Landslides: Human Health Effects

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Landslides: Human Health Effects

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Abbreviations

M	magnitude

Introduction

Landslide is a generic term used to describe the detachment and downward movement of soil, rock, or other earth material under the influence of gravity (Figure 1).

Landslides occur in a variety of materials (earth, debris, rock, organic materials), move at varying rates (millimeters per year to tens of meters per second), and can involve various styles of movements (fall, flow, slide, spread) (Table 1). Landslides can have a variety of stages of activity ranging from relict to dormant to active. They can be retrogressive, progressive, advancing or enlarging, move along planar or curved surfaces, and be shallow or deep. In addition to this, they are often complex involving more than one type of material and style of movement.

Managing landslides and landslide-prone terrain necessitated their classification to enable intelligent and efficient communication. There are several classifications in use today. In general, landslide nomenclature is based on material type and movement type (summarized in Figure 2).

Material Types

The terms used for landslide materials should describe the displaced material as it was before the landslide occurred. For example, the term rock slide describes the in-place intact bedrock before displacement rather than the rubble or debris in the landslide deposit.

Rock describes intact, in-place bedrock.

Debris refers to generally loose, unsorted material, typically derived from colluvium, till, glaciofluvial sands and gravels, and anthropogenic materials. Debris typically consists of a mix of pebbles, cobbles, and boulders in a matrix of sand, silt, or clay. Debris can contain significant volumes of organic material, including trees and humus.

Earth refers to generally unsorted, cohesive, plastic materials with a predominant particle size ranging below 2 mm.

Mud refers to liquid or semiliquid clay-rich materials (or earth with a high water content). Such materials include clay-rich, sensitive, glaciomarine sediments occurring in some coastal areas, lake sediments, and some volcanic muds.

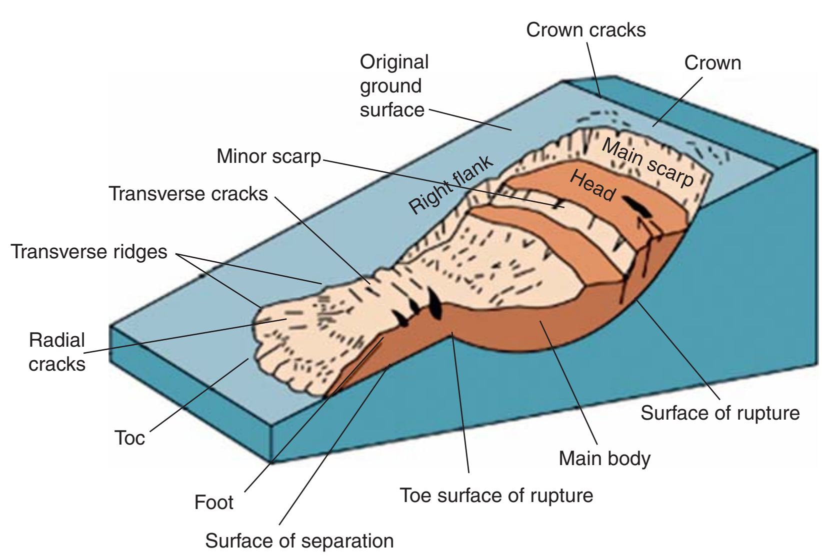

Figure 1 Anatomy of a landslide. Adapted from Varnes DJ (1978) Slope movement types and processes. In: Schuster RL and Krizek RJ (eds.) *Landslides, Analysis and Control. Transportation Research Board Special Report 176*, pp. 11–33. Washington, DC: National Academy of Sciences.

Table 1 Abbreviated classification of slope movements

Type of movement	*Type of material bedrock*	*Coarse soil*	*Fine soil*
Topple	*Rock topple*	*Debris topple*	*Earth topple*
Fall	Rock fall	Debris fall	Earth fall
Slide	Rock slide	Debris slide	Earth slide
Spread	Rock spread	Debris spread	Earth spread
Flow	Rock flow	Debris flow	Earth flow

Source: Modified from Cruden DM and Varnes DJ (1996) Landslide types and processes. In: Turner AK and Schuster RL (eds.) *Special Report 247: Landslides Investigation and Mitigation*, pp. 36–75. Washington, DC: National Research Council, Transportation Research Board.

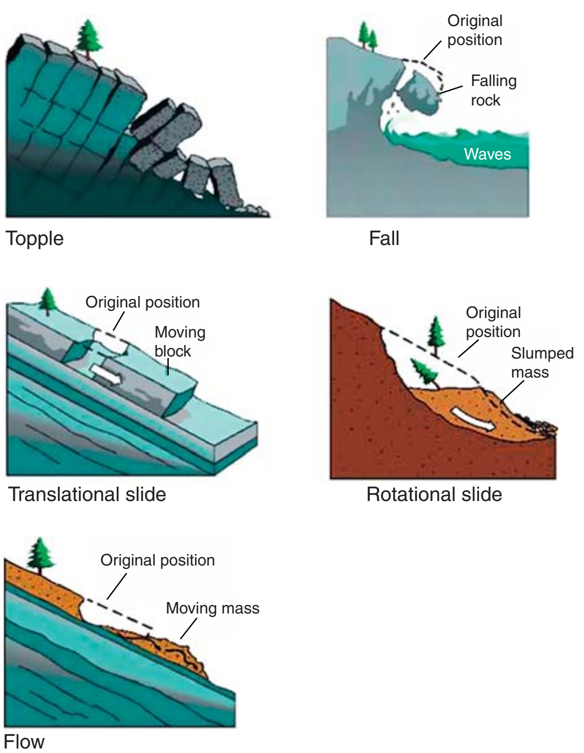

Figure 2 Cartoons of landslide movement type. Modified from British Columbia Geological Survey, Branch of the B.C. Ministry of Energy, Mines, and Petroleum (1993) *Landslides in British Columbia, Information Circular 1993–1997*, http://www.em.gov.bc.ca/Mining/Geolsurv/Surficial/landslid/ls2.htm (accessed July 2010).

Organic materials include both saturated lowland peats and thick upland forest humus forms known as folisols.

Movement Type

Topple refers to the forward rotational movement of a mass of soil or rock outward from a slope about a point or axis below the center of gravity of the displaced mass. Toppling is sometimes driven by force exerted by surficial materials or bedrock upslope of the displaced mass and sometimes by ice or water in cracks in the mass. Because the moving mass is still attached to its base, toppling is considered by some to be a precursor to a landslide, rather than a landslide movement. Topples are usually the precursors to falls (Figure 3).

Fall refers to the detachment of soil or rock with little or no shear displacement and descent mainly through the air by falling, bouncing, and rolling (Figure 4).

Slide involves movement of a relatively intact soil or rock mass along a surface of rupture or along one or several discrete shear surfaces. These surfaces often form characteristic slickensides (Figure 5) or polished surfaces, akin to those in fault zones. Sliding can be translational (the surface of rupture is sub planar or undulating), rotational (the surface of rupture is curved and concave and is sometimes referred to as a 'slump'), or can be intermediate or a combination of the two (rotational–translational). The displaced mass initially remains intact, but as the detached material slides farther, the displaced mass tends to break up. When the disrupted mass begins to flow, the landslide is no longer termed a slide.

Flow involves the movement of a mass with significant internal distortion or disruption (Figure 6). Flows have distributed shear surfaces. A 'flow-like' landslide will often begin as a slide moving along a rupture surface, but then continues as a flow down unconfined surfaces (e.g., debris avalanche) or confined channels (e.g., debris flow) for long distances. In granular materials, the initial sliding movement leads very quickly to complete disintegration, producing flow-like motion characterized by nearly complete remoulding of the moving mass. The term flow is often restricted to channelized movement.

Avalanche is often used to describe an unconfined flow, and is especially used for rapid landslides that have long runout distances (Figure 7).

Spread is extension of a cohesive soil or rock mass and subsidence of the fractured mass of cohesive material into a softer underlying material. Spreads may result from the liquefaction or flow and extrusion of soft or weak materials underlying competent materials. An example of a bedrock spread is shown in Figure 8.

Complex landslides involve more than one type of material, and consequently involve more than one type of movement. Large rock slides change behavior when the displaced rock mass impacts soil. Three common scenarios include rock slides that transform into earth flows, debris flows, and debris avalanches (Figure 9).

Landslide Causes and Triggers

It is important to distinguish between the causes and triggers of landslides. In the broad sense, cause is the sum of factors that renders a slope unstable and trigger is the

Figure 3 Toppling in the Swiss Alps. Photograph by Stephan Gruber, University of Zurich.

Figure 4 A damaging rockfall occurred on March 8, 2010, and caused the closure of Interstate-70 through Glenwood Canyon, Colorado, for a week. This highway extends from the east coast to the west coast of the United States, and is a crucial route for commercial trucking, tourists, and other travelers. Photograph by Behrooz Far, Colorado Department of Transportation.

proverbial straw that breaks the camel's back. Causal factors of instability include preconditions such as weathering and inherent weakness in soil or rock, and active natural and human processes such as glacial erosion, river erosion, tectonics, changes in climate, wildfire, deforestation, road construction, and blasting (Table 2). The trigger may be an earthquake shock, increase in surface loading (surcharge), or heavy rainfall (Table 3).

Figure 5 Slides, such as this earth slide near Fort St. John, British Columbia, have discrete shear surfaces. The rupture surface here is polished, akin to that found in a fault zone. Such a polished surface is known as a slickenside. Photographs by Marten Geertsema, British Columbia Ministry of Forests and Range.

Figure 6 Mud flows following a rainstorm in the Peace River, British Columbia, area. Sliding in the source areas gives way to flowing in the narrow transport zones. Photograph by Marten Geertsema, British Columbia Ministry of Forests and Range.

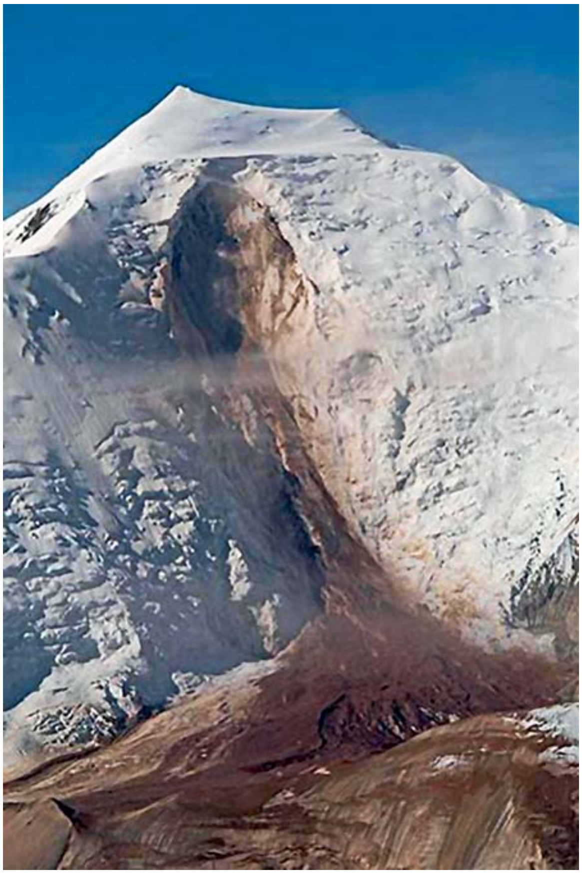

Figure 7 Rock avalanche at Mount Steele, Yukon. Photograph by Panya Lipovsky, Yukon Geological Survey.

Figure 8 Rock spread west of Fort Nelson, British Columbia. The ridges are transverse to the direction of movement. Photograph by Marten Geertsema, British Columbia, Ministry of Forests and Range.

Rain-Triggered Landslides

In general, the more water that falls on a slope, the greater the likelihood of landslides. Hillslopes, however, are complicated. Depending on the landslide type, some slopes respond rapidly to rainfall, others have delayed responses. In any case, antecedent conditions have been shown to be very important. Usually, soils must become saturated, allowing the buildup of pore pressures, before landslides will happen. Threshold pore water pressures develop more rapidly in shallow soils than in deeper materials. Landslides that respond rapidly to changes in precipitation include shallow debris slides, debris flows, and rockfall. Landslides that have delayed responses to changes in precipitation and temperature are usually the larger, deep-seated rock slides, earth slides, and earth flows. Figure 10 shows widespread landsliding in response to an intense rainstorm in Venezuela.

Earthquake-Triggered Landslides

Ground shaking from earthquakes has been attributed to the triggering of landslides around the world. Earthquakes increase stress, increase temporary pore water pressures, and decrease soil strength. The overall effect of ground motion, however, is dependent on the topographic and geological setting. In some setting, ground motions can be amplified.

These landslides are some of the most catastrophic ones as they can occur at many places at once, usually surrounding the zone of heavy shaking in an earthquake epicentral area. Slide movement is often sudden and rapid, precluding any effective type of preparedness or evacuation. Examples of earthquake-triggered landslides from Pakistan and El Salvador are presented in Figures 11 and 12, respectively. A further example of earthquake-triggered landslides is the case of the 2008 Wenchuan earthquake in China, discussed in the section 'Rock avalanches.'

Volcanic Landslides

A special type of debris flow, a lahar, occurs as a result of volcanic activity. Lahar is an Indonesian word describing mudflows and debris flows that originate from the slopes of a volcano. Both types of flows contain a high concentration of rock debris to give them the internal strength necessary to transport huge boulders as well as buildings and bridges and to exert extremely high-impact forces against objects in their paths.

Pyroclastic Flow: High-speed avalanches of hot ash, rock fragments, and gas move down the sides of a volcano during explosive eruptions or when the steep edge of a dome breaks apart and collapses. These pyroclastic flows, which can reach 800 °C and can travel up to 100 km per hour, are capable of knocking down and burning everything in their way.

The May 1980 eruption of Mount St. Helens, a volcano in the state of Washington, caused the world's largest historic landslide, a 2.8 km^3 rock slide–debris

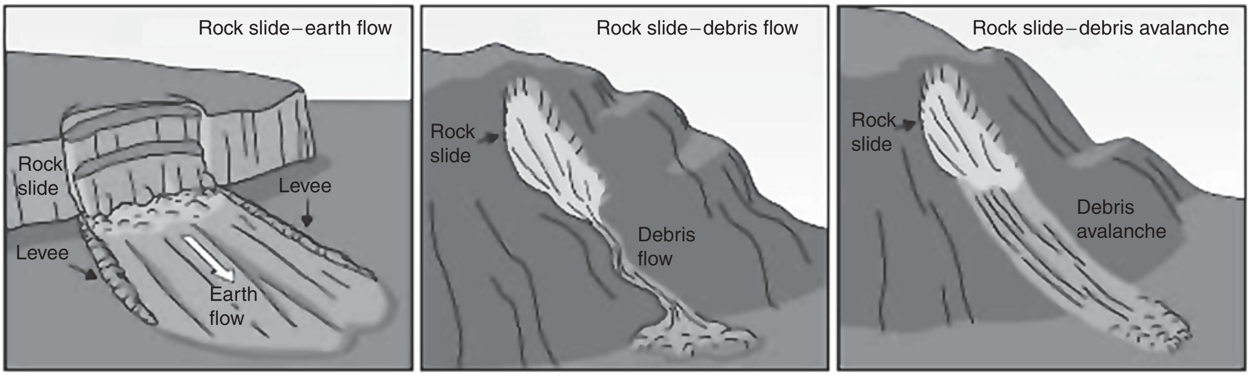

Figure 9 Cartoon of various rock slide interactions on impact with soil. Modified from Geertsema M, Clague JJ, Schwab JW, and Evans SG (2006) An overview of catastrophic landslides in northern British Columbia. *Engineering Geology* 83: 120–143.

Table 2 Landslide causes

Preconditions	*Landslide causes*	
	Active processes	*Human activity*
Shear zones	Weathering	Deforestation
Fractured and jointed rock masses	Isostatic rebound	Alteration of hillslope drainage
Sensitive soils	Stream erosion	Unstable fills
Liquefiable soil	Piping	Site loading
Favorable dip to bedding planes	Slope loading (sedimentation)	Toe slope excavation
Schistosity	Glacial erosion	Irrigation, pipe leakage
Presence of swelling clay	Wave erosion	Blasting
Hydrological discontinuities	Ice segregation	Mining spoil piles
Presheared soil	Permafrost thaw	Stream or ocean current alteration
Buried valleys	Tectonism	
	Fluctuating water table	
	Increased pore pressures	
	Wildfire	

Table 3 Landslide triggers

Landslide triggers	
Natural triggers	*Human triggers*
Intense rainfall, snowmelt, rain on snow, earthquakes	Blasting, or other vibrations
Volcanic eruptions	Drainage diversion
Permafrost thawing	Toe excavation
Flooding	Site loading
Other landslides (e.g., rock slides may trigger earth flows)	Water leakage
	Rapid drawdown or filling of reservoirs

avalanche that traveled approximately 22 km, destroying nine highway bridges, many kilometers of highways, roads, and railroads, and numerous private and public buildings. An explosive eruption on 19 March 1982 sent pumice and ash 14 km into the air and resulted in a lahar (the dark deposit on the snow, shown in Figure 13).

Wildfire-Caused Landslides

Postwildfire debris flows

Expansion of man-made developments into fire-prone wildlands has created situations in which wildfires can destroy lives and property, as can the flooding and debris flows that are common in the aftermath of the fires. Fast-moving, highly destructive debris flows triggered by intense rainfall are one of the most dangerous postfire hazards. Postfire debris flows are generally triggered by one of two processes: surface erosion caused by rainfall runoff, and landsliding caused by infiltration of rainfall into the ground. Runoff-dominated processes are by far the most prevalent processes because fires commonly reduce the infiltration capacity of soils, which increases runoff and erosion.

Forest fires sometimes create hydrophobic layers in soil. Thick acidic humus forms, coarse-textured soils, high-intensity fires, and prolonged periods of intense heat are important factors for the creation of water-repellent soil. Hydrophobic substances are released from humus forms and condensed at depth. Extremely high surface temperatures may actually destroy surface hydrophobicity but cause a subsurface water-repellent layer to form deeper in the soil (perhaps 1–10 cm in depth).

With a hydrophobic layer at depth restricting infiltration, surface soil may become saturated following precipitation, leading to overland flow, soil detachment, and erosion. The eroded material may coalesce into shallow landslides, or fill gullies and transform into debris flows (Figure 14).

Figure 10 Heavy rainfall triggered these debris slides and flows in Venezuela in 1999. Photograph by US Geological Survey.

Figure 11 The Hattian Bai Landslide Dam, Pakistan, 2005. This earthquake-induced landslide buried villages, blocked a river, and allowed a lake to form behind the landslide. Landslide dams pose a flood risk to areas upstream of the blockage, as stream or river flow is stopped, and a potential risk of catastrophic flooding downstream, if the dams were to breach or fail suddenly. Photograph by US Geological Survey.

Thawing Permafrost and Landslides

Permafrost is thawing in subpolar regions and in mountain regions around the world. This has led to increased rock slides in the European Alps as well as western Canada, and to increased flows and slides in soils in low-lying areas. Permafrost-related landslides are also related to wildfires. Fire causes thinning of insulating moss, which, in turn, allows soils to warm, thawing permafrost and thickening active layers. This can promote a variety of landslide types (Figure 15).

Figure 12 Destruction of a section of the Pan-American Highway east of Ilopango, El Salvador, by a 500 000 m^3 landslide triggered by the January 2001 El Salvador earthquake (M7.6). It is a complex soil avalanche thought to be triggered by liquefaction-induced soil softening or ground movement near the toe of the slope. Photograph by E.L. Harp, US Geological Survey.

Figure 13 Lahar caused by the 1982 eruption of Mount St. Helens in Washington, USA. Photograph by Tom Casadevall, US Geological Survey.

Quick-Clay Landslides

Rapid landslides occur on nearly level gradients in some clay soils. They occur in sediments that are prone to sudden liquefaction. The sediments can be relatively strong in the undisturbed state. A small vibration or load can make them flow like wet porridge. Such materials are referred to as sensitive clays. In the extreme states, when the undisturbed strength is more than 30 times greater than the remoulded strength, such sediments are called quick clays (Figure 16).

Many coastlines were submerged by the weight of glaciers during the last glaciation. As the ice retreated, the sea migrated inland with the retreating icefronts. Glaciomarine sediments composed of rock flour, silt, and clay minerals were deposited in the sea by glacial meltwater. As the glaciers melted, the land began to rebound isostatically, rising as much as 300 m above present-day sea level. The glaciomarine sediments were now exposed to rainfall and groundwater. Salts in the clays were gradually being leached out of the sediments. Salt content would decrease from an initial $30\,g\,l^{-1}$ to below $1\,g\,l^{-1}$. With a lower salt content, repulsive forces between particles increased, leaving the saturated, porous sediment prone to collapse.

In freshwater, clay particles tend to settle much slower than the larger silt particles. In saltwater, clays and silts aggregate together forming floccules and settle with a random orientation. Negative, repulsive charges on the clay particles are neutralized by cations such as Na^+ and Ca^{2+} in seawater. The resulting sediment has an open structure with high water contents. The positive charges of the salts maintain the interparticle bonds.

An imposed load, vibration, or bank erosion can trigger collapse of the sedimentary structure in sensitive glaciomarine soil, causing liquefaction. During liquefaction, the weight of the soil is transferred from the solids to the pore water.

Global Distribution

Hotspots

Landslides occur around the globe, but certain areas are particularly noteworthy. The main landslide hotspots

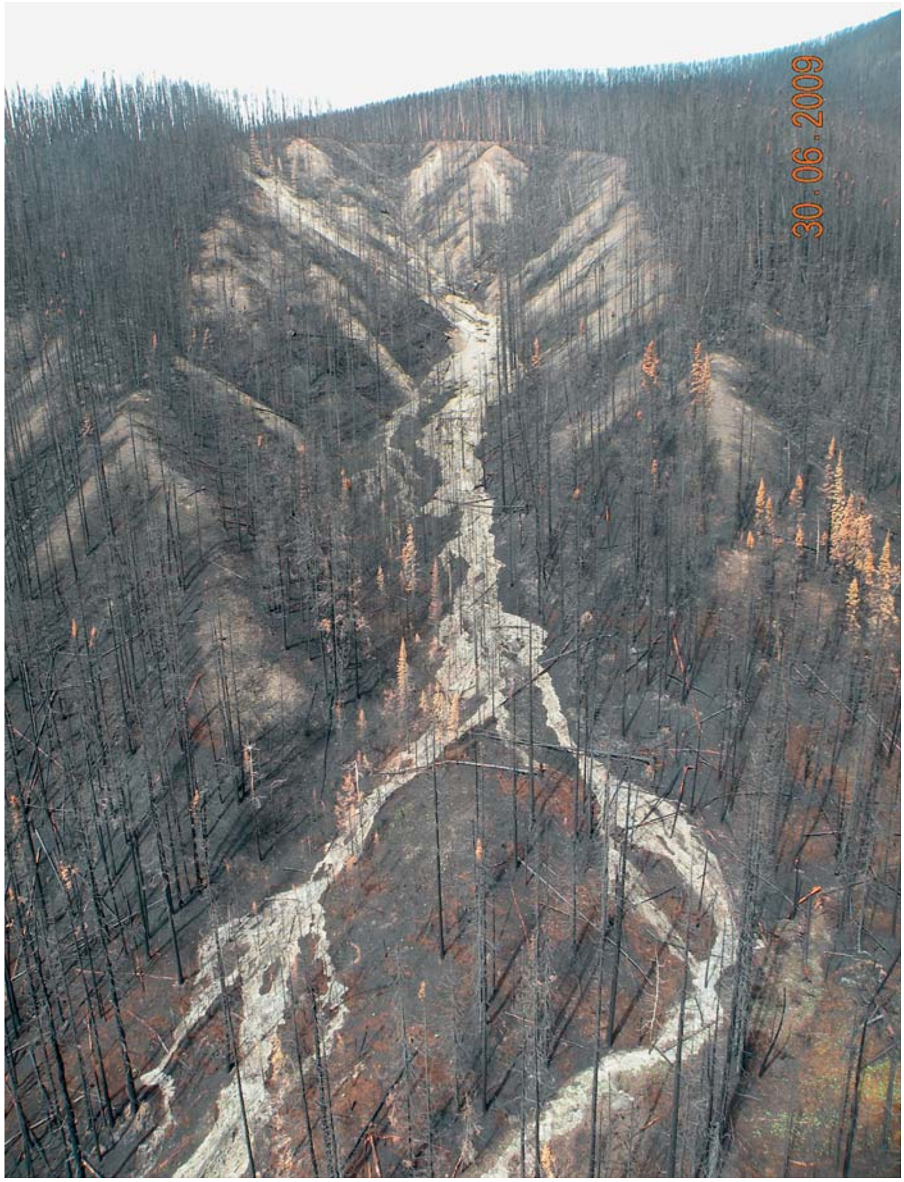

Figure 14 Hydrophobic soil conditions and heavy rain triggered debris flows in a 2009 wildfire in northern British Columbia. Photograph by Marten Geertsema, British Columbia, Ministry of Forests and Range.

include Central America, northwestern South America, northwestern North America, the Caucasus region, Iran, Turkey, Tajikistan, Kyrgyzstan, the Himalayas, Taiwan, Philippines, Indonesia, New Guinea, New Zealand, Italy, and Japan.

Certain types of landslides occur only in small areas of the globe. Flows related to permafrost thawing are especially common in arctic and subarctic regions (Figure 14). Rock slides related to permafrost thaw are restricted to certain high mountain ranges. Flowslides involving sensitive glaciomarine clays occur in coastal regions that were depressed below sea level during glaciations.

Few Notable Landslide Types and Disasters

Quick-Clay Landslides

Rissa, Norway

On 29 April 1978, a catastrophic landslide occurred near the town of Rissa, Norway. The largest landslide of the century in Norway, it covered 33 ha and involved 5–6 million cubic meters of sensitive glaciomarine clay. The landslide was triggered by the placement of a small earth fill from the excavation of a barn. Seven farms and five homes were destroyed. Fortunately, of 40 people who were within the slide area, when movement started, only one was killed.

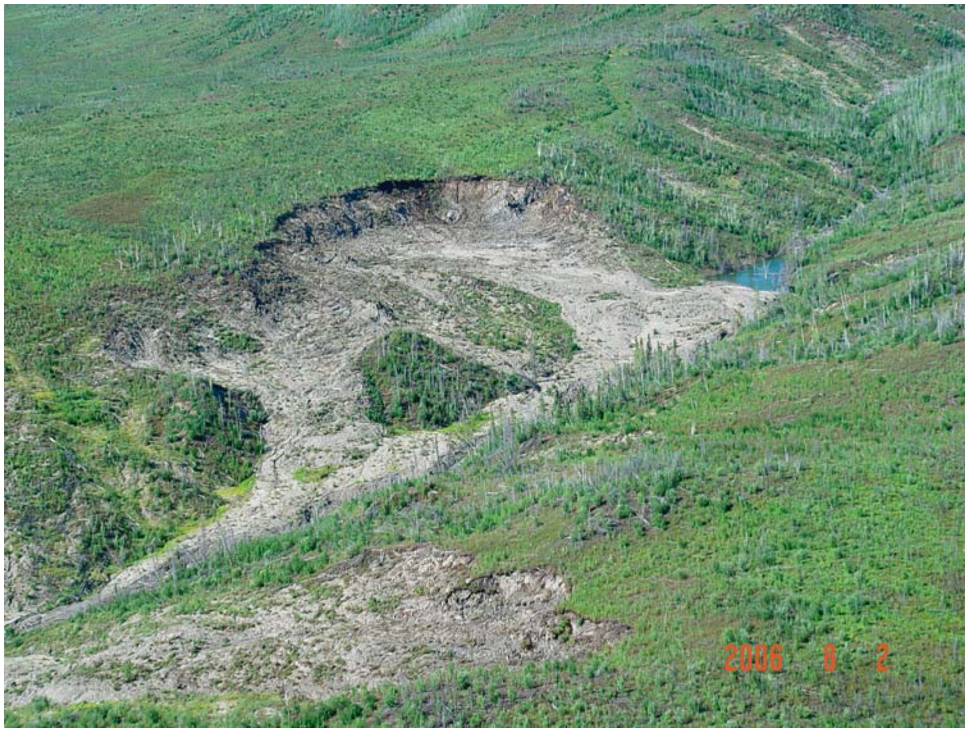

Figure 15 Retrogressive thaw flow in Canada's Northwest Territories. Permafrost thawed here sometime after a forest fire occurred. Photograph by Marten Geertsema, British Columbia, Ministry of Forests and Range.

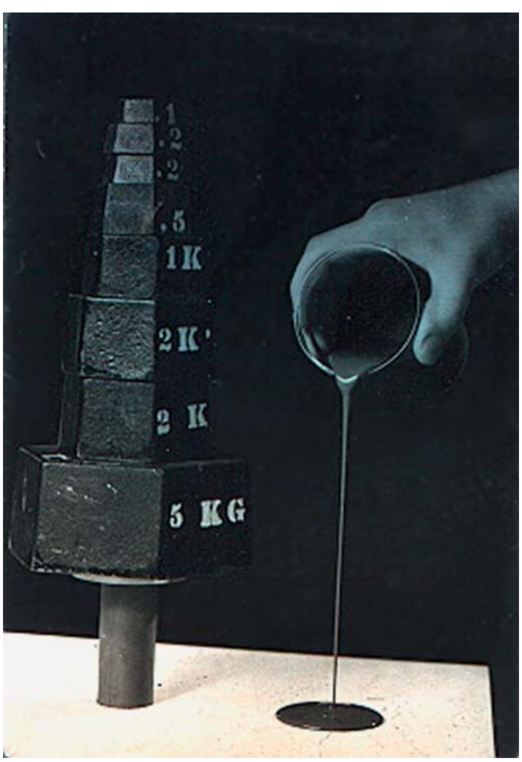

Figure 16 Strength difference between undisturbed and remoulded quick clay. Photograph courtesy Natural Resources Canada.

The landslide was caught on film by an amateur photographer. A documentary of the landslide is available on DVD from the Norwegian Geotechnical Institute.

St. Jean Vianney, Canada

On 4 May 1971, 7 million cubic meters of sensitive glaciomarine clay at Saint Jean Vianney, Quebec, suddenly liquified and flowed at a rate of more than 25 km per hour into the Rivière du Petit-Bras carrying along 40 residential houses (Figure 17). The 32 ha zone of depletion left by the flow was 32 ha in area, and up to 30 m in depth. The 1971 landslide happened inside the scar of a much larger landslide that occurred 500 years earlier.

Debris Flows

Debris flows are rapid, saturated landslides that typically transport material through a channel or gully and deposit the debris on a fan. Although some debris flows may initiate in channels, many begin as slides on hillslopes and become flows when they become confined in channels. Debris flows may attain speeds of 20 m per second, and can be highly destructive.

Hurricane Mitch tracked across Honduras in October 1998. Intense rainfall exceeded 900 mm in places and triggered more than 500 000 landslides throughout the nation, of which more than 95% were debris flows. These

Figure 17 The Saint Jean Vianney landslide in Quebec, Canada, occurred in glaciomarine quick clays. The flow destroyed 40 houses.

Figure 18 The 1999 Venezuela debris flows destroyed infrastructure and carried many victims out to sea. Up to 30 000 people perished. Photograph by US Geological Survey.

landslides damaged an estimated 70% of the Honduran road network and killed approximately 1000 people.

Heavy rain also triggered catastrophic debris flows along the north coast of Venezuela in December 1999 (Figure 18). The disaster occurred along a 40 km section of the coast between La Guiara and Naiguita in the state of Vargas. Only approximately 1000 bodies were recovered – many people were buried by debris or were swept out to sea. The landslides may have killed up to 30 000 people.

Rock Avalanches

Frank

In 1903, a large rock avalanche destroyed the town of Frank, a coal mining settlement in south western Alberta,

Figure 19 Rock avalanche at Frank, Alberta. The 1903 landslide buried the town of Frank killing more than 70 people. Photograph by Marten Geertsema, British Columbia Ministry of Forests and Range.

Figure 20 A rock slide-debris avalanche that buried the village of Guinsaugon, Southern Leyte, Philippines, in February 2006. Photograph by Dr. Taro Uchimura.

Canada. Thirty million cubic meters of limestone thundered down Turtle Mountain, covering approximately 300 ha of the valley floor (Figure 19). The mountain continues to be monitored to this day. Coal mining in Turtle Mountain may have contributed to the landslide.

Rock Slide–Debris Avalanches

A rock slide that transforms into a debris avalanche is a complex type of landslide. This occurs where the impact of a rock slide loads fine-grained soil. Because water cannot easily escape from the soil, such sudden loading tends to elevate pore pressures and causes the soil to liquefy and flow. The result is that the landslides travel much greater distances than if this second phase did not occur. Two recent devastating examples of rock slide–debris avalanches are the 2006 Guinsaugon and the 2008 Donghekou landslides that happened in the Philippines and China, respectively.

Guinsaugon rock slide–debris flow

This landslide (Figure 20) occurred 4 days after abnormally heavy rain. The village of Guinsaugon had been evacuated as a precaution due to the rain, but the inhabitants returned after nothing happened. A small earthquake (M 2.6) preceded the landslide. On 17 February 2006, 20 million cubic meters of mud and rock destroyed Guinsaugon and approximately 1100 of its inhabitants.

Donghekou rock slide–debris avalanche

This devastating landslide (Figure 21) was triggered by the 2008 Wenchuan earthquake. The 12 May 2008 Wenchuan earthquake, measuring 8.0 M_s (Chinese Earthquake Administration), occurred in an area of high, steep mountains in Sichuan Province. Disasters caused by earthquake-induced landslides and rock avalanches formed an important portion of the total earthquake effects and casualties. The landslides slid into rivers and formed at least 34 landslide dams. The resulting formation of massive lakes and subsequent flooding events has drastically altered the river and streamflow in the area, impacting water quality and seriously affecting fish populations. The landslides destroyed roads, houses, and pipelines and buried hundreds of people, due to rapid, catastrophic movement, and the extremely large volume of material. The geomorphic nature of the natural environment of this area has been altered to the extreme.

Figure 21 The 12 million cubic meters Donghekou landslide, triggered by the 2008 Wenchuan, China, earthquake, buried three villages and two tour buses. The 2.5 km long landslide covered more than 1 km^2 of area. The landslide dammed two confluent rivers forming a massive lake. The Chinese army created a new watercourse through the slide using dynamite and heavy equipment, allowing river flow to resume, and to reduce the pressure and increasing water volume caused by the buildup of water behind the dam. There is a new road, also constructed by the army, over the rock slide and through the main part of the slide, as the old road is buried. The landslide also inundated a bus stop area, burying two large tourist buses, a car, and up to 300 people. The slide was massive in volume and moved so rapidly that it generated two areas of air blast – a phenomenon that is so forceful that it can level trees. Photograph by Lynn Highland, US Geological Survey.

Landslide-Generated Tsunamis

Both submarine and subaerial landslides can cause damaging displacement waves in bodies of water.

Submarine landslide is a general term used to describe the down slope mass movement of geologic materials from shallower to deeper regions of the ocean. Such events may produce major effects to the depth of shorelines, ultimately affecting boat dockings and navigation. These types of landslides can occur in rivers, lakes, and oceans. Large submarine landslides triggered by earthquakes have caused deadly tsunamis, such as the 1929 Grand Banks (off the coast of Newfoundland, Canada) tsunamis. Very large submarine landslides have occurred off the shores of the Hawaiian islands, and there is a high risk of future occurrences. One of the most notable submarine landslides, the Storegga landslide, occurred off the coast of Norway 8200 years ago. The landslide, approximately the size of Great Britain, triggered a tsunami that was felt over much of the North Atlantic Ocean.

Tsunamis may also be caused by landslides that occur above ground but enter water bodies. The energy of the landslide entering the water body generates a series of displacement waves.

In 1958, a M7.9 earthquake triggered a large rockfall – rock slide (30 mm^3) in Lituya Bay, a fjord in southeastern Alaska. The displacement wave swept through the fjord to a maximum height of 524 m. It then sped down Lituya Bay to its mouth. Three fishing boats were anchored inside the bay near its entrance. The wave sank two of the boats, claiming two lives. Two people in the third boat survived after the vessel was swept out of the fjord into the Pacific Ocean. The 1958 event was the fourth landslide-generated tsunami to strike Lituya Bay in approximately one century. Others have occurred in 1854, 1899, and 1936, respectively. An incipient rock slide above Tidal Inlet, Alaska, could create a tsunami if it were to fail catastrophically (Figure 22).

Economic Impacts of Landslides

Estimating the losses from landslides is a difficult undertaking, given that some losses are due to destruction from an individual landslide (direct costs), but in many cases landslide damage is indirect; for example, a landslide may damage a pipeline but the losses indirectly caused by this landslide due to the interruption of the pipeline function are often much greater than the simple replacement of a damaged pipeline. Earthquakes and floods often are seen as the cause of losses, when, actually landslides caused by earthquakes and floods may, in fact, account for much of the damages and losses. As most

Figure 22 Detached landslide mass perched above the northern shore of Tidal Inlet, Glacier Bay National Park, Alaska. Landslides in the past have slid into this and surrounding inlets rapidly displacing water and causing large waves. The landslides in these areas are due to several factors: debutressing of slopes due to retreating glaciers and earthquake shaking. The resultant large waves are a hazard to cruise ships that frequent the area and the landslides cause large amounts of sediment to be suddenly deposited into these ecologically fragile waters. Photograph by Gerry Wieczorek, US Geological Survey.

areas of the world do not provide insurance or compensation for landslide damage, the real damage impacts from a financial standpoint are largely unknown.

Benefits of Landslides (Landslides as Natural Disturbance Agents)

Although often thought of as destructive, landslides can have benefits to the natural environment in the form of the alteration of plant and animal habitats. As a type of disturbance agent, landslides contribute to habitat diversity by changing site, soil, and vegetation patterns. Plant succession can be affected through the removal of mature vegetation establishments by landslides, providing an opportunity for pioneer species to begin thriving, which results in renewed forest species diversity in certain areas. This, in turn, may provide an improved source of food for wildlife. Some types of fish habitats may be enhanced by the introduction of large rocks, wood, and sediment transported and deposited by landslides and debris flows.

The Future

The problem of deaths, injuries, and property loss due to landslides has been intensified by burgeoning populations in landslide-prone areas. Undoubtedly, this trend will continue in the twenty-first century as populations are projected to increase, and potentially buildable and arable land areas shrink in size. It has been shown to be useful to educate people about landslides through school and community-based education about hazard awareness. As land-use tools such as hazard studies, GIS, and planning become more widespread, exposure to landslide hazard is likely to decrease in some areas.

Landslide Mitigation

Vulnerability to landslide hazards is a function of a site's location (topography, geology, drainage), type of activity, and frequency of past landslides. The effects of landslides on people and structures can be lessened by total avoidance of landslide hazard areas or by restricting, prohibiting, or imposing conditions on hazard-zone activity. Local governments can accomplish this through land-use policies and regulations. Individuals can reduce their exposure to hazards by educating themselves on the past hazard history of a desired site and by making inquiries to planning and engineering departments of local governments. They could also hire the professional services of a geotechnical engineer, a civil engineer, or an engineering geologist who can properly evaluate the hazard potential of a site, built or unbuilt. The following types of mitigation for various types of landslides are only a general guide, and there are several recommended sources for more detailed information.

Soil Stabilization

Stability increases when groundwater is prevented from rising in the slide mass by (1) directing surface water away from the landslide, (2) draining groundwater away from the landslide to reduce the potential for a rise in groundwater level, (3) covering the landslide with an impermeable membrane, and (4) minimizing surface irrigation. Slope stability is also increased when weight or retaining structures are placed at the toe of the landslide or when mass (weight) is removed from the head of the slope. Planting or encouraging natural growth of vegetation can also be an effective means of slope stabilization.

Rockfall Mitigation

Rockfall is common in areas of the world with steep rock slopes and cliffs. Commonly, these are mountainous or plateau areas, whether in coastal areas or among isolated rock formations. Rockfall causes extraordinary amounts of monetary damage and death, the former mostly by impeded transportation and commerce due to blocked highways and waterways and the latter as direct casualties from falling rocks. Diverting paths and highways around rockfall areas is sometimes implemented but is not always practical. Many communities post danger signs around areas of high rockfall hazard, but this does not prevent rockfall from occurring. Some methods of rockfall hazard mitigation include catch ditches, benches, scaling and trimming, cable and mesh, shotcrete, anchors, bolts, dowels, and controlled blasting.

Debris-Flow Hazard Mitigation

Owing to the speed and intensity of most debris flows, they are very hard to stop once they have started. However, there are methods to contain and deflect debris flows primarily through the use of retaining walls and debris-flow basins. Other mitigation methods include modifying slopes, preventing them from being vulnerable to debris-flow initiation through the use of erosion control, revegetation, and the prevention of wildfires, which are known to intensify debris flows on steep slopes.

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