TXT-tool 0.001-2.1 Landslide Types: Descriptions, Illustrations and Photos

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Abstract

Regardless of the exact definition used or the type of landslide under discussion, understanding the basic mechanics and processes of a typical landslide is critical. With an increasing awareness and mandate to fully understand new building site characteristics, improve existing critical infrastructure and appreciating the importance of an area's landslide history, typing landslides according to shared characteristics gives vital information about the future performance of a site, in relation to potential landslide hazards. We provide here, a basic primer for an understanding of the similarities and differences of the nature and physics of landslide movement. Type of material, speed of motion, slope angle, potential frequency of occurrence, weather and climatic influences, and man-made disturbances as well as other factors have a bearing on landslide motion, size and impact, yet we can generally group and categorize most landslides into more understandable groupings. Landslide typology is constantly evolving and becoming more exact, given the expanding tools of site investigation, improving computer and GIS modeling, and careful peer analysis.

Keywords

Landslide types · Landslide classification · Typology
Landslide materials · Landslide speed · Landslide process

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Contents

1 Introduction

Geologists, engineering geologists, geotechnical engineers and other professionals often rely on unique and slightly differing definitions of landslides. This diversity in definitions reflects the complex nature of the many disciplines associated with studying landslide phenomena. For our purposes, landslide is a general term used to describe the downslope movement of soil, rock, and organic materials under the effects of gravity and also the landform that results from such movement (Cruden 1991) (see Fig. 1 for an example of one type of landslide, showing the commonly-accepted terms for the various parts of a landslide).

Varying classifications of landslides are associated with specific mechanics of slope failure and the properties and characteristics of failure types; these will be discussed briefly herein.

There are a number of other phrases/terms that are often used interchangeably with the term "landslide" including most frequently the terms mass movement and slope failure. One commonly hears such terms applied to all types and sizes of landslides.

Figure 1 shows the position and the most common terms used to describe the unique parts of a landslide. From there, we paraphrase the work of Highland and Bobrowsky (2008) with an update and improvement on the topics of landslide type schematics and example photographs.

2 Basic Landslide Types

A landslide is a downslope movement of rock or soil, or both, occurring on the surface of rupture—either curved (rotational slide) or planar (translational slide) rupture—in which much of the material often moves as a coherent or semi-coherent mass with little internal deformation. Notably, in some cases, landslides may also involve other types of movement, either at the inception of the failure or later, if properties change as the displaced material moves downslope.

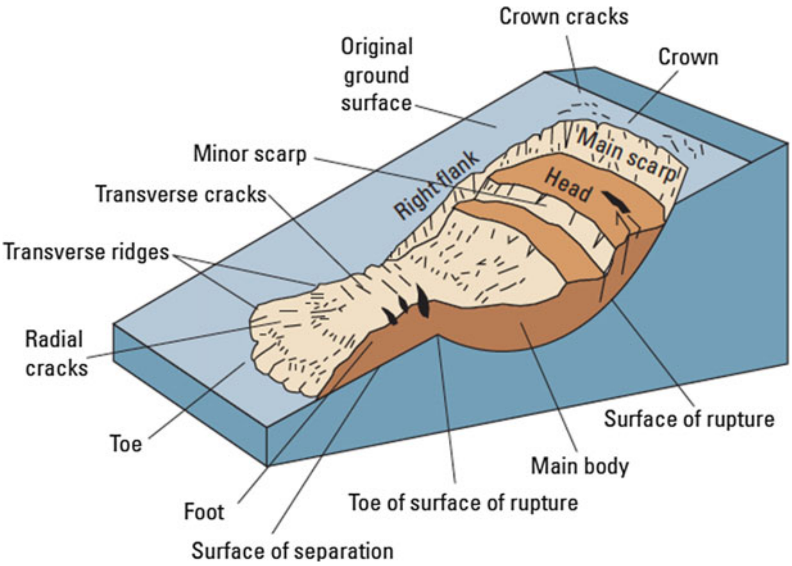


Fig. 1 This graphic illustrates commonly-used labels for the parts of a landslide. The image shows a rotational landslide that has evolved into an earthflow. (modified from Varnes 1978)

This section provides descriptions and illustrations of the various types of landslides. Understanding the characteristics of the specific type of landslide hazard in your area is vitally important to consider when planning or adopting appropriate mitigating action to lessen the risk of loss and damage. The type of landslide will determine the potential speed of movement, likely volume of displacement, distance of run-out, as well as the possible effects of the landslide and the appropriate mitigating measures to be considered.

Landslides can be classified into different types on the basis of the type of movement and the type of material involved (Cruden and Varnes 1996). In brief, material in a landslide mass is either rock or soil (or both); the latter is described as earth if mainly composed of sand-sized or finer particles and debris if composed of coarser fragments. The type of movement describes the actual internal mechanics of how the landslide mass is displaced: fall, topple, slide, spread, or flow. Thus, landslides are primarily described using two terms that refer respectively to material and movement (that is, rockfall, debris flow, and so forth). Landslides may also form a complex failure encompassing more than one type of movement (that is, rock slide—debris flow).

We define "type of movement" as synonymous with "landslide type." Each type of movement can be further subdivided according to specific properties and characteristics, and the main subcategories of each type are described elsewhere. Less common subcategories are not discussed here but are referred to in the source reference.

2.1 Falls

A fall begins with the detachment of soil or rock, or both, from a steep slope along a surface on which little or no shear displacement has occurred. The material subsequently descends mainly by falling, bouncing, or rolling.

2.1.1 Rockfall

Falls are abrupt, downward movements of rock or earth, or both, that detach from steep slopes or cliffs. The falling material usually strikes the lower slope at angles less than the angle of fall, causing bouncing. The falling mass may break on impact, may begin rolling on steeper slopes, and may continue until the terrain flattens, or encounters a structure or other obstacles.

Occurrence and relative size/range

Common worldwide on steep or vertical slopes—also in coastal areas, and along rocky banks of rivers and streams. The volume of material in a fall can vary substantially, from individual rocks and clumps of soil to massive blocks thousands of cubic meters in size.

Velocity of travel

Very rapid to extremely rapid, free-fall; bouncing and rolling of detached soil, rock, and boulders. The rolling velocity depends on slope steepness.

Triggering mechanism

Undercutting of slope by natural processes such as streams and rivers or differential weathering (such as the freeze/thaw cycle), human activities such as excavation during road building and (or) maintenance, and earthquake shaking or other intense vibration.

Effects (direct/indirect)

Falling material can be life-threatening. Falls can damage property beneath the fall-line of large rocks. Boulders can bounce or roll great distances and damage structures or kill people. Damage to roads, railroads, and highways is particularly intense: rockfalls can cause deaths to those in vehicles hit by rocks and can block highways and railroads.

Corrective measures/mitigation

Rock curtains or other slope covers, protective covers over roadways, retaining walls to prevent rolling or bouncing, explosive blasting of hazardous target areas to remove the source, scaling, removal of rocks or other materials from highways and railroads can be used. Rock bolts or other similar types of anchoring used to stabilize cliffs, as well as scaling, can lessen the hazard. Warning signs are recommended in hazardous areas for awareness. Stopping or parking under hazardous cliffs should be avoided.

Predictability

Mapping of hazardous rockfall areas has been completed in a few areas around the world. Rock-bounce calculations and estimation methods for delineating the perimeter of rockfall zones have also been determined and the information widely published. Indicators of imminent rockfall include terrain with overhanging rock or fractured or jointed rock along steep slopes, particularly in areas subject to frequent freeze-thaw cycles. Also, cut faces in gravel pits may be particularly subject to falls. Figures 2, 3, 4, 5 and 6 show a schematic and photographs of rockfall.

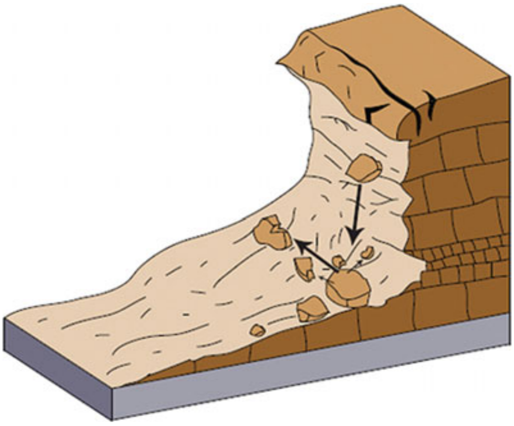


Fig. 2 Schematic illustration of rockfall. Note that rocks may roll and bounce at potentially great distances depending on a number of factors

2.1.2 Topple

A topple is recognized as the forward rotation out of a slope of a mass of soil or rock around a point or axis below the center of gravity of the displaced mass. Toppling is sometimes driven by gravity exerted by the weight of material upslope from the displaced mass. Sometimes toppling is due to water or ice collecting in cracks in the mass. Topples can consist of rock, debris (coarse material), or earth materials (fine-grained material). Topples can be complex and composite.

Occurrence

They are known to occur globally, often prevalent in columnar-jointed volcanic terrain, as well as along stream and river courses where the banks are steep.

Velocity of travel

They are extremely slow to extremely rapid, sometimes accelerating throughout the movement depending on distance of travel.

Triggering mechanism

Topples are sometimes driven by gravity exerted by material located upslope from the displaced mass and sometimes by water or ice occurring in cracks within the mass; also, vibration, undercutting, differential weathering, excavation, or stream erosion.

Effects (direct/indirect)

They can be extremely destructive, especially when failure is sudden and (or) the velocity is rapid. They can potentially block waterways or highways causing flooding and interference of travel.

Corrective measures/mitigation

In rock there are many options for the stabilization of topple-prone areas. Some examples for reinforcement of these slopes include rock

Fig. 3 This rockfall in North Carolina (USA), occurred on a highway through Pigeon River Gorge, on October, 2009, and caused traffic delays for weeks. Photo by North Carolina Department of Transportation

bolts and mechanical and other types of anchors. Seepage is also a contributing factor to rock instability, and drainage should be considered and addressed as a corrective means.

Predictability

Topples are not generally mapped for susceptibility; some inventory of occurrence exists for certain areas. Monitoring of topple-prone areas is useful; for example, the use of tiltmeters. Tiltmeters are used to record changes in slope inclination near cracks and areas of greatest vertical movements. Warning systems based on movement measured by tiltmeters could be effective. Figures 7, 8, 9 and 10 show a schematic and photos of topple.

2.2 Slides

A slide is a downslope movement of a soil or rock mass occurring on surfaces of rupture or on relatively thin zones of intense shear strain. Movement does not initially occur simultaneously over the whole of what eventually becomes the surface of rupture; the volume of displacing material enlarges from an area of local failure.

2.2.1 Rotational Landslide

A landslide on which the surface of rupture is curved upward (spoon-shaped) and the slide movement is more or less rotational about an axis that is parallel to the contour of the slope. The displaced entity may, under certain circumstances, move as a relatively coherent mass along the rupture surface with little internal deformation. The head of the displaced material may move almost vertically downward, and the upper surface of the displaced material may tilt backwards toward the scarp. If the slide is rotational and has several parallel curved planes of movement, it is called a slump.

Occurrence

Because rotational slides occur most frequently in homogeneous materials, they are the

Fig. 4 Large rocks brought down by the January 12, 2010 (Magnitude 7) earthquake. The earthquake caused many landslides and rockfalls. Photograph by Randy Jibson, U.S. Geological Survey

most common landslide occurring in “fill” materials.

Relative size/range

They are associated with slopes ranging from about 20°–40°. In soils, the surface of rupture generally has a depth-to-length ratio between 0.3 and 0.1.

Velocity of travel (rate of movement)

Velocity is extremely slow (less than 0.3 m or 1 ft every 5 years) to moderately fast (1.5 m or 5 feet per month) to rapid.

Triggering mechanism

Intense and (or) sustained rainfall or rapid snowmelt can lead to the saturation of slopes and increased groundwater levels within the mass; rapid drops in river level following floods, ground-water levels rising as a result of filling reservoirs, or the rise in level of streams, lakes, and rivers, which cause erosion at the base of slopes. These types of slides can also be earthquake-induced.

Effects (direct/indirect)

These can be extremely damaging to structures, roads, and lifelines but are not usually life-threatening if movement is slow. Structures situated on the moving mass also can be severely damaged as the mass tilts and deforms. The large volume of material that is displaced is difficult to permanently stabilize. Such failures can dam rivers, causing flooding.

Fig. 5 Jalalabad Road, Afghanistan—Rockfall on the Jalalabad Road which is a highway from Kabul to Surobi and Jalalabad, Afghanistan, February 28, 2007. Photo by Sven Dirks http://commons.wikimedia.org/wiki/File:Jalalabad_Road_rock_fall.jpg

Mitigation measures

Instrumental monitoring to detect movement and the rate of movement can be implemented. Disrupted drainage pathways should be restored or re-engineered to prevent future water buildup in the slide mass. Proper grading and engineering of slopes, where possible, will reduce the hazard considerably. Construction of retaining walls at the toe may be effective to slow or deflect the moving soil; however, the slide may overtop such retaining structures despite good construction.

Predictability

Historical slides can be reactivated; cracks at tops (heads) of slopes are good indicators of the initiation of failure. Figures 11, 12 and 13 show a schematic and photos of rotational landslides.

2.2.2 Translational Landslide

The mass in a translational landslide moves out, or down and outward, along a relatively planar surface with little rotational movement or backward tilting. This type of slide may progress over considerable distances if the surface of rupture is sufficiently inclined, in contrast to rotational slides, which tend to restore the slide equilibrium. The material in the slide may range from loose, unconsolidated soils to extensive slabs of rock, or both. Translational slides commonly fail along geologic discontinuities such as faults, joints, bedding surfaces, or the contact between

Fig. 6 A large rockfall due to the May, 2008 Wenchuan, China Earthquake. Rockfalls such as this one are often deadly, although rockfalls can involve small rocks, large boulders, and/or combinations of both, and may disrupt transportation routes for weeks or months. Photo by Dave Wald, U.S. Geological Survey

Fig. 7 Schematic illustration of a topple

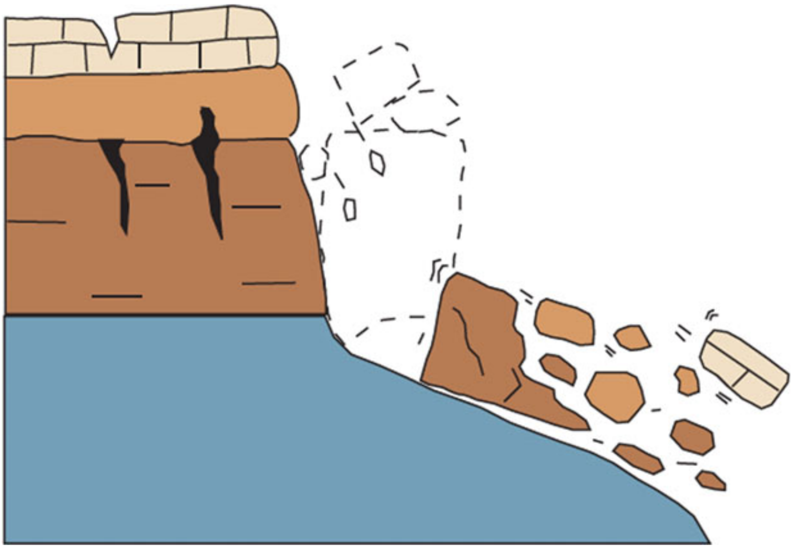


Fig. 8 A Topple in the vicinity of Jasper National Park, British Columbia, Canada. Photo by G. Bianchi Fasani

rock and soil. In northern environments the slide may also move along the permafrost layer.

Occurrence

These are one of the most common types of landslides, worldwide. They are found globally in all types of environments and conditions.

Relative size/range

They are generally shallower than rotational slides. The surface of rupture has a distance-to-length ratio of less than 0.1 and can range from small (residential lot size) failures to very large, regional landslides that are kilometers wide.

Velocity of travel

Movement may initially be slow (5 feet per month or 1.5 m per month) but many are moderate in velocity (5 feet per day or 1.5 m per day) to extremely rapid. With increased velocity, the landslide mass of translational failures may disintegrate and develop into a debris flow.

Triggering mechanism

They are primarily triggered by intense rainfall, rise in groundwater within the slide due to rainfall, snowmelt, flooding, or other inundation of water resulting from irrigation, or leakage from pipes or human-related disturbances such as

Fig. 9 A topple in a granite outcrop, near the summit of Mount Evans, Arapaho National Forest, Colorado (USA). Photo by Lynn Highland, retired U.S. Geological Survey

undercutting. These types of landslides can be earthquake-induced.

Effects (direct/indirect)

Translational slides may initially be slow, damaging property and (or) lifelines; in some cases they can gain speed and become life-threatening. They can also dam rivers, causing flooding.

Mitigation measures

Adequate drainage is necessary to prevent sliding or, in the case of an existing failure, to prevent a reactivation of the movement. Common corrective measures include leveling, proper grading and drainage, and retaining walls. More sophisticated remedies in rock include anchors, bolts, and dowels, which in all situations are best implemented by professionals. Translational slides on moderate to steep slopes are very difficult to stabilize permanently.

Predictability

There is a high probability of repetitive occurrence in areas where they have occurred in the past, including areas subject to frequent strong earthquakes. Widening cracks at the head or toe bulge may be an indicator of imminent failure. Figures 14, 15 and 16 show a schematic and photos of a translational landslide.

2.3 Spreads

A spread is an extension of a cohesive soil or rock mass combined with the general subsidence of the fractured mass of cohesive material into softer underlying material. Spreads may result from liquefaction or flow (and extrusion) of the softer underlying material. Types of spreads include block spreads, liquefaction spreads, and lateral spreads.

2.3.1 Lateral Spreads

Lateral spreads usually occur on very gentle slopes or essentially flat terrain, especially where a stronger upper layer of rock or soil undergoes extension and moves above an underlying softer, weaker layer. Such failures commonly are accompanied by some general subsidence into the weaker underlying unit. In rock spreads, solid ground extends and

Fig. 10 A topple in sandstone, at Fisher Towers, near Moab, Utah (USA). Photo by Lynn Highland, retired U.S. Geological Survey

Fig. 11 Schematic of a Rotational landslide

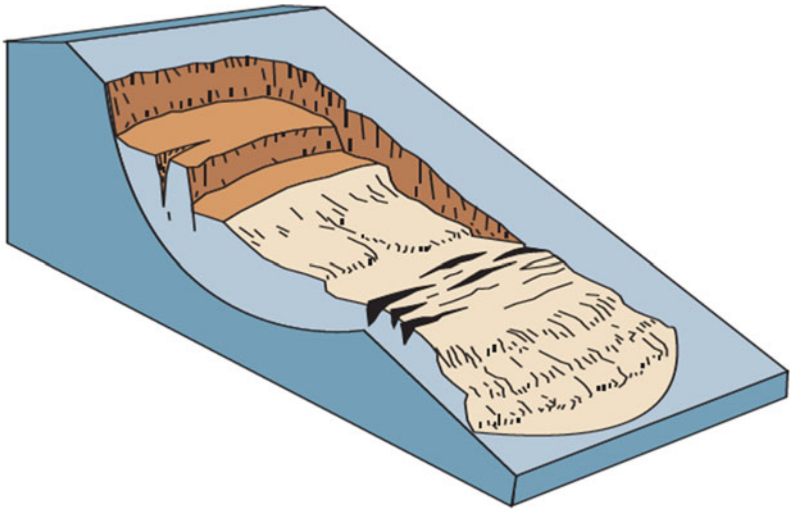


Fig. 12 This photo shows a rotational landslide triggered by rainfall in San Benito County, California (USA), in 1998. This landslide occurred as a reactivation of an old landslide in Pleistocene non-marine claystone, sandstone and conglomerate, and was located next to the San Andreas Rift Zone. Photo by Lynn Highland, retired U.S. Geological Survey

fractures, pulling away slowly from stable ground and moving over the weaker layer without necessarily forming a recognizable surface of rupture. The softer, weaker unit may, under certain conditions, squeeze upward into fractures that divide the extending layer into blocks. In earth spreads, the upper stable layer extends along a weaker underlying unit that has flowed following liquefaction or plastic deformation. If the weaker unit is relatively thick, the overriding fractured blocks may subside into it, translate, rotate, disintegrate, liquefy, or even flow.

Occurrence

They occur worldwide and known to occur where there are liquefiable soils. Common, but not restricted, to areas of seismic activity.

Relative size/range

The area affected may start small in size and have a few cracks that may spread quickly, affecting areas of hundreds of meters in width.

Velocity of travel

They may be slow to moderate and sometimes rapid after certain triggering mechanisms, such as an earthquake. Ground may then slowly spread over time from a few millimeters per day to tens of square meters per day.

Triggering mechanism

Triggers that destabilize the weak layer include: Liquefaction of lower weak layer by

Fig. 13 A photo of a rotational landslide, showing the Dainichi-san landslide triggered by the October 23, 2004 Mid-Niigata Prefecture earthquake (Sassa 2005)

Fig. 14 Schematic of a Translational landslide

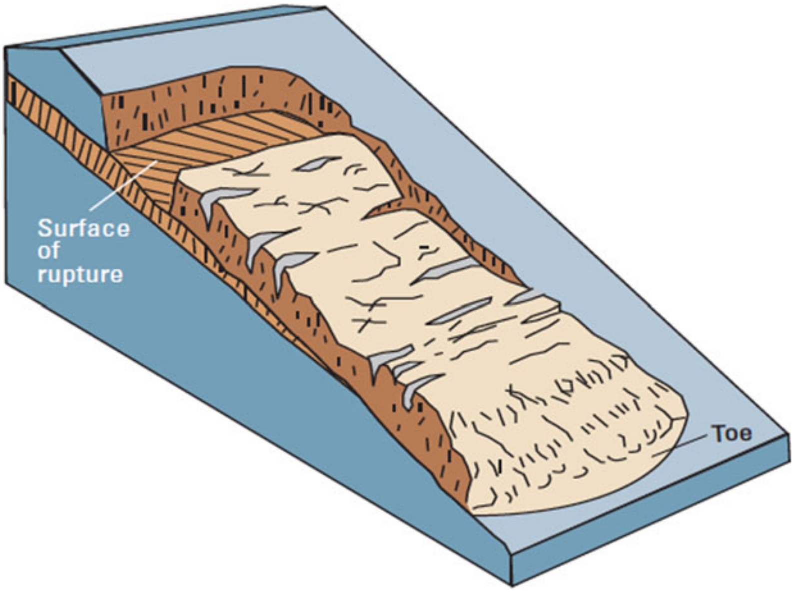


Fig. 15 The Minami-Aso landslide shows a translational landslide in a steep slope. The landslide was triggered by the Kumamoto Earthquake of 2016 in Japan (Dang et al. 2016). Photo taken from UAV by Khang Dang and Kyoji Sassa

Fig. 16 The June 14, 2008 Aratozawa landslide in Japan is an example of rotational movement in the upper area of the headscarp and translational movement in the central and lower part. It can be typed as a Complex Landslide, since it includes more than one type of movement (Miyagi et al. 2010). This photo was taken by Fukuoka H. in 2008. See Figs. 44 and 45 for thematic illustration and photo of a Complex landslide

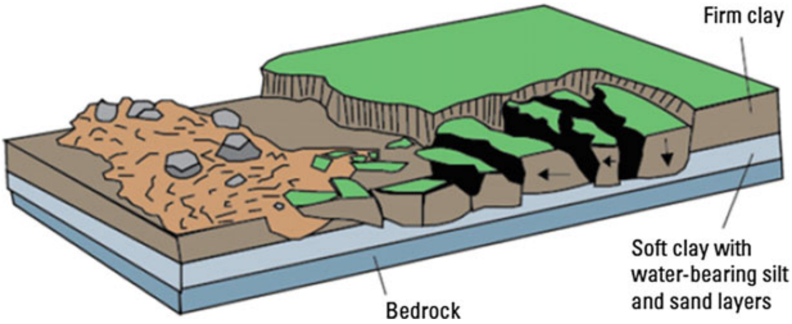


Fig. 17 Schematic of a Lateral Spread

Fig. 18 Lateral spreads at Hebgen Lake near West Yellowstone, Montana (USA), due to the effects of the Magnitude 7.3 Hebgen Lake earthquake, on August 18, 1959. Photo by R.B. Colton, U.S. Geological Survey

earthquake shaking; Natural or anthropogenic overloading of the ground above an unstable slope; Saturation of underlying weaker layer due to precipitation, snowmelt, and (or) ground-water changes; Liquefaction of underlying sensitive marine clay following an erosional disturbance at base of a riverbank/slope; Plastic deformation of unstable material at depth (for example, salt).

Fig. 19 The effects of lateral spreading in Christchurch, New Zealand as a result of the February 22, 2011 Christchurch Earthquake. *Photo* Wikipedia Commons. https://commons.wikimedia.org/wiki/File:25_Feb_River_Road.jpg

Effects (direct/indirect)

These can cause extensive property damage to buildings, roads, railroads, and lifelines. They can spread slowly or quickly, depending on the extent of water saturation of the various soil layers. Lateral spreads may be a precursor to earthflows.

Fig. 20 Lateral spreading caused by the magnitude 6.5 El Salvador, Central America earthquake of February 13, 2001. Area shown is on the eastern shore of Lago de Ilopango. Photograph by Anthony Crone, U.S. Geological Survey

Mitigation measures

Liquefaction-potential maps exist for some places but are not widely available. Areas with potentially liquefiable soils can be avoided as construction sites, particularly in regions that are known to experience frequent earthquakes. If high ground-water levels are involved, sites can be drained or other water-diversion efforts can be adopted.

Predictability

There is a high probability of recurrence in areas that have experienced previous problems. They are most prevalent in areas that have an extreme earthquake hazard as well as liquefiable soils. Lateral spreads are also associated with susceptible marine clays and are a common problem throughout the St. Lawrence Lowlands of eastern Canada. Figures 17, 18, 19 and 20 show a schematic and photos of lateral spread.

2.4 Flows

A flow is a spatially continuous movement in which the surfaces of shear are short-lived, closely spaced, and usually not preserved. The component velocities in the displacing mass of a flow resemble those in a viscous liquid. Often, there is a gradation of change from slides to flows, depending on the water content, mobility, and evolution of the movement.

2.4.1 Debris Flows

A debris flow is a form of rapid mass movement in which loose soil, rock and sometimes organic matter combine with water to form a slurry that flows downslope. They have been informally and inappropriately called "mudslides" due to the large quantity of fine material that may be present in the flow. Occasionally, as a rotational or translational slide gains velocity and the internal mass loses cohesion or gains water, it may evolve into a debris flow. Dry flows can sometimes occur in cohesionless sand (sand flows). Debris flows can be deadly as they can be extremely rapid and may occur without any warning.

Occurrence

Debris flows occur around the world and are prevalent in steep gullies and canyons; they can be intensified when occurring on slopes or in gullies that have been denuded of vegetation due to wildfires or forest logging. They are common in volcanic areas with weak soil.

Relative size/range

These types of flows can be thin and watery or thick with sediment and debris and are usually confined to the dimensions of the steep gullies that facilitate their downward movement. Generally the movement is relatively shallow and the runout is both long and narrow, sometimes extending for kilometers in steep terrain. The debris and mud usually terminate at the base of the slopes and create fanlike, triangular deposits called debris fans, which may also be unstable.

Velocity of travel

They can be rapid to extremely rapid (35 miles per hour or 56 km per hour) depending on consistency and slope angle.

Triggering mechanisms

Debris flows are commonly caused by intense surface-water flow, due to heavy precipitation or rapid snowmelt, that erodes and mobilizes loose soil or rock on steep slopes. Debris flows also commonly mobilize from other types of landslides that occur on steep slopes, are nearly saturated, and consist of a large proportion of silt- and sand-sized material.

Effects (direct/indirect)

Debris flows can be lethal because of their rapid onset, high speed of movement, and the fact that they can incorporate large boulders and other pieces of debris. They can move objects as large as houses in their downslope flow or can fill structures with a rapid accumulation of sediment

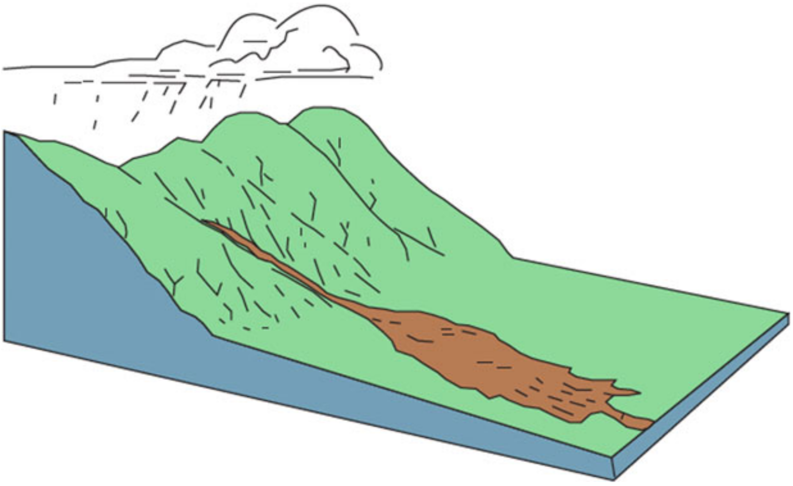


Fig. 21 Schematic illustration of a debris flow

Fig. 22 Heavy rains triggered a debris flow at Arapahoe Ski Area, Colorado (USA) July 28, 1999. Photo by Ed Harp, U.S. Geological Survey

and organic matter. They can affect the quality of water by depositing large amounts of silt and debris.

Mitigation measures

Flows usually cannot be prevented; thus, homes should not be built in or adjacent to steep-walled gullies that have a history of debris flows or are otherwise susceptible due to wildfires, soil type, or other related factors. New flows can be directed away from structures by means of deflection, debris-flow basins can be built to contain flow, and warning systems can be put in place in areas where it is known at what rainfall thresholds debris flows are triggered.

Fig. 23 A photo of the July 20, 2003 debri flow which occurred in Minamata City, Kyushu Island, Japan, resulting in 14 deaths and 15 houses destroyed (Sassa et al. 2004)

Evacuation, avoidance, and (or) relocation are the best methods to prevent injury and life loss.

Predictability

Maps of potential debris-flow hazards exist for some areas. Debris flows can be frequent in any area of steep slopes and heavy rainfall, either seasonally or intermittently, and especially in areas that have been recently burned or the vegetation removed by other means. Figures 21, 22, 23 and 24 show a schematic and images of debris flows.

2.4.2 Lahars (Volcanic Debris Flows)

The word “lahar” is an Indonesian term. Lahars are also known as volcanic mudflows. These are flows that originate on the slopes of volcanoes and are a type of debris flow. A lahar mobilizes the loose accumulations of tephra (the airborne solids erupted from the volcano) and related debris.

Occurrence

Lahars are found in nearly all volcanic areas of the world.

Relative size/range

Lahars can be hundreds of square kilometers or miles in area and can become larger as they gain speed and accumulate debris as they travel downslope; or, they can be small in volume and affect limited areas of the volcano and then dissipate downslope.

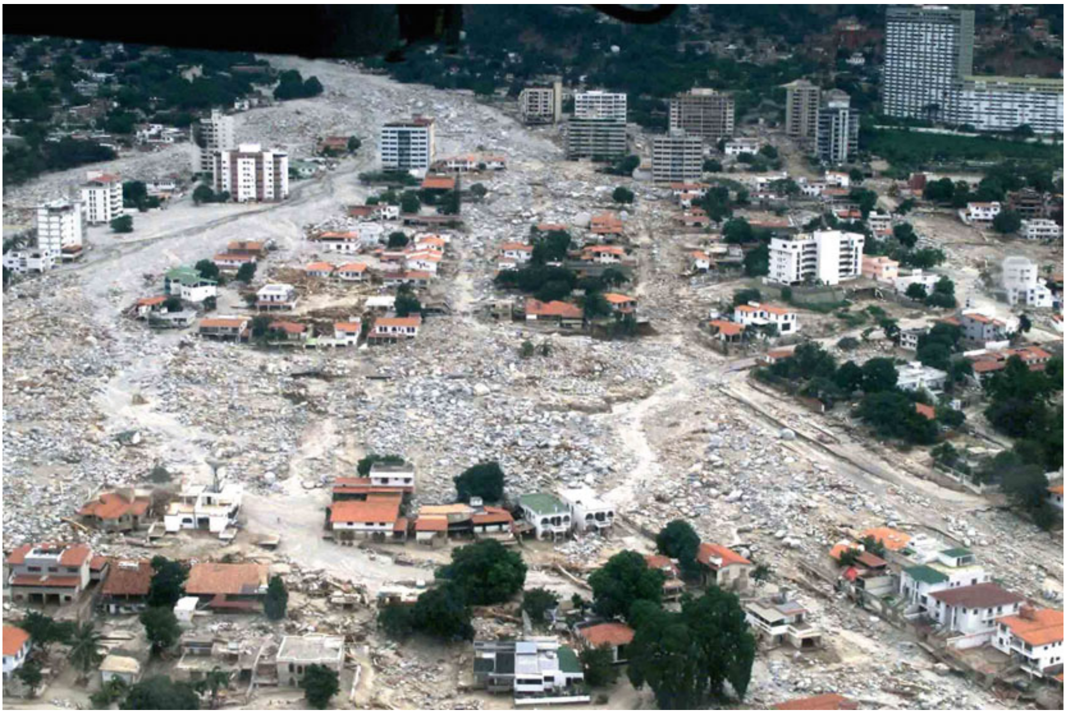


Fig. 24 Debris-flow damage to the city of Caraballeda, located at the base of the Cordillera de la Costan, on the north coast of Venezuela. In December 1999, this area was hit by Venezuela's worst natural disaster of the 20th century; several days of torrential rain triggered flows of mud, boulders, water, and trees that killed as many as 30,000 people (Photo by L.M. Smith, Waterways Experiment Station, U.S. Army Corps of Engineers)

Velocity of travel

Lahars can be very rapid (more than 35 miles per hour or 56 kilometres per hour) especially if they mix with a source of water such as melting snowfields or glaciers. If they are viscous and thick with debris and less water, the movement will be slow to moderately slow.

Triggering mechanism

Water is the primary triggering mechanism, and it can originate from crater lakes, condensation of erupted steam on volcano particles, or the melting of snow and ice at the top of high volcanoes. Some of the largest and most deadly lahars have originated from volcanic eruptions or venting which suddenly melts surrounding snow and ice and causes rapid liquefaction and flow down steep volcanic slopes at catastrophic speeds.

Effects (direct/indirect)

Effects can be extremely large and devastating, especially when triggered by a volcanic eruption and consequent rapid melting of any snow and ice—the flow can bury human settlements located on the volcano slopes. Some large flows can also dam rivers, causing flooding upstream. Subsequent breaching of these weakly cemented dams can cause catastrophic flooding downstream. This type of landslide often results in large numbers of human casualties.

Mitigation measures

No corrective measures are known that can be taken to prevent damage from lahars except for avoidance by not building or locating in their paths or on the slopes of volcanoes. Warning systems and subsequent evacuation work in some instances may save lives. However, warning

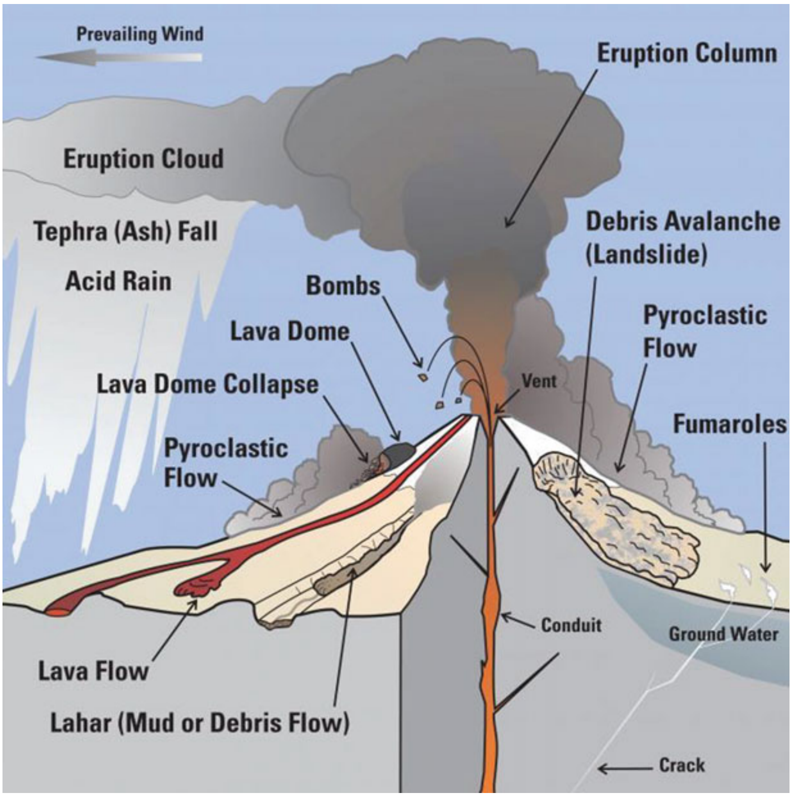


Fig. 25 Schematic illustration of volcano hazards, which includes lahars (lower *left* of illustration). Note that debris avalanches and pyroclastic flows can also occur. Lahars often flow in the same manner as debris and lava flows, and course along the same drainage paths. Illustration modified from U.S. Geological Survey

systems require active monitoring, and a reliable evacuation method is essential.

Predictability

Susceptibility maps based on past occurrences of lahars can be constructed, as well as runout estimations of potential flows. Such maps are not readily available for most hazardous areas. Figures 25, 26 and 27 show a schematic and photos of lahars.

2.4.3 Debris Avalanche

Debris avalanches are essentially large, extremely rapid, often open-slope flows formed when an unstable slope collapses and the resulting fragmented debris is rapidly transported away from the slope. In some cases, snow and ice will contribute to the movement if sufficient water is present, and the flow may become a debris flow and (or) a lahar.

Occurrence

Debris avalanches occur worldwide in steep terrain environments. They are also common on very steep volcanoes where they may follow drainage courses.

Relative size/range

Some large avalanches have been known to transport material blocks as large as 3 km in size, several kilometers from their source.

Fig. 26 On November 13, 1985, the Nevado del Ruiz stratovolcano in Tolima, Colombia, erupted, after 69 years of dormancy. As pyroclastic flows erupted from the volcano's crater, they melted the mountain's glaciers, sending four enormous lahars down its slopes at 50 kilometers per hour (30 miles per hour). The lahars picked up speed in gullies and coursed into the six major rivers at the base of the volcano; they engulfed the town of Armero, killing more than 20,000 of its almost 29,000 inhabitants. Photo by Darrell Herd, U.S. Geological Survey

Velocity of travel

Travel is rapid to extremely rapid; such debris avalanches can travel close to 100 m/s.

Triggering mechanism

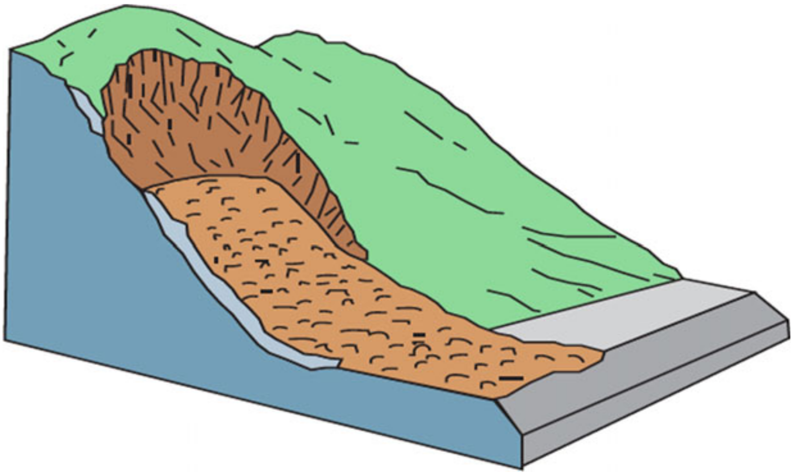
In general, the two types of debris avalanches are those that are "cold" and those that are "hot." A cold debris avalanche usually results from a slope becoming unstable, such as during collapse of weathered slopes in steep terrain or through the disintegration of bedrock during a slide-type landslide as it moves downslope at high velocity. At that point, the mass can then transform into a debris avalanche. A hot debris avalanche is one that results from volcanic activity including volcanic earthquakes or the injection of magma, which causes slope instability.

Effects (direct/indirect)

Debris avalanches may travel several kilometers before stopping, or they may transform into more water-rich lahars or debris flows that travel many tens of kilometers farther downstream. Such failures may inundate towns and villages and impair stream quality. They move very fast and thus may prove deadly because there is little chance for warning and response.

Fig. 27 Photo of a lahar, caused by the 1982 eruption of Mount St. Helens, Washington, USA. Photo by Tom Casadevall, U.S. Geological Survey

Fig. 28 Schematic of a Debris Avalanche



Corrective measures/mitigation

Avoidance of construction in valleys on volcanoes or steep mountain slopes and real-time warning systems may lessen damages. However, warning systems may prove difficult due to the speed at which debris avalanches occur—there may not be enough time after the initiation of the event for people to evacuate. Debris avalanches cannot be stopped or prevented by engineering means because the associated triggering mechanisms are not preventable.

Fig. 29 A debris avalanche which buried a village in Guinsaugon, Southern Leyte, Philippines, in February, 2006 (Photo by University of Tokyo Geotechnical Team)

Predictability

If evidence of prior debris avalanches exists in an area, and if such evidence can be dated, a probabilistic recurrence period might be established. During volcanic eruptions, chances are greater for a debris avalanche to occur, so appropriate cautionary actions could be adopted. Figures 28, 29 and 30 show a schematic and photos of debris avalanches.

2.4.4 Earthflow

Earthflows can occur on gentle to moderate slopes, (see Fig. 33) generally in fine-grained soil, commonly clay or silt, but also in very weathered, clay-bearing bedrock. The mass in an earthflow moves as a plastic or viscous flow with strong internal deformation. Susceptible marine clay (quick clay) when disturbed is very vulnerable and may lose all shear strength with a change in its natural moisture content and suddenly liquefy, potentially destroying large areas and flowing for several kilometers. Size commonly increases through headscarp retrogression. Slides or lateral spreads may also evolve downslope into earthflows. Earthflows can range from very slow (creep) to rapid and catastrophic. Very slow flows and specialized forms of earthflow restricted to northern permafrost environments are discussed elsewhere.

Occurrence

Earthflows occur worldwide in regions underlain by fine-grained soil or very weathered bedrock. Catastrophic rapid earthflows are common in the susceptible marine clays of the St. Lawrence Lowlands of North America, coastal Alaska and British Columbia, and in Scandinavia.

Relative (size/range)

Flows can range from small events of 100 m^2 in size to large events encompassing several square kilometers in area. Earthflows in

Fig. 30 Oblique aerial view of the Hattian Bala, Pakistan debris avalanche showing the avalanche scarp, travel path and debris. The debris avalanche was triggered by the October 8, 2005 Pakistan Earthquake. As a result, the Karli stream drainage was blocked, causing the impoundment of a lake (seen in *lower left* area of photo). Photograph by USAID

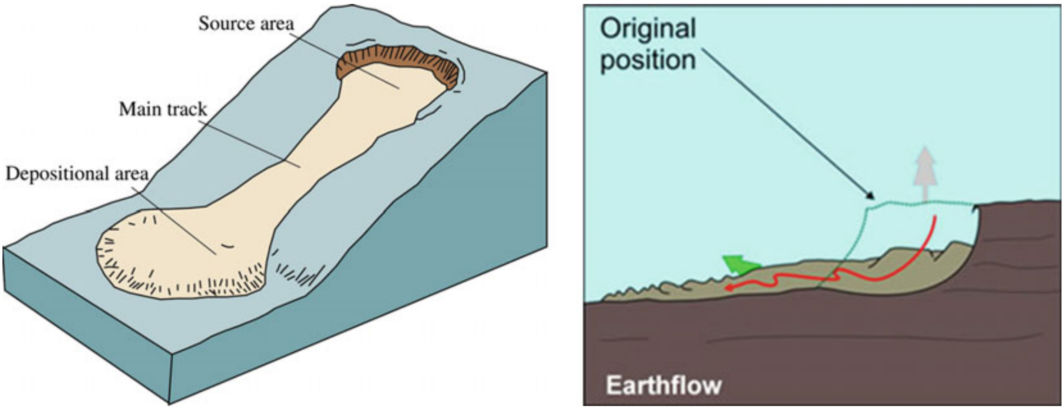


Fig. 31 Schematic illustrations of an Earthflow. The photo at *left* shows a schematic of a steep slope earthflow (see Fig. 35 for a photo), and the photo at *right* shows a cross-section/schematic of an earthflow on a shallow slope (see Fig. 34 for a photo of a shallow-slope earthflow)

Fig. 32 Photo the Slumgullion Landslide, Colorado, USA. This earth flow occurred approximately 700 years ago, dammed the Lake Fork of the Gunnison River, which caused flooding the valley, forming Lake Cristobal. Photo by Jeff Coe, U.S. Geological Survey

susceptible marine clays may runout for several kilometers. Depth of the failure ranges from shallow to many tens of meters.

Velocity of travel

They range from slow to very rapid.

Triggering mechanisms

Triggers include saturation of soil due to prolonged or intense rainfall or snowmelt, sudden lowering of adjacent water surfaces causing rapid drawdown of the ground-water table, stream erosion at the bottom of a slope, excavation and construction activities, excessive loading on a slope, earthquakes, or human-induced vibration.

Effects (direct/indirect)

Rapid, retrogressive earthflows in susceptible marine clay may devastate large areas of flat land lying above the slope and also may runout for considerable distances, potentially resulting in human fatalities, destruction of buildings and linear infrastructure, and damming of rivers with resultant flooding upstream and water siltation problems downstream. Slower earthflows may damage properties and sever linear infrastructure.

Corrective measures/mitigation

Improved drainage is an important corrective measure, as is grading of slopes and protecting the base of the slope from erosion or excavation. Shear strength of clay can be measured, and

Fig. 33 On April 27, 1993, a landslide severely damaged three homes near the town of LaFayette in the Tully Valley, 24 km (15 miles) south of Syracuse, New York. This landslide can be classified as a rapid slump-earth flow. Material involved consists of red lake clay deposits of glacial origin, covered by glacial till and colluvium of varying thickness. Photo by Gerry Wieczorek, U.S. Geological Survey

potential pressure can be monitored in suspect slopes. However, the best mitigation is to avoid development activities near such slopes.

Predictability

Evidence of past earthflows is the best indication of vulnerability. Distribution of clay likely to liquefy can in some cases be mapped and has been mapped in many parts of eastern North America. Cracks opening near the top of the slope may indicate potential failure. Figures 31, 32, 33, 34 and 35 show schematics and photos of an earthflow.

2.4.5 Creep

Creep is the informal name for a slow earthflow and consists of the imperceptibly slow, steady downward movement of slope-forming soil or rock. Movement is caused by internal shear stress sufficient to cause deformation but insufficient to cause failure. Generally, the three types of creep are: (1) seasonal, where movement is within the depth of soil affected by seasonal changes in soil moisture and temperature; (2) continuous, where shear stress continuously exceeds the strength of the material; and (3) progressive, where slopes are reaching the point of failure for other types of mass movements.

Occurrence

Creep is widespread around the world and is probably the most common type of landslide, often preceding more rapid and damaging types of landslides. Solifluction, a specialized form of creep common to permafrost environments, occurs in the upper layer of ice-rich, fine-grained soils during the annual thaw of this layer.

Fig. 34 The 1993 Lemieux Landslide was a rapid earth flow in sensitive marine clay near Ottawa, Canada. The headscarp retrogressed 680 m into level ground above the riverbank. About 2.8 million tons of clay and silt liquefied and flowed into the South Nation River valley, damming the river (Photo by G.R. Brooks, Geological Survey of Canada)

Relative size/range

Creep can be very regional in nature (tens of square kilometers) or simply confined to small areas. It is difficult to discern the boundaries of creep since the event itself is so slow and surface features representing perceptible deformation may be lacking.

Velocity of travel

Velocity is very slow to extremely slow. Usually less than 1 m (0.3 ft) per decade.

Triggering mechanism

For seasonal creep, rainfall and snowmelt are typical triggers, whereas for other types of creep there could be numerous causes, such as chemical or physical weathering, leaking pipes, poor drainage, destabilizing types of construction, and so on.

Effects

Because it is hard to detect in certain places because of the slowness of movement, creep is sometimes not recognized when assessing the suitability of a building site. Creep can slowly pull apart pipelines, buildings, highways, fences, and so forth, and can lead to more drastic ground failures that are more destructive and faster moving.

Corrective measures/mitigation

The most common mitigation for creep is to ensure proper drainage of water, especially for

Fig. 35 The 1995 La Conchita, California (USA) earthflow occurred after heavy rains. No one was killed or injured, as it moved relatively slowly. This landslide later reactivated in 2005, and moving much more rapidly, killed 10 people. Photo by Mark Reid, U.S. Geological Survey

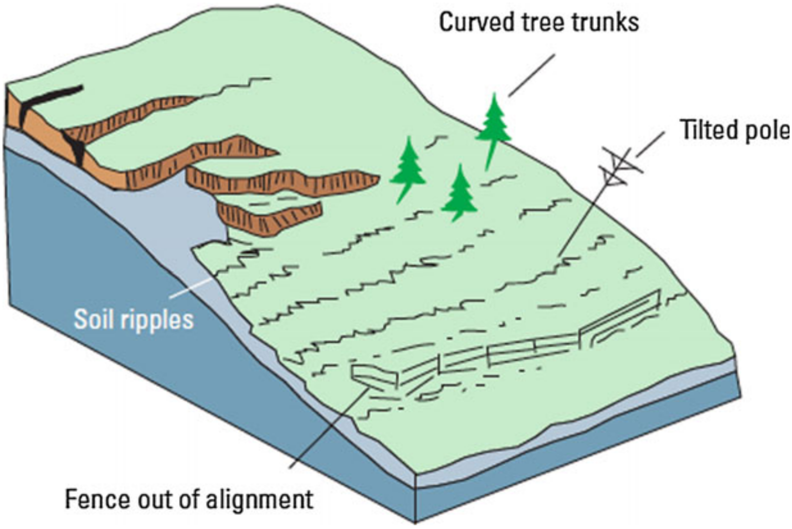


Fig. 36 Schematic illustration of a slow-moving flow, called Creep

Fig. 37 An Illustration of creep and it's effect on trees and forests. Photo by NOAA/NGDC/Colorado Geological Survey, Public Domain http://www.ngdc.noaa.gov/hazardimages/picture/show/1551

the seasonal type of creep. Slope modification such as flattening or removing all or part of the landslide mass, can be attempted, as well as the construction of retaining walls.

Predictability

These are indicated by curved tree trunks, bent fences and (or) retaining walls, tilted poles or fences, and small soil ripples or ridges on the surface. Rates of creep can be measured by inclinometers installed in boreholes or by detailed surface measurements. Figures 36, 37, 38 and 39 show a schematic and photos of creep.

2.4.6 Flows in Permafrost

Failures in permafrost conditions involve the movement of fine-grained, previously ice-rich

Fig. 38 A photo showing the surface expression of Creep in a region in the Buzau subcarpathians in Romania. The slope is composed of Neogene clays and marls, and entirely covered with colluvial deposits. Photo by Dr. Dan Balteanu, Romanian Academy

soil and can occur on gentle slopes. Seasonal thaw of the upper meter of frozen ground melts ground ice and results in oversaturation of the soil, which in turn loses shear strength and initiates flows. Solifluction, a form of cold environment creep, involves very slow deformation of the surface and forms shallow lobes elongated downslope. Active layer detachments, also known as skinflows, involve rapid flow of a shallow layer of saturated soil and vegetation, forming long, narrow flows moving on the surface but over the underlying

Fig. 39 This is an earthflow on Mission Pass in the California (USA) coastal ranges. The lateral lines on the hillside show creep. Public domain: NOAA/NGDC, B. Bradley, University of Colorado. http://www.ngdc.noaa.gov/hazardimages/picture/show/1537

permanently frozen soil. This type of movement may expose buried ice lenses, which when thawed may develop into retrogressive thaw flows or possibly debris flows. Retrogressive thaw flows are larger features with a bimodal shape of a steep headwall and low-angle tongue of saturated soil. This type of feature will continue to expand through headscarp retrogression until displaced vegetation buries and insulates the ice-rich scarp.

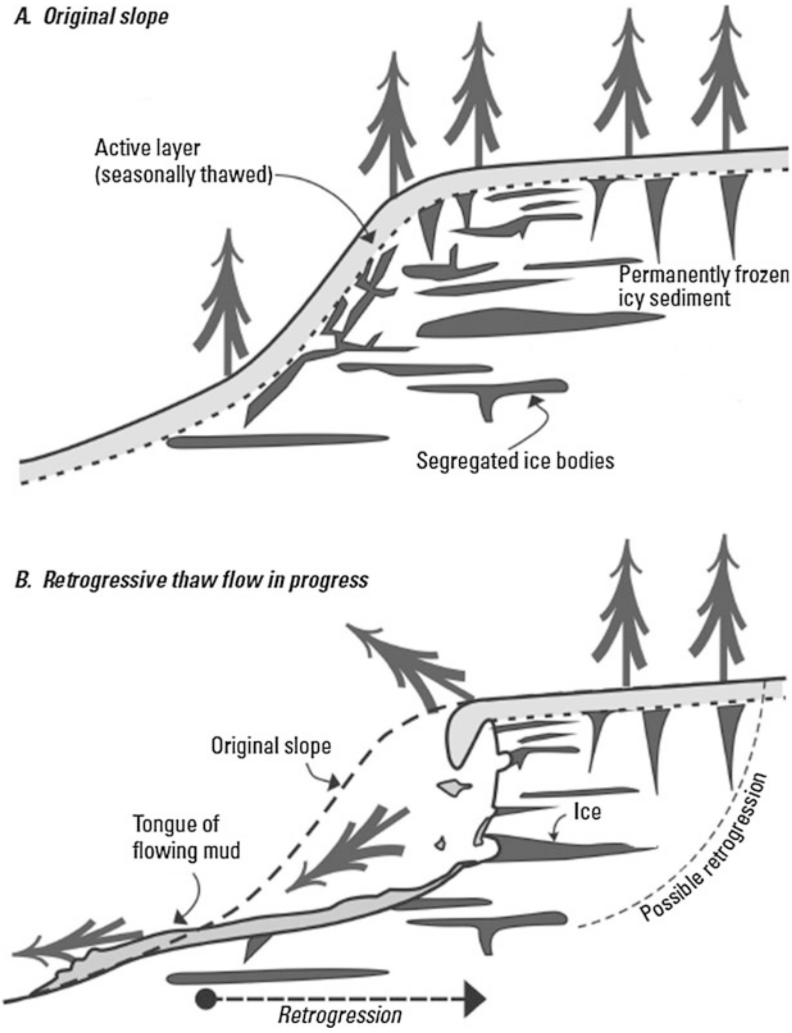


Fig. 40 Schematic illustration of a retrograde flow in permafrost

Occurrence

Flows are common in ice-rich permafrost soils in northern latitudes and high altitudes (cold environments).

Relative size/range

Flows are generally small but can increase in size through headscarp retrogression. They may evolve into a larger debris flow.7

Velocity of travel

Velocity is very slow (solifluction); slow (retrogressive thaw flow); rapid (active layer detachment).

Triggering mechanisms

May be triggered by above-average summer temperatures, frost wedges, wildfire, and anthropogenic disturbances to insulating peat

Fig. 41 Lake with a large, active retrogressive thaw slump. Image courtesy of Steve Kokelj Government of the Northwest Territories, Canada

layer. Such landslides are particularly likely in warming climates.

Effects (direct/indirect)

Damage to pipelines and roads and other structures can be severe.

Corrective measures/mitigation

Infrastructure designs that have minimal effect on the surface peat layer or temperature of the active layer and avoidance, when possible, of ice-rich soils when planning roads and other infrastructure, can reduce risk. Ice content of the upper soil can be readily tested.

Predictability

If ice-rich soil thaws, it will flow. In some areas, ice content has been mapped; in other areas, ice content can be estimated on the basis of specific mapped units shown on surficial geology maps. Figures 40, 41, 42 and 43 show a schematic and photos of permafrost-related flow.

Fig. 42 In 2004 a large chunk of earth collapsed along the upper Selawik River in Alaska as a result of permafrost failure, spewing mud and silt into the water and pushing the river against its far bank. Sediment from the collapse turned the clear upper Selawik River into an opaque, turbid stream. Climate change may make these more common as permafrost begins to melt, with severe impacts on water quality and wildlife

2.5 Complex

These are landslides that feature components of two or more of the basic types of landslides and can occur either simultaneously or at different times during the onset of slope failure. Figures 44 and 45 show a schematic and photo of a complex landslide.

The landslide involved a complex sequence of events–including rotation, translation and flow mechanisms, including transformation into a debris flow at the terminus of the landslide–as such, it can be referred to as a debris-avalanche flow (Wartman et al. 2016)

3 Conclusion

The development of the typing of landslides is ongoing and evolving, as new information is obtained, and some past landslides are re-evaluated. Classifications of natural phenomena are always evolving and there are differing professional opinions on the process. One recent effort is a publication by Hungr et al. (2014) which is published in its entirety in the Teaching Tools. The reader is encouraged to read this publication for both new information, and as an example of how the typing of landslides is

Fig. 43 Photograph of a retrogressive thaw flow, in the Northwest Territories, Canada. Wildfire has likely contributed to the size of the flow by means of damage to an insulating moss layer, resulting in the thickening of the active layer, which is thawing permafrost. Photo by Marten Geertsema, Ministry of Forests, British Columbia, Canada

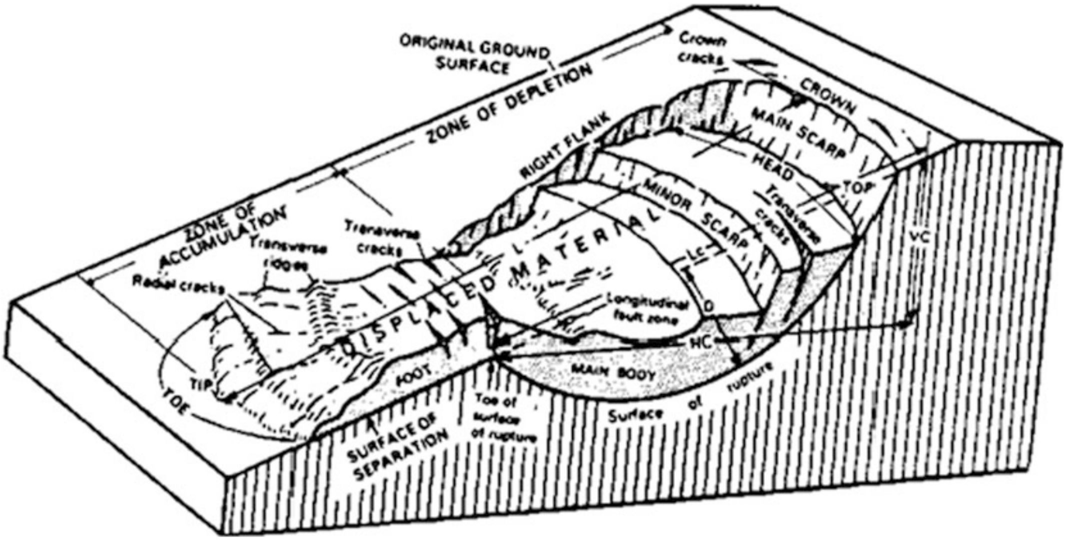


Fig. 44 Schematic illustration of a Complex landslide

Fig. 45 This photo shows a recent example of a complex landslide. This landslide occurred in northwest Washington (USA) on March 22, 2014. Landslide debris covered about 40 homes and other structures as well as nearly a mile of a highway, State Route 530. It also caused 43 fatalities in the community of Steelhead Haven near Oso, Washington

approached, as well as how the science of landslide typing continues to improve.

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