph courtesy of R. Bergeron, ministère de l'Énergie et des Ressources, Québec, and Canadian Forces, Bagotville

Lemieux, Ontario

Engineering studies, initiated following a large landslide on the South Nation River in 1971, concluded that the town of Lemieux 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.

Figure 23. Lemieux Landslide, Ontario. Aerial view of the 1993 Lemieux landslide taken 4 days after the event. The flood waters of the South Nation River, which rose 12 metres to overtop the debris dam, have inundated the mouth of the landslide scar.
Source: Geological Survey of Canada, photo number GSC 1993-296; Photographer: S.G. Evans

How can we protect ourselves from landslides?

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. Planning allows homes, schools, hospitals, fire and police stations, power-lines, gas pipelines, and roads to be safely located away from potentially unstable zones. For communities that are already established, the municipal or provincial authorities must consider whether protective engineering measures or buy-outs and moving of people and buildings should be undertaken. For example, the town of Lemieux was abandoned in recognition of a landslide risk prior to the 1993 earthflow.

If unstable slopes can not be avoided, there are numerous engineered methods of reducing risk. Local topography and geology, which determine the type of landslide likely to occur, also determines the appropriate mitigation method. It should be noted that these artificial techniques are costly to install or maintain, and in some cases, their capacity may be exceeded.

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 (for example shortcrete) 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.

Figure 24. Debris Deflection Dykes. Debris deflection dykes (arrow), constructed in 1976, protect the town of Port Alice, Vancouver Island, from debris flows.
Source: Geological Survey of Canada, photo number GSC 2000-082; Photographer: S.G. Evans, 1983

Figure 25. Catchment Dam. View down a debris flow pathway along Charles Creek, on Howe Sound, British Columbia, to a debris flow retention structure constructed in the mid-1980s to protect homes in Strachan Creek. The structure was designed to retain a debris flow event of 29 000 cubic metres.
Source: Geological Survey of Canada, photo number GSC 2000-083; Photographer: S.G. Evans

Innovative mitigation techniques are used at some sites. These include active slope monitoring and early warning systems and innovative structures. For example, near Peace River, Alberta, the west abutment of the Little Smoky River Bridge was built on a slow-moving landslide. Rollers placed under the superstructure allow this abutment to slowly move toward the river without damaging the bridge.

Ultimately the best mitigation may be a combination of sensible landuse planning and engineered works to protect critical sites.

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.
- Know who to notify if you recognize these signs (for example municipal emergency contact number(s); municipal engineer).

- Have an emergency plan and an emergency kit at the ready - Public Safety Canada website "Is your family prepared?" (http://www.getprepared.gc.ca/index-eng.aspx) has excellent advice on what to include in both and these can be put to good use in any natural disaster or emergency.

List of Major Landslide Disasters

1841: Québec, Quebec.
1841-05-17. Rockslide destroyed houses on Champlain Street. 32 dead. Source: Evans, 2001.

1852: Québec, Quebec.
1852-07-14. Rockslide destroyed houses on Champlain Street at Cap Blanc. 7 dead. Source: Evans, 2001.

1864: Québec, Quebec.
1864-10-11. Rockslide destroyed houses on Champlain Street. 4 dead. Source: Evans, 2001.

1870: Sainte-Geneviève-de-Batiscan, Quebec.
1870-10-25. Earthflow in Leda Clay, along the Champlain River, overwhelmed a house. 4 dead. Source: MRNQ, 1972, Les glissements de terrain au Québec. Ministère des richesses naturelles du Québec, Direction générale des mines, Rapport S-134.

1877: Sainte-Geneviève-de-Batiscan, Quebec.
1877-05-01. Earthflow in Leda Clay overwhelmed mill and adjoining house. 5 dead. Source: Evans, 2001.

1889: Québec, Quebec.
1889-09-19. Rockslide destroyed houses on Champlain Street. 50 dead. Source: Evans, 2001.

1891: North Pacific Cannery, British Columbia.
1891-07-06. (District of Port Edward) Worker's homes overwhelmed by debris flow or flood caused by the breach of a landslide dam after heavy rains. 35 dead. Source: Evans, 2001.

1894: Saint-Alban, Quebec.
1894-04-27. Farmhouses carried away by massive landslide in Leda Clay. 4 dead. Source: Evans, 2001.

1895: Saint-Luc-de-Vincennes, Quebec.
1895-09-21. Home destroyed by earthflow in Leda Clay. 5 dead. Source: Evans, 2001.

1897: Sheep Creek, near Rossland, British Columbia.
1897-04-20. Debris flow struck railway maintenance camp at Red Mountain. 7 dead. Source: Evans, 2001.

1898: Quesnel Forks, British Columbia.
1898-02-??. Three miners killed. Source: Evans, 2001.

1903: Frank, Alberta.
1903-04-23. Rock avalanche from Turtle Mountain buried part of the coal mining town of Frank, including homes, roads, CP Railway, and Oldman River. 75 dead. Source: Evans, 2001.

1905: Spences Bridge, British Columbia.
1905-08-13. Landslide in gravel moved into Thompson River and caused a displacement wave which swept victims away. 15 dead. Source: Evans, 2001.

1908: Notre-Dame-de-la-Salette, Quebec.
1908-04-26. Earthflow in Leda Clay into Lièvre River caused displacement wave containing blocks of ice which destroyed homes. Victims were swept away. 33 dead. Source: Evans, 2001.

1909: Burnaby, British Columbia.
1909-11-28. Slump of railway embankment; work train derailed. 22 dead. Source: Evans, 2001.

1910: Saint-Alphonse-de-Bagotville, Quebec.
1910-04-15. Construction camp buried by earthflow in Leda Clay caused by blasting during construction of railway. 4 dead. Source: Evans, 2001.

1910: Coucoucache, Quebec.
1910-04-18. Slump of railway embankment; work train derailed. 6 dead. Source: Evans, 2001.

1915: Jane Camp, British Columbia.
1915-03-22. (Near Britannia Beach) Rock avalanche from above the portal of mine swept into mining camp. 56 dead. Source: Evans, 2001.

1921: Britannia Beach, British Columbia.
1921-10-28. Culvert in railway fill became blocked, damming Britannia Creek. Collapse of the fill triggered an outburst flood that swept away more than 50 houses 4.5 kilometres downstream. 37 dead. Source: Evans, 2001.

1922: Elcho Harbour, British Columbia.
1922-09-30. Debris avalanche caused by heavy rains destroyed logging camp. 5 dead. Source: Evans, 2001.

1929: Grand Banks, Newfoundland.

1929-11-18. A massive (100 billion cubic metres) submarine landslide off the continental slope south of Newfoundland, triggered by a magnitude 7.2 earthquake, generated a deadly tsunami that struck the shore of the Burin Peninsula, Newfoundland. 27 dead. Source: Evans, 2001.

1930: Capreol, Ontario.
1930-06-26. Slump of railway embankment; passenger train derailed into Vermillion River. 4 dead. Source: Evans, 2001.

1930: Crerar, Ontario.
1930-06-27. Slump of railway embankment; freight train derailed. 8 dead. Source: Evans, 2001.

1938: Portneuf Station, Quebec.
1938-08-30: Earthflow in Leda Clay caused by heavy rain. 9 dead. Source: unpublished GSC data.

1938: Saint-Grégoire-de-Montmorency, Quebec.
1938-09-01.Landslide caused by heavy rains destroyed apartment building below. 4 dead. Source: Evans, 2001.

1946: Beattie Mine, Duparquet, Quebec.
1946-07-19. Clay from the open pit walls flowed into a mine shaft, killing 4 miners underground. Source: Evans, 2001.

1955: Nicolet, Quebec.
1955-11-12. Earthflow in Leda Clay. $10 M damage including destruction of church complex. 3 dead. Source: Evans, 2001.

1957: Prince Rupert, British Columbia.
1957-11-22. Debris avalanche triggered by heavy rains buried 3 houses. 7 dead. Source: Evans, 2001.

1959: Revelstoke, British Columbia.
1959-03-27. Landslide triggered by highway construction struck house. 4 dead. Source: Evans, 2001.

1960: McBride, British Columbia.
1960-09-07. Debris flow; victims were highway construction workers. 3 dead. Source: Evans, 2001.

1962: Rivière Toulnustouc, Quebec.
1962-12-11. Workers killed by landslide in Leda Clay caused by blasting. 9 dead. Source: Evans, 2001.

1962: Saint-Joachim-de-Tourelle, Quebec.
1963-12-11. Earthflow in Leda Clay; victims drove into landslide crater. 4 dead. Source: Evans, 2001.

1964: Ramsay Arm, British Columbia.
1964-09-16. Debris flow caused by heavy rains struck logging camp. 5 dead. Source: Evans, 2001.

1965: Hope, British Columbia.
1965-01-09. Massive rock avalanche buried 2 vehicles on B.C. Highway #3. 4 dead. Source: Evans, 2001.

1965: Ocean Falls, British Columbia.
1965-01-14. Slush avalanche/debris flow caused by melting snow struck community. 7 dead. Source: Evans, 2001.

1968: Camp Creek, British Columbia.
1968-06-05. Debris flow caused by heavy rains struck car on Trans-Canada Highway. 4 dead. Source: Evans, 2001.

1969: Porteau, British Columbia.
1969-02-09. Rockfall struck car at Porteau Bluffs on Squamish Highway. 3 dead. Source: Evans, 2001.

1971: Saint-Jean-Vianney, Quebec.
1971-05-04. Rapid retrogressive earthflow in Leda Clay swept away 40 homes, bridge. 31 dead. Source: Evans, 2001.

1971: Boothroyd, Fraser Canyon, British Columbia.
1971-05-04. CNR train derailed by rockfall. 3 dead. Source: Evans, 2001.

1972: Michel, British Columbia.
1972-03-20. Debris flow from a coal mine waste dump struck CPR maintenance crew, 16 kilometres west of Crowsnest. 3 dead. Source: Evans, 2001.

1973: Harbour Breton, Newfoundland and Labrador.
1973-08-01. Debris avalanche struck houses. 4 houses swept into harbour and destroyed. 4 dead. Source: Evans, 2001.

1975: Devastation Glacier, British Columbia.
1975-07-22. Rock avalanche buried a geophysical survey crew. 4 dead. Source: Evans, 2001.

1980: Belmoral Mine, Val D'Or, Quebec.
1980-05-20. Cave-in of mine roof triggered a flow of lacustrine sediments into mine workings. 8 dead. Source: Evans, 2001.

1981: M-Creek Bridge, Squamish, Highway 99, British Columbia.
1981-10-28. 4 vehicles plunged into creek after debris flow had destroyed bridge on Squamish Highway during heavy rains. 9 dead. Source: Evans, 2001.
1990: Joe Rich, British Columbia.

1990-06-12. Debris avalanche caused by heavy rains destroyed house. 3 dead. Source: Evans, 2001.

Much of the information on landslides has been derived from: Evans, S.G. (2001): Landslides; in A Synthesis of Geological Hazards in Canada, (ed.) G.R. Brooks; Geological Survey of Canada, Bulletin 548, p. 43–79.

Additional information and a large collection of landslide photographs can be found on the Landslides Canada Web site (http://gsc.nrcan.gc.ca/landslides/).

Definitions of underlined terms

Active layer: The upper part of the ground that thaws each summer and refreezes each winter.

Bentonitic: Material which has the ability to swell in water.

Cretaceous: The final period of the Mesozoic era, after the Jurassic and before the Tertiary. It covers the span of time between 136 and 65 million years ago.

Failure mechanisms: Description of the process of slope failure including the reason why the failure occurred and how it occurred.

Geotechnically: The use of engineering principles to understand how earth materials, such as soils and rocks, behave.

Glaciolacustrine sediments: Sediments which were deposited on the bottom of temporary glacial lakes near the end of the last Ice Age.

Headscarp: The abrupt scarp at the head, or top, of a landslide. (Source: American geological Institute, Glossary of geology)

Limestone: A sedimentary rock composed mainly of carbonate of calcium.

Lithology: The scientific description of the composition and formation of rocks.

Permafrost: A layer of permanently frozen soil and rock. The active layer of permafrost refers to that portion of the ground that freezes in winter and thaws in summer; this layer is usually less than one metre in depth. (Source: Government of Canada Climate Change Site, Glossary of Climate Change Terms)

Sandstone: A sedimentary rock consisting of grains of sand cemented together.

Sensitive clay: Clay whose shear strength is decreased to a fraction of its former value on remolding at constant moisture content.

Shale: A fine-grained sedimentary rock, formed by the compaction of clay, silt or mud.