Unit 4 Glaciation, surficial deposits, soils and landslides

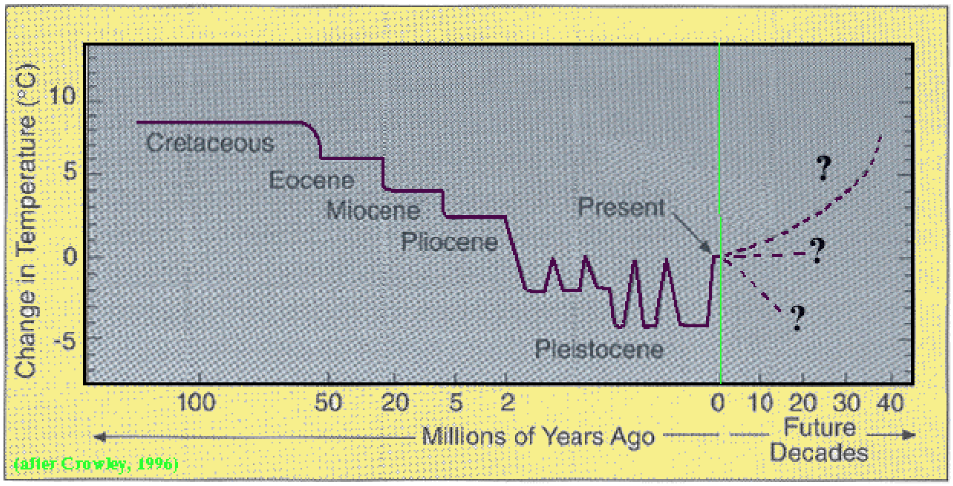
4.1 The Pliocene - Pleistocene glaciations

Many aspects of glaciation, including glacial erosion, glacial landforms and glacial deposits are relevant to environmental geology issues such as slope stability, soil formation and groundwater. Furthermore, an understanding of the causes of glacial and inter-glacial periods is very important from an environmental geology point of view because the process has implications for climate change, its geological origins and its impact on geological processes.

Importance of glaciation to environmental geology

Average surface temperatures over the past 100 million years, based on analyses of various marine and terrestrial deposits as summarized by Crowley (1996)[1], are shown on the figure below. It is evident that there has been an overall drop of between 6 and 8° C since the Cretaceous, a change that is largely ascribed to a reduction in atmospheric carbon dioxide levels over that time

Drop in temperature during the Tertiary



(after Crowley, 1996)

Variations in global temperatures over the past 100 million years (note that the time scale is not linear)

The generally low temperatures experienced during the past 2 to 2.5 million years represent the Pliocene - Pleistocene glaciation[2]. During the Plio-Pleistocene there have been 5 distinct glacial periods, each lasting around one hundred thousand years, and 5 inter-glacial periods. Actually, its 6 if you count the present warm stretch as an "interglacial" and take the view that there is likely to be more ice to come!

Plio-Pleistocene glacial events

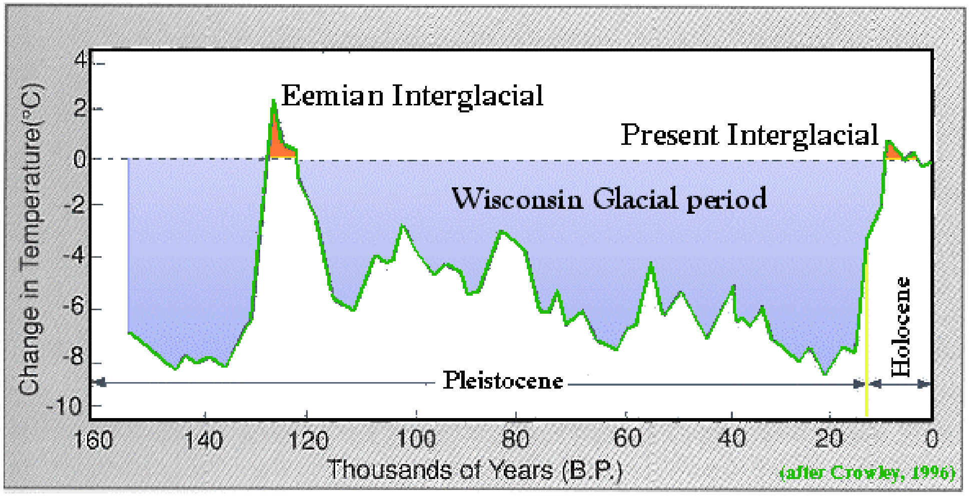
Temperature fluctuations over the past 160,000 years are shown on the figure below. These values are derived from hydrogen isotope measurements on Antarctic ice-cores, and they show that during the glacial interval that lasted from

---

[1] From Crowley, 1996. The atmospheric temperatures values are based largely on oxygen and hydrogen isotope data. Crowley's 1996 paper is included in full at the website of the journal **Consequences**. (see link in the references)

[2] Although it is commonly referred to as the Pleistocene glaciation, its actually Plio-Pleistocene because glacial periods started in the Pliocene, well before the beginning of the Pleistocene at 1.6 m.y.

around 120,000 to 15,000 years b.p. (what we call the Wisconsin Glaciation) the temperature was commonly 3 to 4º C cooler, and as much as 8º C cooler than it is now. The Eemian interglacial period may have been a little warmer than the present interglacial, but it didn't stay warm for very long.



Estimated earth-average temperature variations over the past 160,000 years

The impact of continental distribution on glaciations

Apart from the critical role of greenhouse gases (particularly carbon-dioxide), there are several factors, which can contribute to the onset of a glacial period (ie. a period of much colder than average temperatures, and of continental glaciation in areas which are not glaciated at normal times). One has to do with continental drift, and the concentration of landmasses near to the poles. It has been argued that unless there is a large continental mass near to one or other of the poles, there cannot be a widespread glaciation[3]3. At present the only two large landmasses very near to the poles are Antarctica and Greenland, and while these areas are almost completely glaciated, the extent of their glaciation is restricted by the surrounding oceans. Except under extreme conditions true glacier ice will not extend far out into the oceans. Northern Canada, Alaska, Siberia and northern Europe are also sufficiently close to the north pole to be ice-covered during a glacial period (as they were during the most recent glaciation, which ended only about 10,000 years ago). On the other hand, areas such as Australia and southern Africa, which do not extend south of 40º S, are too far from Antarctic landmass to be glaciated.

Plate tectonics and the Plio-Pleistocene glaciations

The Plio-Pleistocene glaciations cannot be directly attributed to continental drift because the difference in continental positions between 3 m.y. ago, when there was no glaciation and 2 m.y. ago, when there was, only adds up to about 50 kilometres. On the other hand, plate tectonics may have played a different but very significant role in contributing to the onset of the Plio-Pleistocene glaciation. Much of the existing data show that the cooling of the climate was very fast in geological terms, perhaps only a few hundred years, possibly even less. One possibly important event is the connection of North and South America

---

[3] Except in exceptional circumstances, such as the "snowball earth" of the Proterozoic (http://www.mala.bc.ca/~earles/snowball-jan00.htm)

along the Isthmus of Panama. The completion of the isthmus - by subduction-related volcanism - is dated at around 2.5 m.y. ago, and this would have affected the circulation of ocean waters. A significant reduction in the amount of warm equatorial Pacific water moving through the Caribbean towards the northern Atlantic polar region could have led to a sufficient increase in climate extremes to trigger a period of glaciation.

Volcanism and the Plio-Pleistocene glaciations

While changes in the patterns of ocean currents may have been a trigger for the Plio-Pleistocene glaciation, a period of intense volcanism, which has been shown to have occurred at around 2.6 m.y., might also have been a factor. As discussed in Unit 3, it would have to have been a series of very significant events to provide sufficient cooling. The major eruptions of the past 200 years produced, at most, only one or two years of significantly reduced temperatures. On the other hand, if the atmosphere had already been cooled substantially by a drop in carbon-dioxide levels, it might not have taken much extra cooling to start a glacial period

Ice albedo as a positive feedback mechanism

Glaciation provides its own positive feedback. A period of cooling will lead to an increase in build-up of snow and ice, and this will increase the amount of the sun’s energy reflected back to space, thus adding to the cooling effect. This is particularly the case for sea-ice, since snow covered ice is one of the most reflective of earth’s surfaces, while open water is one of the least reflective. An increase in the extent of Arctic and Antarctic sea ice might also inhibit deep circulation of cold polar water towards tropical regions (and circulation of warm tropical water towards polar regions) and would thus lead to more extreme temperatures in the polar regions.

The possible role of methane hydrate

Another positive feedback mechanism, which may be important in controlling the climate, is the existence of vast quantities of methane stored in methane hydrate within sea-floor sediments and in permafrost areas[4]4. The stability of these materials is controlled by ocean water temperature and also by the pressure - which is largely a function of ocean-water depth. Warming of ocean water - perhaps simply because of a change in ocean current patterns - could trigger the release of vast quantities of methane gas, which would have a major greenhouse effect. Conversely, cooling of seawater could lead to greater methane hydrate stability in some areas and hence to a reduction of atmospheric carbon (in the form of carbon dioxide and methane), resulting in cooling.

Milankovitch cycles

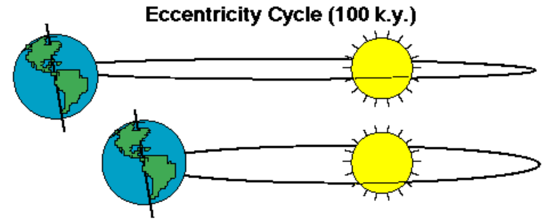
The cyclic nature of the Plio-Pleistocene glaciation can be explained in terms of the periodicity of several aspects of the earth’s motion, both on its axis and in its orbit around the sun. As summarized in the table below, there are periodic variations in the shape of the earth’s orbit (from close to circular to strongly elliptical), in the tilt of the axis of rotation, and in the direction of that tilt (axial precession). Milutin Milankovitch (1879-1958), a Yugoslavian mathematician, argued that combinations of these factors can result in sufficient cooling to trigger a glacial period. He also demonstrated a relationship between these factors and the periodicity of the Pleistocene glacial and inter-glacial periods.

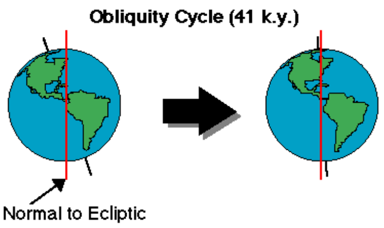
---

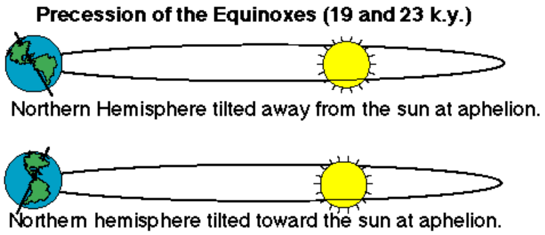
[4] See http://www.mala.bc.ca/~earles/mh-instability-apr00.htm, http://www.mala.bc.ca/~earles/m-hydrate-nov99.htm and http://www.mala.bc.ca/~earles/methane-wipeouts-dec02.htm

While it is clear that variations in the orbital and rotational elements do not change the net amount of the earth's insolation (incoming solar radiation) they do change the amount of light that strikes different parts of the earth. Insolation at around 65° N is interpreted to be important to the growth and decay of ice sheets, so orbital variations that lead to less insolation at that latitude can promote the onset of glaciation. The Milankovitch theory was largely ignored until the publication of a detailed analysis of climate change, based on 450,000 years of sedimentary records, showed a remarkable correspondence between paleo-climate cycles and the estimated climate influences of the orbital variations (Hays, Imbrie and Shackleton, 1976).

Diagrams of the orbital cycles that can impact climate







(Figures from Scott Rutherford, Roger Williams University)

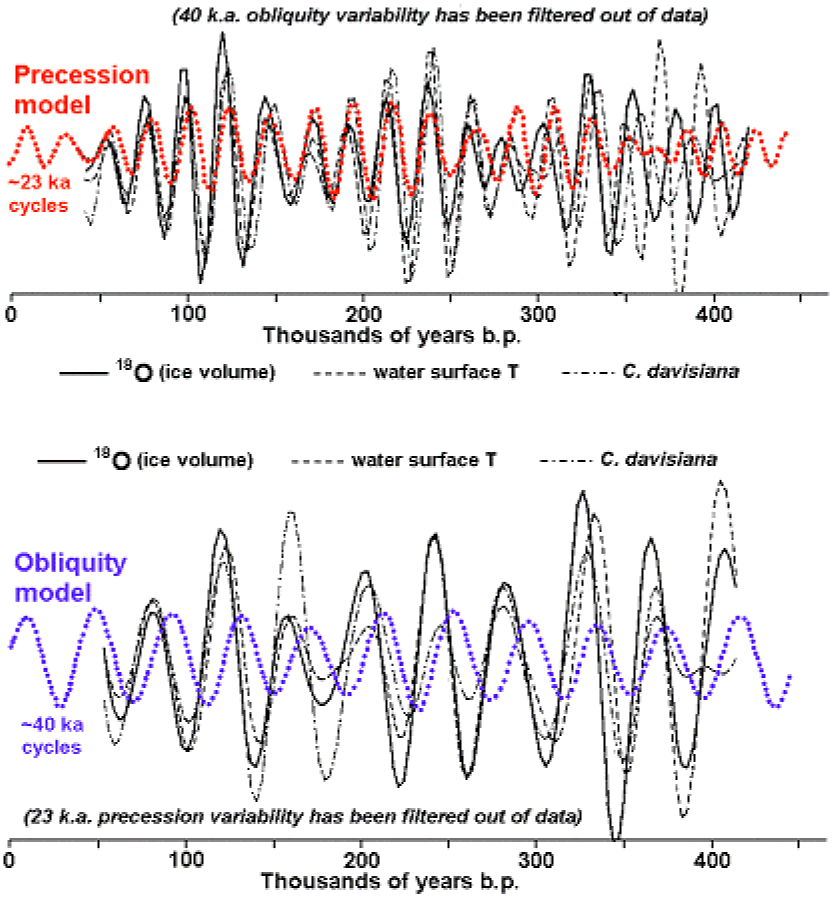
Elements of the earth's motion cited by Milankovitch as being significant to climate variations

Element	Period	Explanation
Orbital eccentricity	~100,000 years	During periods of low orbital eccentricity the winters tend to be warmer and the summers cooler. Ice accumulation is enhanced by cool summers.
axial tilt (obliquity)	~41,000 years	Seasonal contrast is correlated with axial tilt. Seasonal differences are lowest when the axial tilt is lowest (Tilt can range from 22.1 to 24.5°. Currently it is at 23.5°). Lower seasonal contrast leads to growth of ice sheets.
axial wobble (precession)	~19,000 & 23,000 years	Precession affects which hemisphere is pointing towards the sun at its closest approach to the sun (perihelion). Seasonal differences within a hemisphere are reduced when the summer is at aphelion (as the northern hemisphere is at present), and again, lower seasonal differences lead to ice-sheet growth.

The data used by Hays et al. in their study of southern Indian Ocean sediment core samples are shown on the figures below. They show the expected climate effects of precession and obliquity variations (coloured curves), and they include oxygen isotope data from foramnifera (which provides a measure of global ice volume), sea-water surface temperatures determined from the proportions of different radiolarians in the sediment, and the proportion of the radiolarian *C. Davisiana*, which gives an indication of low salinity surface waters.

Data from ocean sediments used by to support the Milankovitch theory of climate forcing related to variations in precession

and obliquity



(from Hays, Imbrie and Shackleton, 1976)

Based on the hypothesis that the variability in these data represent a combination of the effects of the three orbital parameters, Hays et al. filtered out the 40,000-year obliquity periodicity and were left with the curves shown in the precession diagram. These curves are remarkably similar to the predicted precession model periodicity. Hays et al. then filtered out the 23,000-year precession periodicity from the original data, and this time the remaining variability was very similar to the obliquity model, except that there appears to be an approximate 10,000-year offset between the model and the data.

Glaciations are not caused by orbital cycles

Although it is now widely accepted that the Milankovitch cycles are significant in controlling climate, it is unrealistic to suggest that they might have actually caused the Plio-Pleistocene glaciations. Orbital and rotational oscillations have existed throughout the history of the earth, and glacial periods are relatively rare in the geological record[5]. It is reasonable to say, however, that the Milankovitch cycles controlled the timing of glacial advances and retreats.

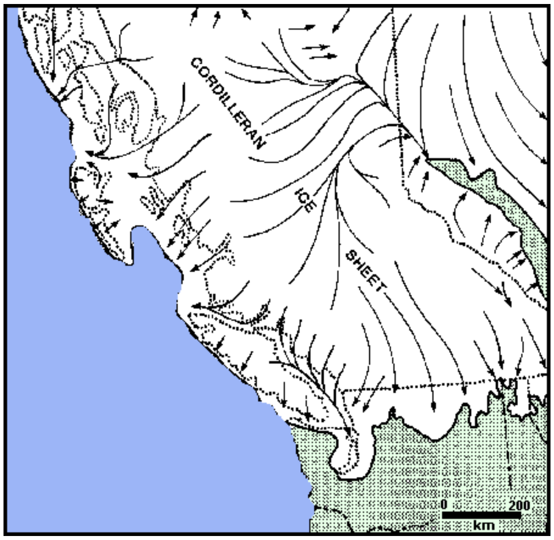
---

[5] For more on Milankovitch and his climate theory visit this NASA website. http://earthobservatory.nasa.gov/cgi-bin/texis/webinator/printall?/Library/Giants/Milankovitch/index.html

The effects of glacial erosion

At various times during the Pleistocene glaciations ice covered virtually all of Canada and a significant part of the north-central U.S. [Keller: Figure 2.22]. There was also extensive glaciation throughout much of Siberia, most of northern Europe and all of Greenland. In most areas these were continental ice sheets that eroded enormous amounts of rock, and left the bedrock planed nearly flat. Mountainous regions, such as the Rockies and the Coast Range, were initially occupied by valley glaciers, which left various glacier-specific landforms such as horns, arêtes, hanging valleys and U-shaped valleys. One of the common features of most of these glacial landforms is very steep valley and mountain sides [Keller: Figures 2.21 and 2.23]. These strongly over-steepened slopes provide for spectacular scenery, but now that the ice is gone they are unstable and prone to severe landsliding. Many of the landslides and landslides hazards of British Columbia can be at least partly attributed to glacial over-steepening.

By the height of the most recent glaciation (ca. 15,000 y b.p.) the alpine glaciers of western Canada had coalesced and essentially all of British Columbia was covered with a continental-type ice sheet – the Cordilleran Ice Sheet - as shown on the figure to the right (Clague, 1994).



Extent of glacial ice in central and southern British Columbia at approximately 15,000 y b.p. (from Clague, 1994)

4.2 Glacial deposits and other unconsolidated deposits

Ice-deposited glacial sediments

Several types of sedimentary deposits are formed under glacial conditions. The ice itself creates a unique type of deposit known as **glacial till,** which is a mixture of fragments ranging in size from very fine clay to very large boulders. The primary characteristic and diagnostic feature of till is that its components are unsorted and unstratified (ie. not layered) because they have been transported by ice (either within or underneath the ice), and not by water or wind[6]. Tills are commonly quite clay-rich (but they always have larger fragments as well). **Lodgement till** is formed from material that is moved along at the base of the ice. **Ablation till** is comprised of material that is moved within or on top of the ice and is deposited when the ice melts. All types of till have the properties of being poorly sorted and comprised of fragments that are not well rounded. Lodgement till is commonly very well compressed (by the weight of the ice), almost to the point of lithification in some cases.

---

[6] Another name for a glacial till is ***diamicton***, which implies a range (*dia*) of grain sizes. Tills typically comprise a mixture of material ranging in size from clay to boulders

Waterlain glacial sediments

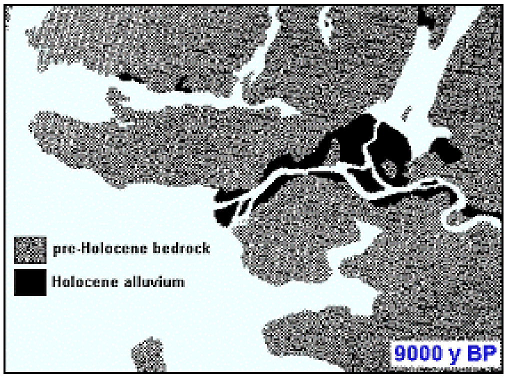
There is normally a lot of water around a glacier - especially at its leading edge - and various types of stratified sediments are deposited in several different environments. These include stream (**glaciofluvial**) deposits - which can also have a wide range of grain sizes, but are usually well sorted and well layered, and lake (**glaciolacustrine**) deposits, which are commonly very fine grained and layered in laminations as thin as a few millimetres. Some glaciofluvial deposits in the Nanaimo area are shown on the figure below.

Wisconsin aged glaciofluvial deposits in the Cedar area near to Nanaimo (note coarse cross-bedded material at the bottom and finer laminated material towards the top)

Slope stability implications of glacial sediments

Most the deposits associated with the Plio-Pleistocene glaciation are only 10,000 to 15,000 years old (largely because most of the earlier Plio-Pleistocene deposits were eroded by subsequent ice advances), and they are generally unconsolidated. Most were deposited in areas that were under ice or under water, but are now exposed on dry land because the ice and its associated water bodies are gone. Because glacial deposits are exposed on land (as steep cliffs in some cases) and because they are unconsolidated, they are especially prone to failure as slumps and slides.

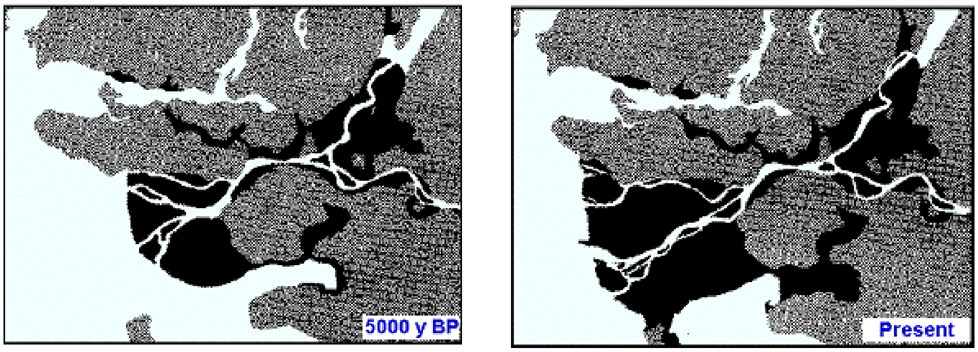
Non-glacial surficial deposits



Progressive growth of the Fraser River delta over the past 9000 years (from Clague, 1994)

(see figures below)

In British Columbia most surficial (ie. unconsolidated) deposits are either glacial, or **fluvial** (river-borne) in origin. For example, most of what is now the Fraser River Delta did not exist 9000 years ago. The unconsolidated materials that underlie all of Richmond, Delta and White Rock, and much of Surrey, have been deposited by the Fraser River in the past few thousand years (compare the figure to the right with those below). The rest of the Fraser Valley (as far as Hope) is also underlain primarily of fluvial deposits.



The Fraser delta at 5000 years ago and at present

Colluvium

Fluvial deposits are also known as **alluvium**. The material that accumulates at the bases of steep slopes and cliffs ("scree" slopes) is called **colluvium** (or "talus"). Colluvium is transported only by gravity, and not by water. It normally includes fragments of varying sizes, up to large boulders, and these fragments are characteristically angular, rather than rounded. Colluvial deposits do not normally pose a significant geological hazard because the slopes are not over-steepened. If the base of a colluvial fan is removed to make a road the upper part of the fan may then become unstable.

Soil

Soil

Soil is a combination of mineral matter, organic matter, water and air. The mineral matter is produced by the weathering of either bedrock or unconsolidated material ("*drift*") that overlies the bedrock, and it commonly includes different kinds of clay minerals, quartz and feldspar grains and small rock fragments. The organic matter is humus, the decayed remains of plant and animal life[7].

Soil horizons

Soil profiles are commonly divided into "horizons". The uppermost layer, beneath the partly decayed organic matter, is the **A horizon**. Most of the humus is confined to this layer. The **E horizon** represents a zone of leaching (or eluviation). Iron oxides and clays are depleted in this layer, and enriched in the underlying **B horizon**. The **C horizon** comprises material that is only marginally different from the underlying rock or overburden (the **parent material**). If the parent material is solid rock, then the C horizon will be broken and weathered rock. If the parent material is unconsolidated (eg. till or alluvium), then it may be difficult to distinguish this from the C horizon. The type of soil which will be found at any particular site will depend on the climate, the type of vegetation, the slope of the site and the drainage, the composition of the parent material (ie. the bedrock or drift), and the amount of time during which the soil has been able to develop.

Climate and soil

Important climate factors include the temperature and the amount of rainfall. Relatively high temperatures will promote rapid soil formation, and very low temperatures will almost preclude soil formation. The amount of rainfall will affect the degree to which certain soluble components will be washed through the soil profile.

---

[7] Soils and soil formation are described in Chapter 3 of Keller.

Vegetation and soil

The type of vegetation (which is obviously also controlled by the climate) will impact the type and quantity of organic matter in the soil.

Slope and soil

The slope is important because it controls the degree to which material will be eroded from or deposited on the site. If the overburden is continually being eroded from a steep slope there will be little opportunity for soil to form. The slope also impacts on the drainage. Soils developed in areas with poor drainage can be different in many ways from those in areas of good drainage.

Parent material and soil

The composition of the parent material will affect the chemistry of the mineral component of the soil, and can have a significant impact on its fertility. Soil developed on mafic volcanic rock, for example, would tend to have higher levels of magnesium, iron and many trace elements than soil developed on granite or mature sandstone. The rate of soil development would also be faster because the minerals in the mafic rock are generally more susceptible to weathering. Soil developed on limestone would likely have high calcium levels.

Time and soil

The importance of time is obvious, but there are so many variables in soil formation that it is futile to try to list rates of formation. Most parts of Canada were covered with glacial ice as recently as 10 to 15 thousand years ago, and in the southern part of the country this has been sufficient time for a reasonably good soil to form. In northern regions the time since deglaciation has been shorter (by a few thousand years) and since the climate is much cooler, most areas are characterized by very thin and poor soils.

Soil classes

In most of British Columbia the soils fall within the class known as **pedalfer**, which means a soil in which aluminum (al) and iron (fer) have been enriched. Typical pedalfers in this region have a dark brown to black A horizon of 5 to 10 cm thickness, a thin E horizon (< 5cm), and a light brown to rusty brown B horizon of around 20 cm thickness. There is sufficient precipitation throughout most of British Columbia for calcium-carbonate to be completely washed out of the soil and into the groundwater. In the **pedocal** soils of dryer climates, however, calcium carbonate accumulates as a hard and white **caliche** layer beneath the B horizon.

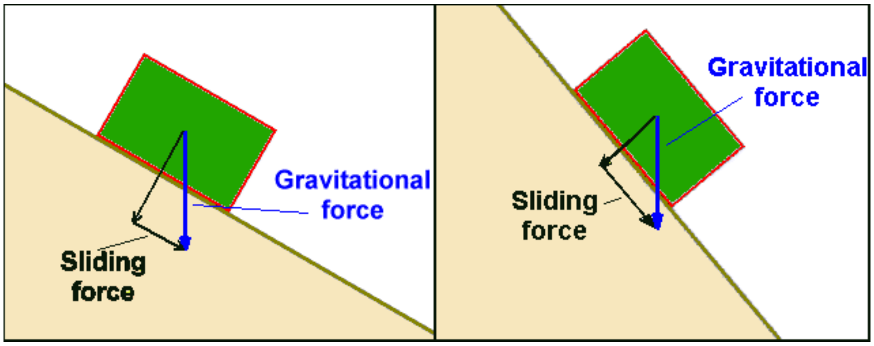
In hot and wet climates a type of soil called **laterite** may develop. Lateritic soils, which can be many metres thick, are characterized by depletion of silica, and hence relative enrichment of aluminum and iron. Aluminum ore or **bauxite** develops as a result of lateritization of parent rock that is already relatively rich in aluminum. If the parent rock is relatively rich in nickel (as many ultra-mafic rocks are) the resulting laterite may be sufficiently rich in nickel to be mined.

4.3 Slope failure

Slope failure

Failure of a slope will occur when the friction holding the material on a slope is less than the force of gravity trying to push it down. The gravitational force is straight down, but on a slope a component of that force will be along the slope (see figure below). The steeper the slope the greater will be the component of gravity down the slope, and hence the greater will be the tendency for failure.

Sliding force as a function of slope

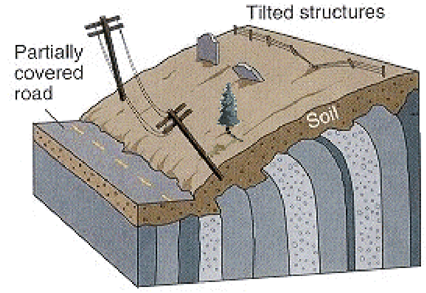


Friction and material strength

The force of friction holding the material in place will be dependant on the strength of cohesion between particles of the material comprising the slope. Strong unfractured rock will have a great deal of strength, while loose sand will have very little. [see Keller Chapter 6 for a discussion on landslides[8]]

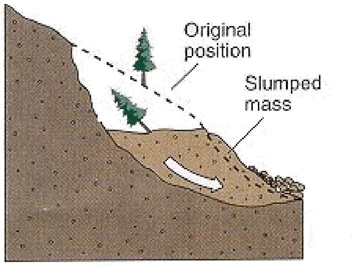
Slope failures are classified into several different types. Some of the important categories are illustrated in the following figures.

Types slope failure in unconsolidated materials



CREEP

Creep is the slow downslope movement of soil and loose rock fragments. Features on the surface will be tilted. Trees may show bent "pistol-butt" trunks.

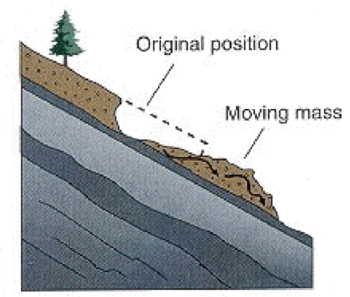


SLUMP

Slump is the slow to moderate movement of materials on a slope. In most cases the materials are unconsolidated or poorly consolidated. The motion is rotational, and the plane of movement is curved.

---

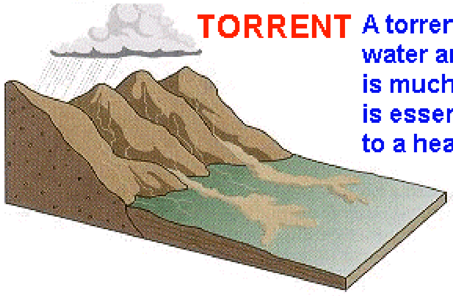
[8] There is also a great deal of information about glaciation, surficial geology, landslides and geological hazards at the Geological Survey of Canada - Terrain Sciences Division’s website



FLOW

Flow is the fluid-like motion of water-saturated material down a slope. The rate of flow may be fast (hours to days), but it is not catastrophic.

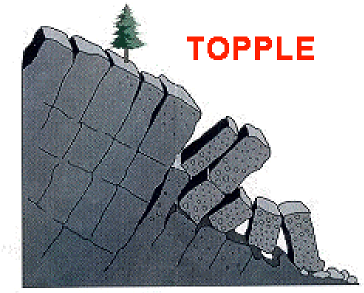
(a DEBRIS FLOW is a type of flow)



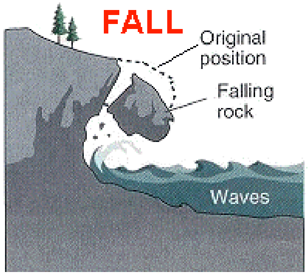
TORRENT

A torrent is a sudden channelized discharge of water and other material. The amount of water is much higher than in a flow, and the material is essentially liquid. A torrent occurs in response to a heavy rainfall or rapid melt (eg. a lahar).

Types of slope failure in solid rock



TOPPLE

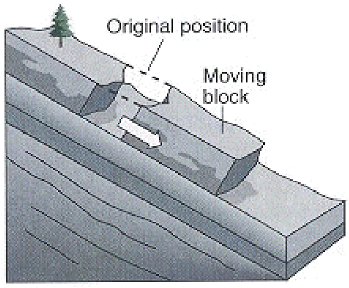


FALL

Topple is end-over-end motion of rock down a slope.

Fall is free fall of rock.

(in a rock avalanche the fragments do not move as a coherent mass)



ROCK SLIDE

A rockslide is the rapid movement of solid rock material down a slope. Movement is typically parallel to bedding planes, faults or other weaknesses in the rock

(a ROCK AVALANCHE is a large rock slide)

Angle of repose

The steepest angle that a pile of unconsolidated material can maintain without collapsing is called the ***angle of repose***. The angle of repose for *dry* sand is around 33º - which means that if you pile up sand the sides of the pile will not be any steeper than 33º. If we add just enough water to wet each grain of sand there will be significant cohesion between the grains (due to surface tension), and the angle of repose will be much higher, as high as 80º under some conditions. If we add enough water so that the grains lose contact with each other, that surface tension will be lost, and there will be almost no friction between the grains. The material will behave as a slurry (ie. like a liquid), and the angle of repose will be effectively zero.

Rock strength

Solid igneous rocks, such as granite or basalt, or metamorphic rocks (such as gneiss) have great strength. On the other hand, any fractures or zones that have been partly altered (eg. to clay minerals) will be weaker, and that will limit the strength of the body of rock. The strength of layered rocks (such as sandstone or shale) or foliated rocks (such as slate or schist) will be controlled by the strength of the weakest layers. For example, a series of interbedded sandstone and mudstone beds will only be as strong as the mudstone, and if the clay minerals within the mudstone become saturated with water those layers may have very little strength. The implications of fractures, faults and bedding planes will be most critical in cases where the orientations of these features are close to that of the slope of the rock face or mountainside.

The significance of clay minerals

The type of clay minerals present can have very significant implications for the effects of water saturation. As discussed in Unit 1, the presence of swelling clays can effect slope stability in three ways - their increase in volume can physically disturb the surrounding rock, their increase in weight can destabilize a rock mass, and the reduction in strength associated with swelling can reduce the cohesion of a rock mass.

Oversteepening and removal of vegetation

Failures commonly occur in areas where the slopes have been over-steepened, either naturally (eg. by glaciation) or by human excavation. Another important factor is the removal of vegetation, which can have the effect of reducing the cohesiveness of the material on a slope[9].

Triggering mechanisms

Water

Slope failures can be triggered by various different factors. The most common trigger is water saturation. Heavy rain, or rapid melting of ice by volcanic activity, are common causes of water saturation, and the effects are an increase of mass of the body of material, loss of friction between grains, and loss of strength of clay-bearing material, especially those with swelling clays.

Earthquakes

Many failures are triggered by earthquakes. Obvious examples are those related to the 1946 quake at Courtenay - like the one at Mt. Colonel Foster. The devastating slide at Nevado Huascaran Peru that caused 25,000 deaths in the towns of Yungay and Ranrahirca, was triggered by a large earthquake situated some 65 km to the east [Keller: Figure 6.15].

Freeze-thaw

Freezing and thawing can also be important in triggering slope failures. Creep is typically primarily caused by freezing and thawing, and some major rock slides can be attributed to freezing and thawing.

Undercutting

Along highways in British Columbia (and elsewhere) there are literally thousands of small slumps that can be generally attributed to the excavation of steep slopes in unconsolidated material, and then to saturation of that material with water. The movement in these situations commonly takes the form of rotation, where the sliding surface is curved, from quite steep at the top to much flatter (or even upward) at the base. Rotational slumps also occur at much larger scales, commonly as a result of undercutting due to fluvial or wave action. The 1888 Haney Slide on the Fraser River is another example of this type of feature (Evans

---

[9] This issue will be discussed in more detail under the topic of forestry operations.

and Savigny, p. 277, 278).

Waste piles

Man-made piles of unconsolidated materials, such as mining wastes, can also be prone to sliding if they are made too steep, or if proper attention is not paid to issues such as their composition (eg. the amount of clay) and the degree of water saturation.

4.4 Slope failure in British Columbia

Slope failures in B.C.

Slope failures, and the potential for failures in southwestern B.C. (excluding Vancouver Island), are described in Evans and Savigny (1994)[10]. Both solid rock and drift deposits in this area are extremely prone to failure because of the high relief, the steep slopes related to glacial erosion, the heavy rain[11], the high frequency of freezing and thawing and the relatively high frequency of seismic events. Most of the past failures, especially those in solid rock, have been catastrophic (ie. rapid) events. Others, especially those involving surficial deposits, have been characterized by relatively slow deformation.

From the map of landslides (E&S: p. 253) it could be interpreted that most of the significant events have been restricted to major transportation corridors, such as the Trans Canada and Hope-Princeton Highways east of Chilliwack and the Sea-to-Sky Highway north of Horseshoe Bay. This is partly an artifact of the degree of media attention and scientific analysis that these slides have received because of their impact on the transportation system and their accessibility. All parts of this region which have steep slopes or thick drift deposits are prone to slides, and slides in remote areas are either not known about, or not well studied because they are difficult to get to.

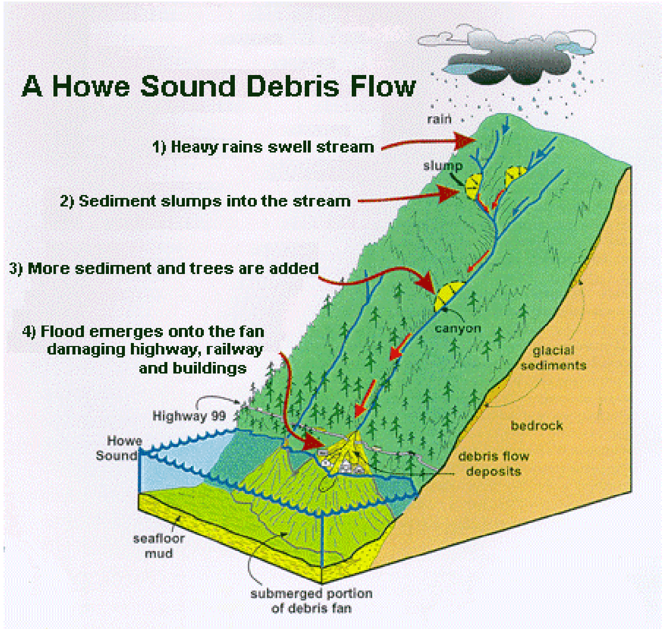
Howe Sound, and the valley of the Squamish River, from Horseshoe Bay north to Whistler, have been shaped by glacial erosion, and the slopes in these areas are extreme. In addition, there have been high-volume volcanic flows at various locations north of Squamish (E&S: p. 265) and some of the flow materials have been prone to failure. Closure of the Sea-to-Sky Highway and the adjacent BC Rail line because of rock slides and debris slides (slides of unconsolidated material) is a common event, and in some years there have been many closures (E&S: p. 254 and 255). Millions of dollars are spent every year dealing with the small and large landslides, and upgrading the highway's defenses to prevent further disruptions (E&S: p. 272 to 276). A summary of the factors leading to generation of debris flows in the Howe Sound area is given on Figure 4.9[12].

---

[10] The paper by Evans and Savigny (E&S) is available from the "Lecture Notes" link.

[11] The close correlation between monthly rainfall amounts and rock-fall frequency in the Fraser Canyon near to Yale is clearly shown in a diagram on p. 256 of Evans and Savigny (1994). There is also a strong negative correlation with temperature, suggesting that the frequency of freezing and thawing (and hence frost wedging) also has an impact on the rate of rock fall release.

[12] There is more information on the Howe Sound debris torrents and structures built to defend against them at the following website: http://www.mala.bc.ca/~earles/howesound/



Processes that lead to the generation of debris torrents in regions such as Howe Sound (from Geoscape Vancouver)

Rubble Creek rock avalanche

As described in Unit 3 there have been numerous volcanic eruptions in the Garibaldi to Mt. Meager area (although none since about 2400 years ago) and numerous historic landslides. One of the most spectacular landslide locations is at Rubble Creek, which is the starting point for the Black Tusk hiking and camping area north of Squamish .

The Barrier

As discussed in Unit 3, a late Pleistocene eruption from Clinker Peak flowed for several kilometres towards the Cheakamus River Valley (E&S: Figure 26). The leading edge of the flow - which abutted into a glacier at the time of the eruption, has failed many times since the glacial retreat, the most recent event being in the winter of 1855-56, when over 30 million cubic metres (over 80 million tonnes) of rock were released from *The Barrier*, and traveled 6 km towards the river valley. The volume of slide material within the Rubble Creek valley is estimated at over 150 million cubic metres, and there is evidence that it is comprised of material from between 5 and 10 landslide events.

Britannia Mine slope failure disasters

Because of the very low population density there have been relatively few casualties from slides in the Howe Sound - Whistler area. The greatest catastrophe was a rock slide at the Jane Camp of the Britannia Mine in March of 1915, which claimed 56 lives, and is described as Canada's second worst landslide disaster (E&S: p. 256 and 257). Six years later a debris flow raced through Britannia Beach, killing 15 (Figure 4.10). The October 1921 event followed several days of heavy rain, but it was largely caused by the blockage of a culvert several kilometres upstream, in the Jane Camp area. The blockage caused water to be dammed up behind a roadway embankment, and the disaster occurred when the embankment failed.

Another major debris flow affected the town of Britannia Beach in September of 1991.

Hope Slide

Hope Slide

At 7 AM on January 9th, 1965 a massive rock slide (or rock avalanche) - the largest in Canada in historical times - occurred in the valley of the Sumalo River, on Highway 3 (Hope - Princeton Highway), approximately 17 km east of Hope. About 47 million tonnes of rock slid down the steep mountainside into the valley, covering several kilometres of the highway and killing 4 people[13].

Significance of rock type

The area of the Hope Slide is underlain primarily by basaltic volcanic rock of the Hozameen Complex (age range 150 to 280 m.y.). The basalt has been metamorphosed, and is now a chlorite schist, which is massive in some parts (ie. non-foliated), and schistose in other parts. The attitude of the schistosity is roughly parallel to the slope of the slide plane. The average mineral composition of this rock is 60% amphibole (hornblende), 15% quartz and feldspar, and 20% c chlorite.

Felsite sills and fault gouge

The basalt has been intruded by "felsite" sills[14] (orientated generally parallel to the schistosity). The felsite includes 70 to 75% quartz and feldspar, 20% amphibole and 10 to 15% biotite and chlorite (ie. it is essentially granitic to granodioritic in composition). The contacts between the felsite and the basalt are characterized by **gouge** - ground up rock fragments and clay minerals -, which is a common feature of fault zones where there has been relative motion between the rocks on either side. This material includes the clay minerals smectite, smectite-chlorite mixed-layer clay and kaolinite, as well as chlorite and talc.

Orientation of foliation and structures

Measurements made in the area of the slide surface show that most of the fractures in the basaltic rock dip in the general direction of the slide surface, at angles close to 45 and 80º from horizontal (some are also close to 20º).

Weather

Weather records for the 25 days prior to the slide indicate that the average temperature was much colder than normal for December 1964 and January 1965. Over this period the average daily temperature did not exceed 0º C on any days, and on most days it was below -10º C. Precipitation levels were close to normal for the period. Approximately 50 mm of rain-equivalent precipitation was recorded in the 10 days prior to the slide, but it is almost certain that most of this fell as snow - especially in the upper parts of the slide area.

Earthquakes

Two earthquakes were recorded in the general area of the slide on January 9th (the epicentres are indicated as being within 10 km of the slide location but the accuracy of the determinations is poor (the epicentre location is listed as + or - 20 km). One quake (M_L 3.2) occurred at 3:56 AM and a second (M_L 3.1) occurred at 6:58 AM. The second of these is presumed to have coincided with the main slide

---

[13] The observations and interpretations of the Hope Slide presented here are taken largely from von Sacken (1991). There is also a description of the slide, and some good photos in Evans and Savigny (1994) (p. 258 and 259).

[14] Felsite is an igneous rock in which the groundmass is comprised almost entirely of very fine grained ("cryptocrystalline") quartz and feldspar. The composition is listed as "quartz plus feldspar" because the grains are too small to be able to distinguish the two, and estimate their proportions, even under a microscope.

event. The first may have been coincident with an earlier smaller slide or avalanche.

Probable factors for the Hope Slide

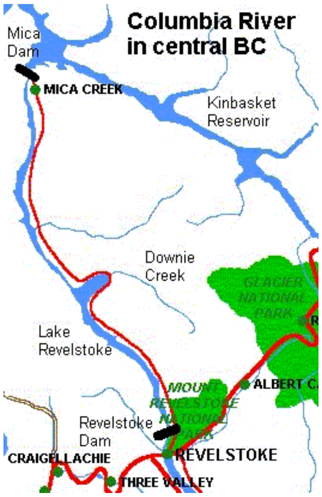
It is suggested that the failure of the rock at the Hope Slide was controlled by the various fractures on the upper part of the slide surface, and by the gouge-filled contacts between felsite and basalt in the lower part.

Doubts about what triggered the Hope Slide

The mechanism or trigger for the Hope Slide is not known. In studies carried out prior to that of von Sacken (1992) it was concluded that the event was triggered by the two earthquakes. The reports from the scene referred to a snow avalanche that blocked the road at around 4 AM, but many believe that this was actually a rock slide (with mixed-in snow) that may have looked like an avalanche in the early-morning darkness. von Sacken has studied the dynamics of the sliding material and, based on the volume of rock and the average vertical displacement (300 m), she concludes that the slides themselves may have caused the seismic events, and not the other way around. The answer to this question may never be resolved satisfactorily because we don't have enough good seismic data to determine the exact locations of the earthquakes, and because we don't know how large the first slide was, nor whether it actually occurred at 4 AM.

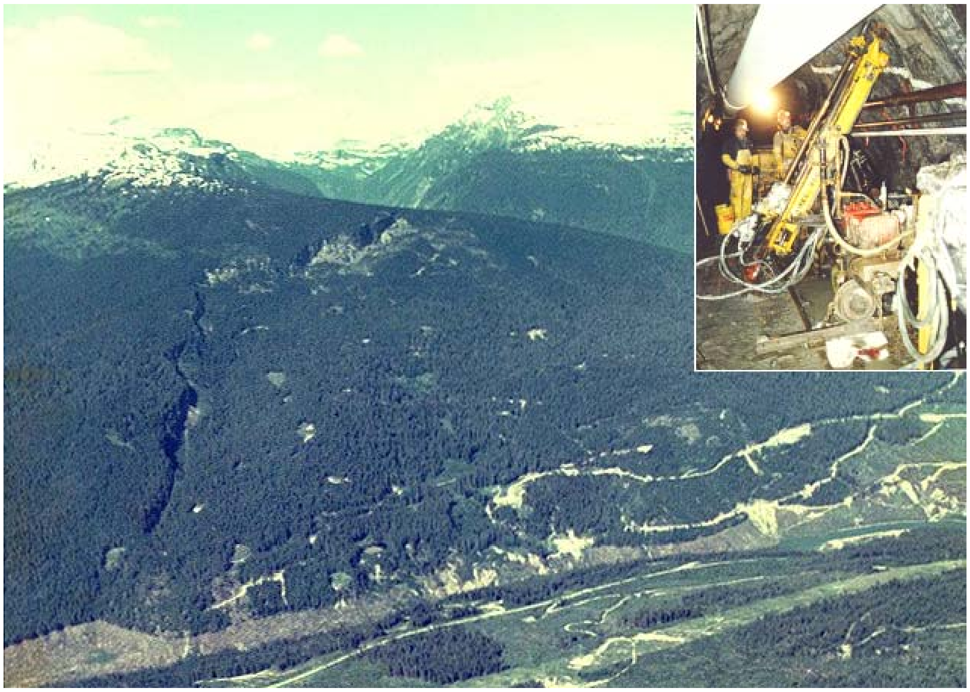
In view of the weather conditions in late December 1964 and early January 1965, it seems unlikely that the Hope Slide was triggered by water saturation of the clay-rich fault gouge in the lower part of the slope, or by freeze-thaw cycles opening up the joints in the upper part of the slope. It is possible, however, that water which had seeped into the rocks in the autumn of 1964 led to saturation of the swelling clays along the basalt-felsite contacts.

Downie Slide



Location of the Revelstoke dam and reservoir

During construction of the Revelstoke Dam in the 1970s it was brought to the attention of BC Hydro engineers that a part of the valley wall of the new reservoir was unstable, and represented a potential risk as a rock avalanche. A huge block of rock (1.4 billion m^3) was creeping down the slope, and although the movement was very slow (cm/year) it was suggested that water-saturation of the fault plane by filling of the reservoir could accelerate this motion. Since a large failure into such a reservoir would have devastating implications for the area downstream, BC Hydro was compelled to stabilize this rock mass. They did so by draining water away from the fault zone at the base of the slide. A plumbing system, consisting of hundreds of metres of tunnels and thousands of metres of drill holes, was created to drain water away from the fault zone. The work was completed in 1982 and now the Downie Slide block is not moving significantly, and is considered to be more stable than it was before the reservoir was built.



The Downie Slide prior to flooding of Lake Revelstoke.

The top-scarp and a scarp along the left side are visible.

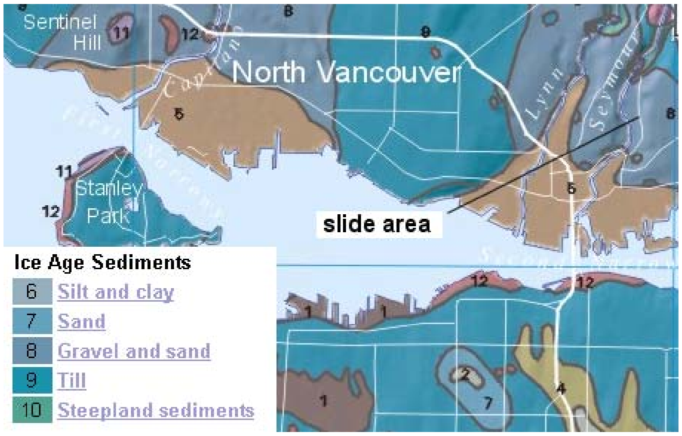
Inset: drilling drainage holes from one of the drainage tunnels.

(Photos courtesy of Randy Bourne, BC Hydro)

January 2005 North Vancouver debris flow

The 2005 N. Vancouver debris flow

In mid-January of 2005 a strong onshore flow of moist Pacific air produced several days of very heavy rain in southwestern B.C., particularly in the Vancouver area. At about 3:30 AM on January 19th an embankment behind a residence in the Seymour River area of North Vancouver failed and the material slid down a steep slope destroying one house and killing one person.



Map of surficial deposits in the slide area

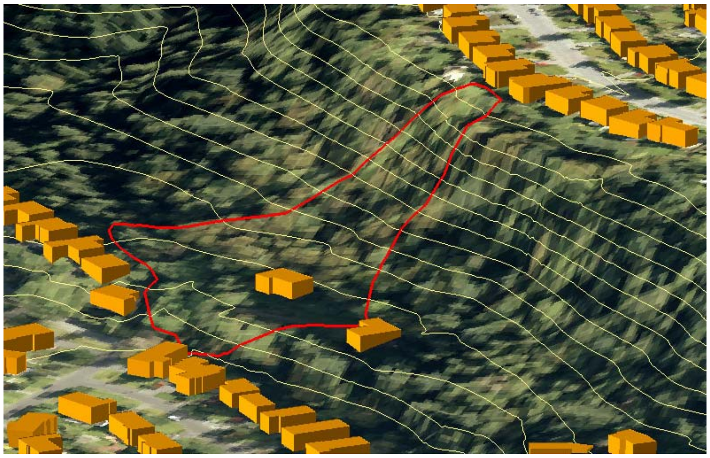
(from Geomap Vancvouver)

The area where the North Vancouver slide took place is underlain by fluvial sediments of glacial origin (see map). These deposits are similar in origin to those of the cliffs at Point Grey. As is the case elsewhere, they have been strongly eroded by marine and fluvial processes, such that some steep slopes remain.

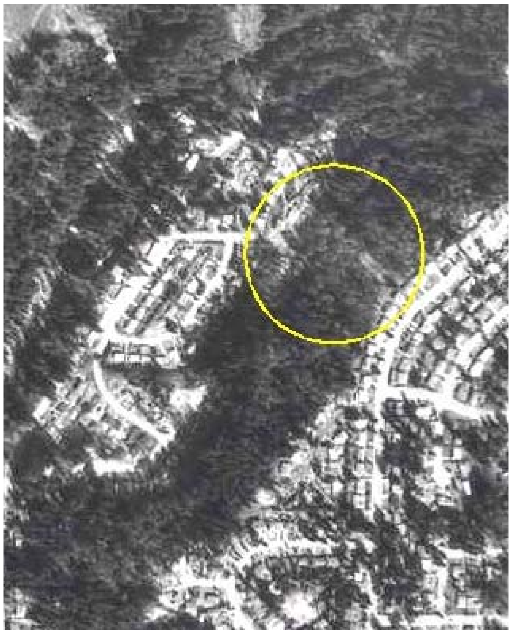
Glacio-fluvial deposits

The January 2005 slope failure occurred in a residential area with a known history of previous failures. Early analysis of the incident indicate that it was attributable to an embankment in a back yard at the top of a steep slope (see figure below). The material behind the embankment became saturated with water (possibly as a result of a poorly-designed drainage system) and then the embankment failed and the slide propagated several hundred metres down the slope, completely destroying one house.

In view of the water-saturated nature of the material, and its relatively fast rate of movement, this failure can be most appropriately described as a debris flow.



District of North Vancouver perspective view of the failure area



Left: View from the bottom of the debris flow looking up past the house that was destroyed.

Right: Air photo taken before the 2005 slide. Note evidence of a previous slide at this location.

References

Clague, J., 1994, *Quaternary stratigraphy and history of south-central British Columbia*, in J. Monger (ed) Geology and Geological Hazards of the Vancouver Region, **Geol. Surv. Canada**, Bull. 481, p. 181-191

Crowley, T., 1996, Remembrance of Things Past: Greenhouse Lessons from the Geologic Record, **Consequences**, V. 2. (available at: http://www.gcrio.org/CONSEQUENCES/winter96/geoclimate.html)

Evans, S. and Savigny, K , 1994, *Landslides in the Vancouver-Fraser Valley-Whistler region*, in J. Monger (ed) Geology and Geological Hazards of the Vancouver Region, **Geol. Surv. Canada**, Bull. 481, p. 251-286.

Hays, J., Imbrie, J., and Shackleton, N., 1976, Variations in the Earth's orbit: pacemaker of the ice ages, **Science**, V. 194, p. 1121-1132.

von Sacken, R., 1991, New data and re-evaluation of the 1965 Hope Slide, British Columbia, 1991, MSc Thesis, Univ. of British Columbia.