DML – 502 Lecture - 1

Landslide Hazard Assessment & Mitigation

Introduction

Subject Code : DML-502
Course Title: Landslide Hazard Assessment & Mitigation

"To understand mapping and hazard assessment techniques of landslides and protection against landslide."

S. No. 1

Introduction: Definition; Classification of landslides and mass movements, Overview of hazard assessment techniques on regional, semi-detail and detailed scales and their application for planning purposes; Terrain classification and mapping methods, use of RS and GIS.

Definition: Classification of landslides and mass movements

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Introduction

What is a Landslide?

- **"Landslide"** denotes the downward movement of earth/sediments/mass the influence of gravity. Since it is the movement of mass it is also known as mass movements (in geology). Gravity is the primary driving force for a landslide to occur, but there are other factors affecting slope stability that produce specific conditions that make a slope prone to failure. In many cases, the landslide is triggered by a specific event (such as a heavy rainfall, an earthquake, a slope cut to build a road, and many others), although this is not always identifiable.

The material types are Rock, Earth, Soil, Mud and Debris, are defined as follows:

Rock: is "a hard or firm mass that was intact and in its natural place before the initiation of movement".

Soil: is "an aggregate of solid particles, generally of minerals and rocks, that either was transported or was formed by the weathering of rock in place.

Gases or liquids filling the pores of the soil form part of the soil".

Earth: "describes material in which 80% or more of the particles are smaller than 2 mm, the upper limit of sand-sized particles".

Mud: "describes material in which 80% or more of the particles are smaller than 0.06 mm, the upper limit of silt-sized particles".

Debris: "contains a significant proportion of coarse material; 20% to 80% of the particles are larger than 2mm, and the remainder is less than 2 mm".

Classification of landslides and mass movements

Classification

- In traditional usage, the term landslide has at one time or another been used to cover almost all forms of mass movement of rocks and regolith at the Earth's surface. In **1978, geologist David Varnes** noted this imprecise usage and proposed a new, much tighter scheme for the classification of mass movements and subsidence pro cesses.[20]

Varnes, D. J. 1978. Slope movement types and processes. In: *Special Report 176: Landslides: Analysis and Control* (Eds: Schuster, R. L. & Krizek, R. J.). Transportation and Road Research Board, National Academy of Science, Washington D. C., 11-33.

TYPE OF MOVEMENT		TYPE OF MATERIAL		
		BEDROCK	ENGINEERING SOILS	
			Predominantly coarse	Predominantly fine
FALLS		Rock fall	Debris fall	Earth fall
TOPPLES		Rock topple	Debris topple	Earth topple
SLIDES	ROTATIONAL	Rock slide	Debris slide	Earth slide
	TRANSLATIONAL			
LATERAL SPREADS		Rock spread	Debris spread	Earth spread
FLOWS		Rock flow (deep creep)	Debris flow (soil creep)	Earth flow
COMPLEX		Combination of two or more principal types of movement		

Abbreviated version of Varnes´ classification of slope movements (Varnes 1978)

http://pubs.usgs.gov/fs/2004/3072/fs-2004-3072.html

Classification of landslides and mass movements

Classification

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- The material types used by the various schemes are **Rock, Earth,**
- **Soil, Mud and Debris.**
- The five kinematically distinct types of movement are described in the, sequence: **- fall, - topple, - slide, - spread, - flow.**

Combining the two terms gives classifications such as:
Rock fall, Rock topple, Debris slide, Debris flow, Earth slide, Earth spread etc.
https://en.wikipedia.org/wiki/Landslide (Maintained by iRALL)
(Refer to the citations which are scientific articles)

Type of movement	Rock	Soil
Fall	*Rock/ice* fall	*Boulder/debris/silt* fall
Topple	Rock block topple	*Gravel/sand/silt* topple
	Rock flexural topple	
Slide	Rock rotational slide	*Clay/silt* rotational slide
	Rock planar slide	*Clay/silt* planar slide
	Rock wedge slide	*Gravel/sand/debris* slide
	Rock compound slide	*Clay/silt* compound slide
	Rock irregular slide	
Spread	Rock slope spread	*Sand/silt* liquefaction spread
		Sensitive clay spread
Flow	*Rock/ice* avalanche	*Sand/silt/debris* dry flow
		Sand/silt/debris flowslide
		Sensitive clay flowslide
		Debris flow
		Mud flow
		Debris flood
		Debris avalanche
		Earthflow
		Peat flow
Slope deformation	Mountain slope deformation	Soil slope deformation
	Rock slope deformation	Soil creep
		Solifluction

Classification of landslides and mass movements

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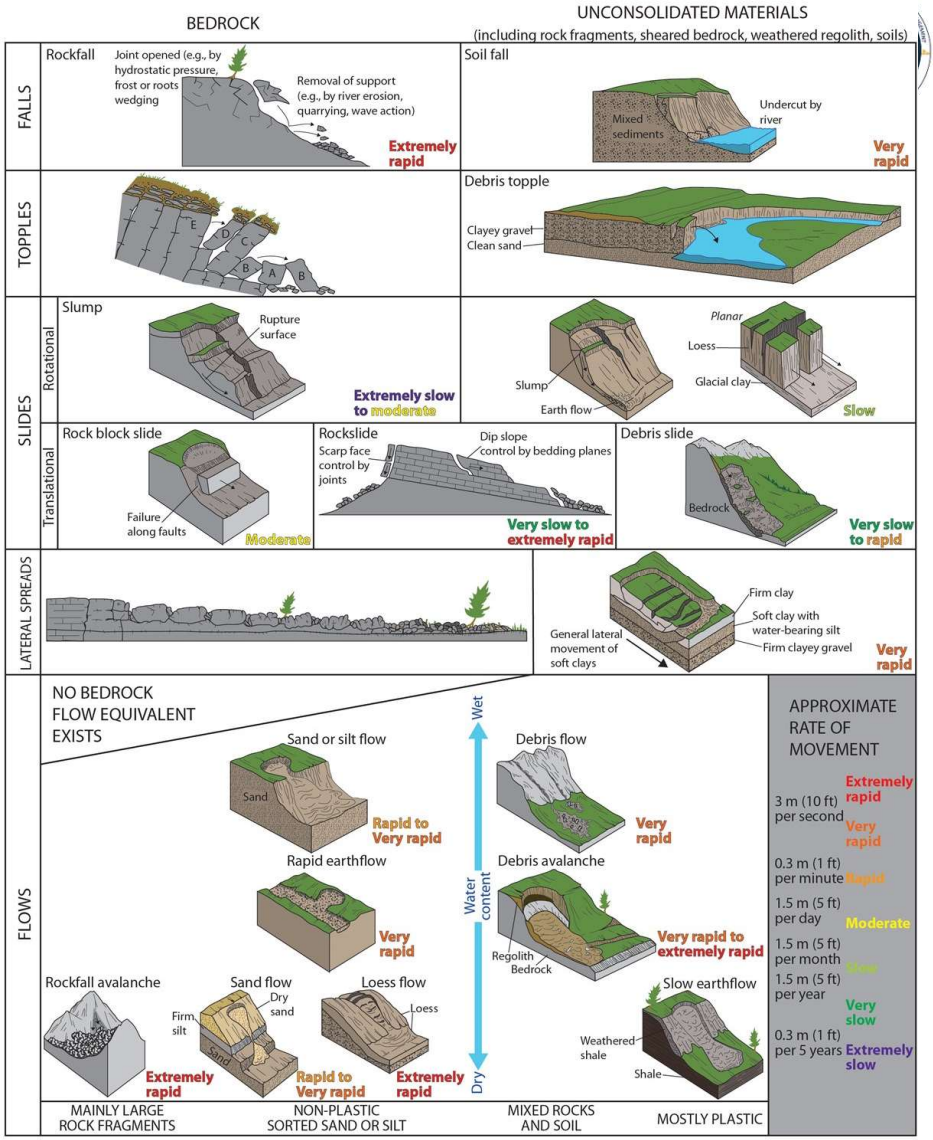
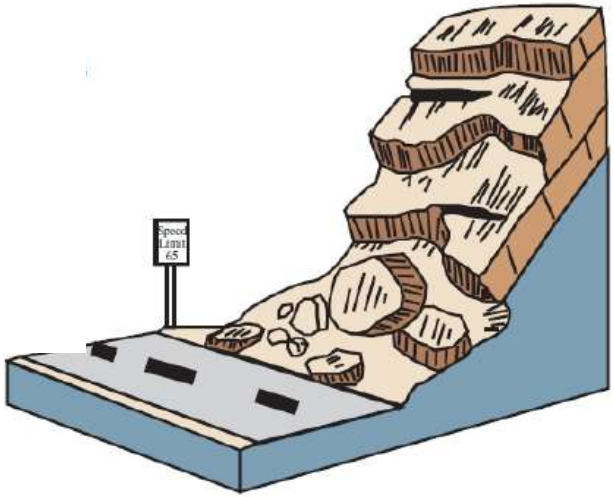
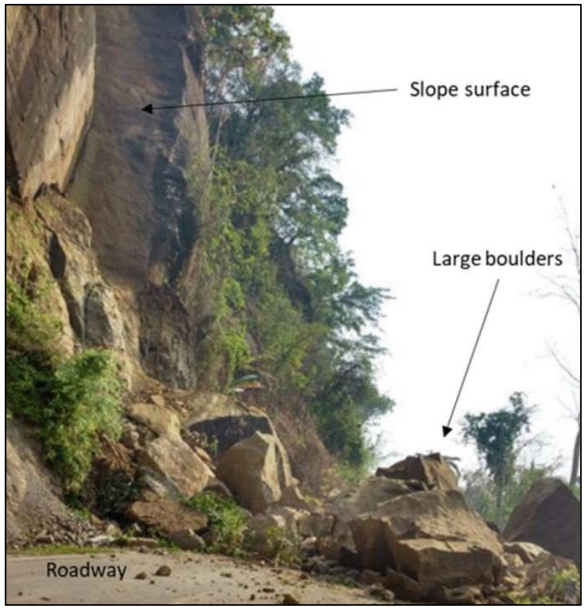


Classification of landslides and mass movements

Falls are abrupt movements of masses of geologic materials, such as rocks and boulders, that become detached from steep slopes or cliffs. Separation occurs along discontinuities such as fractures, joints, and bedding planes, and movement occurs by free-fall, bouncing, and rolling. Falls are strongly influenced by gravity, mechanical weathering, and the presence of interstitial water.



Rockfall



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.

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.

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 or 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 and railroads is particularly high: rockfalls can cause deaths in vehicles hit by rocks and can block highways and railroads.

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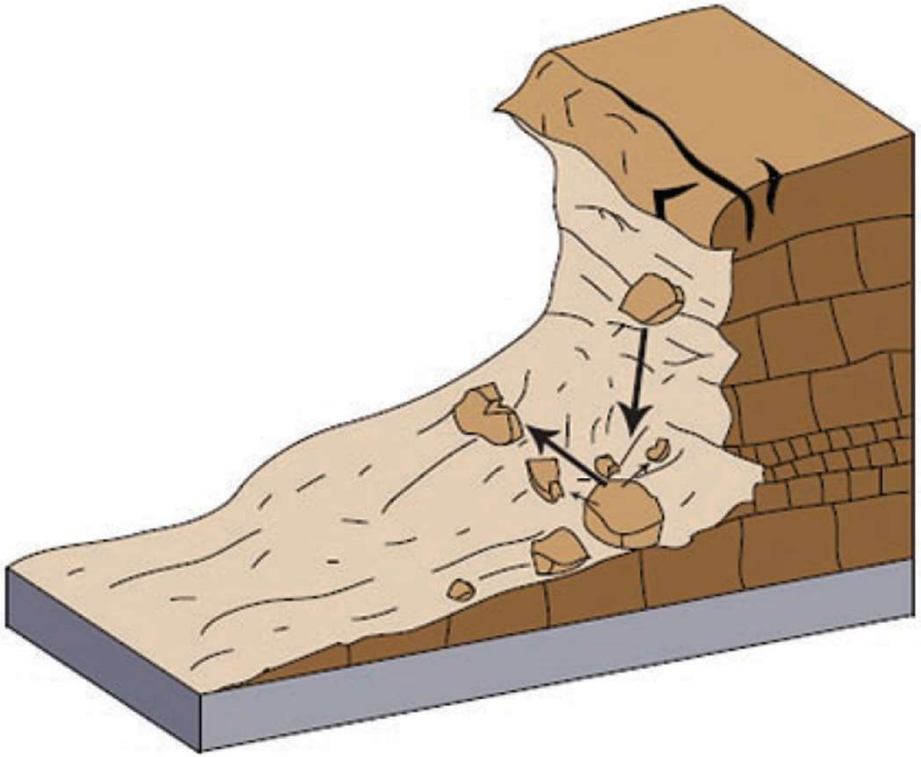
Rockfall



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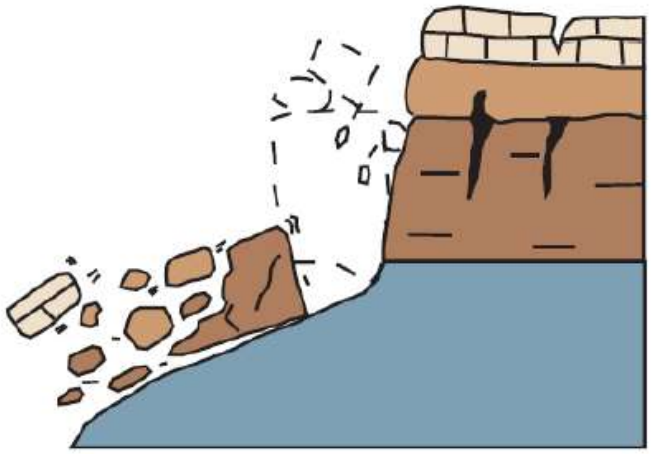
Classification of landslides and mass movements

TOPPLES: Toppling failures are distinguished by the forward rotation of a unit or units about some pivotal point, below or low in the unit, under the actions of gravity and forces exerted by adjacent units or by fluids in cracks.



Topple

Rock topple

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 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

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

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

Triggering mechanism

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.

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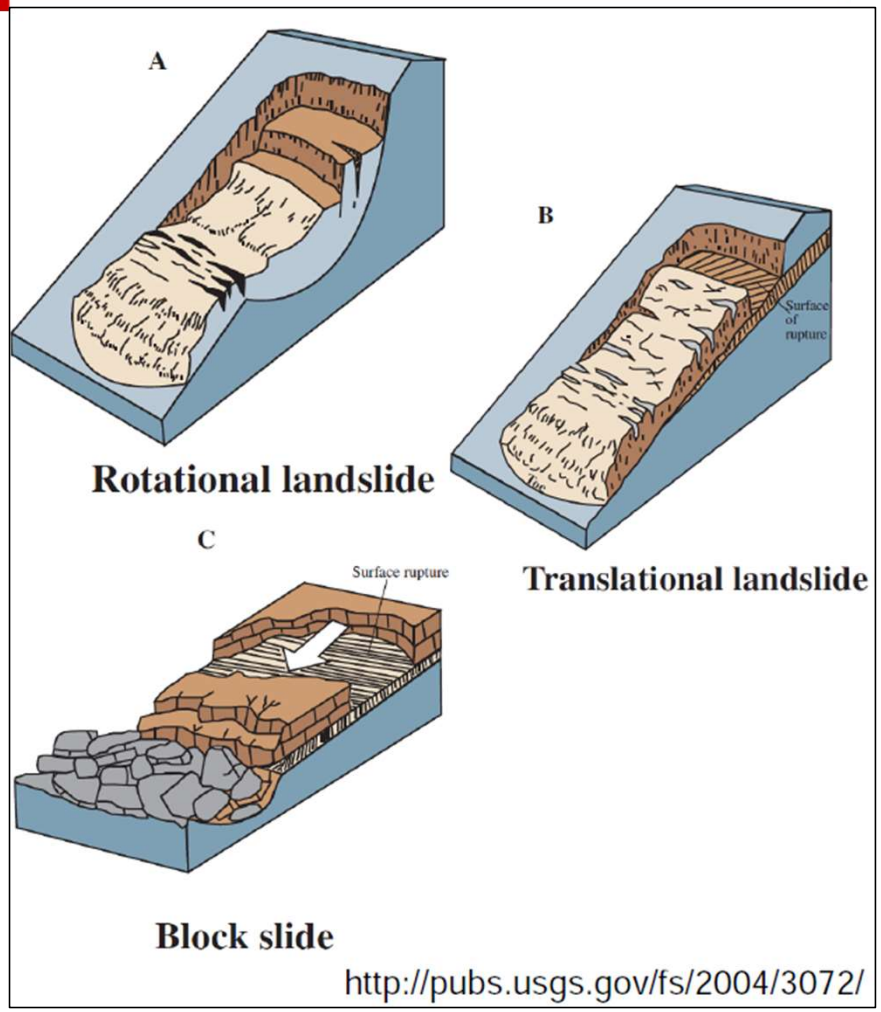
Classification of landslides and mass movements

SLIDES: Although many types of mass movements are included in the general term "landslide," the more restrictive use of the term refers only to mass movements, where there is a distinct zone of weakness that separates the slide material from more stable underlying material. The two major types of slides are **rotational slides** and **translational slides**.

***Rotational slide*:** This is a slide in which the surface of rupture is curved concavely upward and the slide movement is roughly rotational about an axis that is parallel to the ground Surface and transverse across the slide).

Translational slide*:** In this type of slide, the landslide mass moves along a roughly planar surface with little rotation or backward tilting. **A *block slide is a translational slide in which the moving mass consists of a single unit or a few closely related units that move downslope as a relatively coherent mass



Slides

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.

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 mass 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 most common landslide occurring in "fill" materials.

Relative size/range

Associated with slopes ranging from about 20 to 40 degrees. In soils, the surface of rupture generally has a depth-to-length ratio between 0.3 to 0.1.

Velocity of travel (rate of movement)

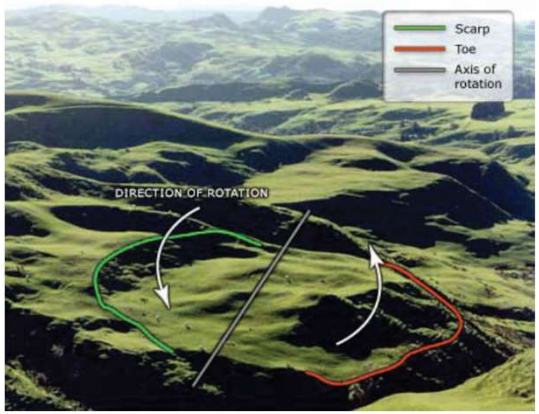
Extremely slow (less than 0.3 meter or 1 foot every 5 years) to moderately fast (1.5 meters or 5 feet per month) to rapid.

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)

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.



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Slides

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

Occurrence

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

Relative size/range

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

Triggering mechanism

Primarily intense rainfall, rise in ground water 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 undercutting. These types of landslides can be earthquake-induced.

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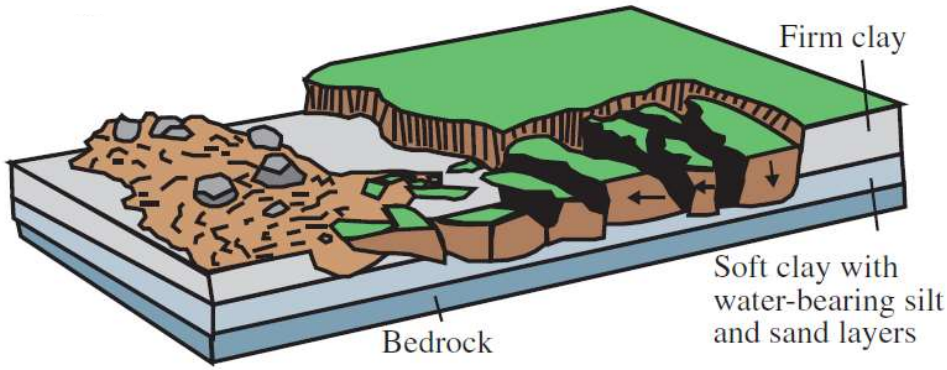
Classification of landslides and mass movements

A translational landslide that occurred in 2001 in the Beatton River Valley, British Columbia, Canada. (Photograph by Réjean Couture, Canada Geological Survey.)

Highland, L.M., and Bobrowsky, Peter, 2008, The landslide handbook—A guide to understanding landslides: Reston, Virginia, U.S. Geological Survey Circular 1325, 129 p.

Classification of landslides and mass movements



Lateral spread

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Spreads

Spreads

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.

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 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

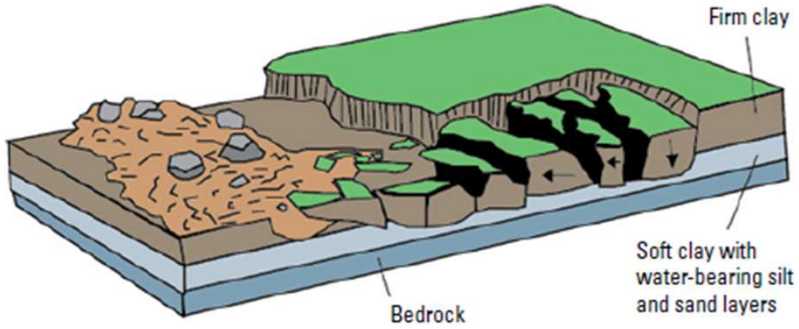
Worldwide and known to occur where there are liquefiable soils. Common, but not restricted, to areas of seismic activity.

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

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.



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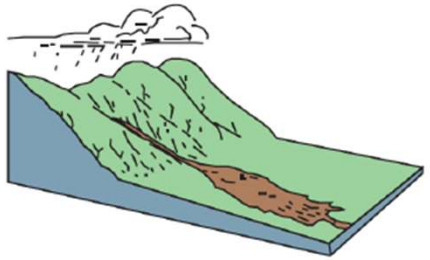
Classification of landslides and mass movements

FLOWS: There are five basic categories of flows that differ from one another in fundamental ways.

a. Debris flow: A debris flow is a form of rapid mass movement in which a combination of loose soil, rock, organic matter, air, and water mobilize as a slurry that flows downslope. Debris flows include <50% fines. 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. Debris-flow source areas are often associated with steep gullies, and debris-flow deposits are usually indicated by the presence of debris fans at the mouths of gullies. Fires that denude slopes of vegetation intensify the susceptibility of slopes to debris flows.



Debris flow

http://pubs.usgs.gov/fs/2004/3072/

Classification of landslides and mass movements

A cluster of debris avalanches and debris flows of January, 2010 in the Serrana Region of Brazil (Courtesy of A.L. Coelho-Netto, Federal University of Rio de Janeiro)

A debris flow drainage and fan in the Khumbu Valley, Nepal (Photo by O. Hungr)

Classification of landslides and mass movements

FLOWS:

b. Debris avalanche: This is a variety of very rapid to extremely rapid debris flow.

c. Earth flow: Earth flows have a characteristic "hourglass" shape. The slope material liquefies and runs out, forming a bowl or depression at the head. The flow itself is elongate and usually occurs in fine-grained materials or clay-bearing rocks on moderate slopes and under saturated conditions. However, dry flows of granular material are also possible.

d. Mud flow: A mudflow is an earth flow consisting of material that is wet enough to flow rapidly and that contains at least 50 percent sand-, silt-, and clay-sized particles. In some instances, for example in many newspaper reports, mudflows and debris flows are commonly referred to as "mud slides."

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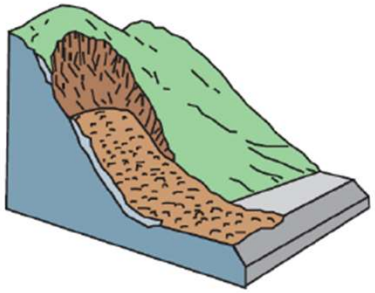

Debris avalanche

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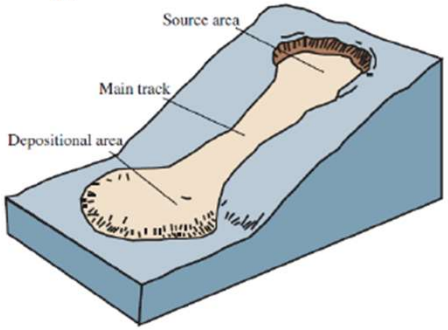


Earthflow

http://pubs.usgs.gov/fs/2004/3072/

Classification of landslides and mass movements

FLOWS:

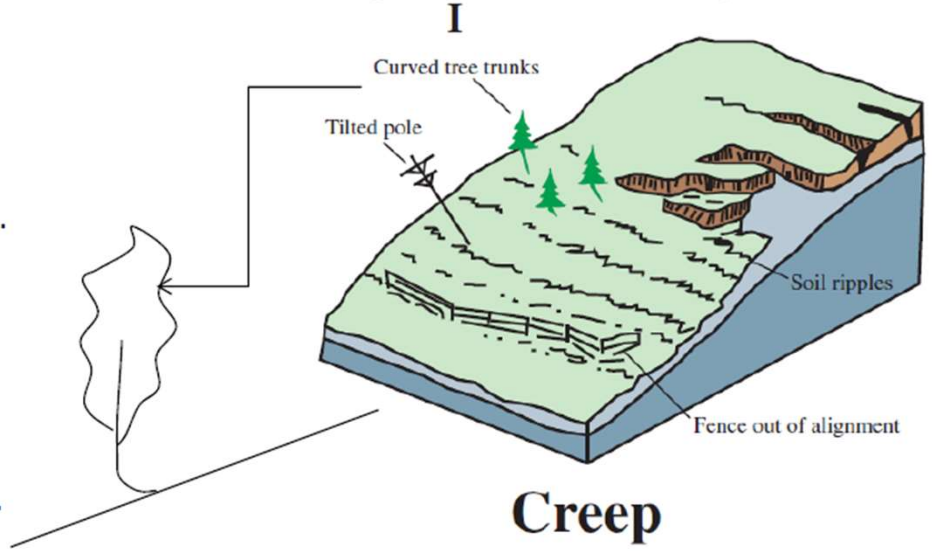
e. Creep: Creep is the imperceptibly slow, steady, downward movement of slope-forming soil or rock. Movement is caused by shear stress sufficient to produce permanent deformation, but too small to produce shear failure. There are generally three types of creep:

(1) seasonal, where movement is within the depth of soil affected by seasonal changes in soil moisture and soil temperature;

(2) continuous, where shear stress continuously exceeds the strength of the material;

(3) progressive, where slopes are reaching the point of failure as other types of mass movements.

Creep is indicated by curved tree trunks, bent fences or retaining walls, tilted poles or fences, and small soil ripples or ridges.



Creep

http://pubs.usgs.gov/fs/2004/3072/

Flows

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.

Debris Flows

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

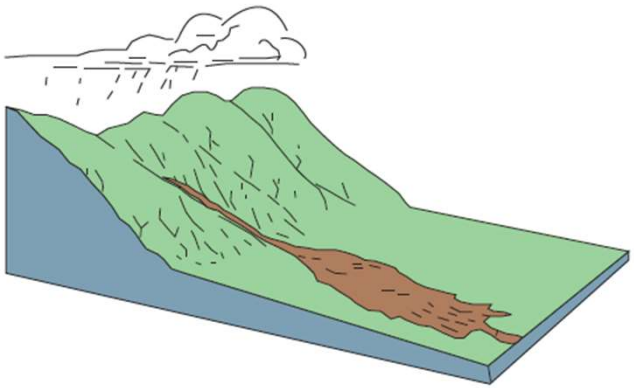
Debris flows occur around the world and are prevalent in steep gullies and canyons; they can be intensified when occurring on slopes or in gullies that have been denuded of vegetation due to wildfires or forest logging. They are common in volcanic areas with weak soil.

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

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



Flows

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

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.

Velocity of travel

Lahars can be very rapid (more than 35 miles per hour or 50 kilometers 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 eruptions or volcanic venting which suddenly melts surrounding snow and ice and causes rapid liquefaction and flow down steep volcanic slopes at catastrophic speeds.

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Avalanches

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

Occur worldwide in steep terrain environments. Also common on very steep volcanoes where they may follow drainage courses.

Relative size/range

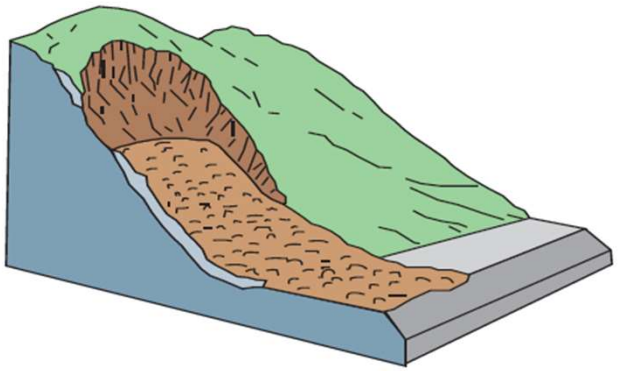
Some large avalanches have been known to transport material blocks as large as 3 kilometers in size, several kilometers from their source.

Velocity of travel

Rapid to extremely rapid; such debris avalanches can travel close to 100 meters/sec.

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.



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Flows

Earthflow

Earthflows can occur on gentle to moderate slopes, 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)

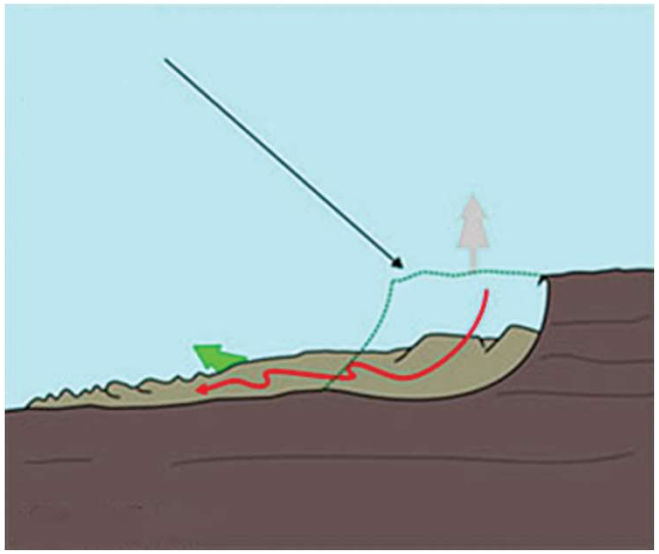
Flows can range from small events of 100 square meters in size to large events encompassing several square kilometers in area. Earthflows in susceptible marine clays may runout for several kilometers. Depth of the failure ranges from shallow to many tens of meters.

Velocity of travel

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.



The Landslide Handbook—A Guide to Understanding Landslides

Flows

Slow Earthflow (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.

Relative size/range

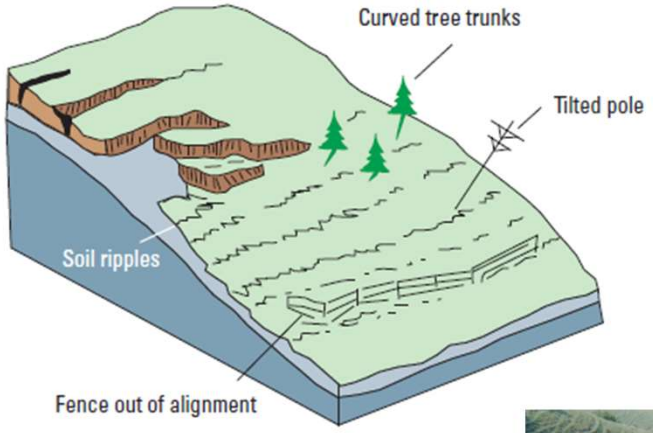
Creep can be very regional in nature (tens of square kilometers) or simply confined to small areas. It is difficult to discern the boundaries of creep since the event itself is so slow and surface features representing perceptible deformation may be lacking.

Velocity of travel

Very slow to extremely slow. Usually less than 1 meter (0.3 foot) 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.



Flows

Flows in Permafrost

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

Occurrence

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

Relative size/range

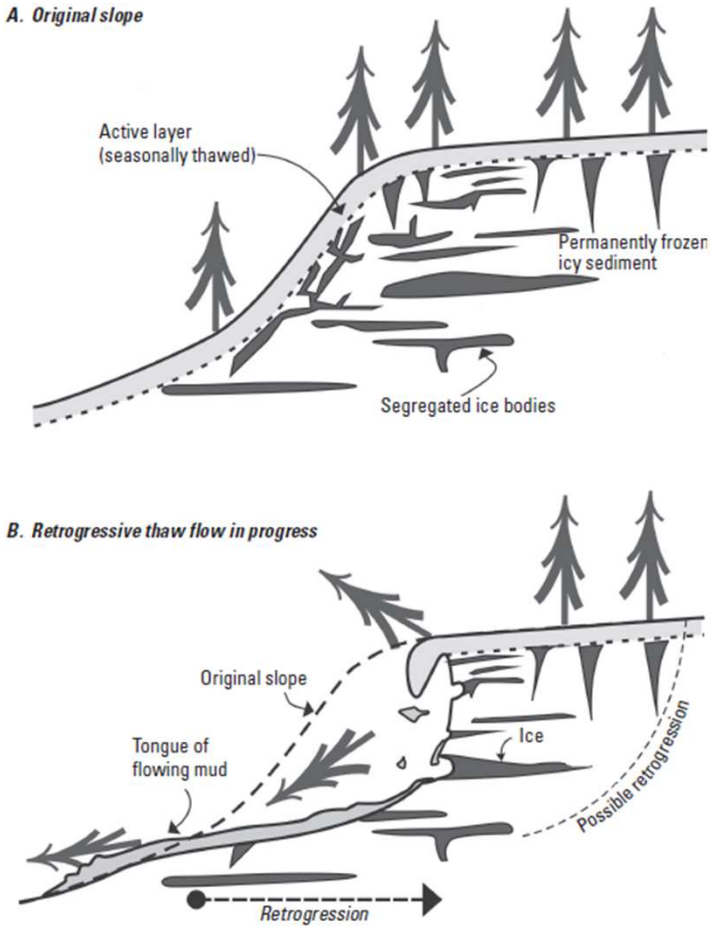
Flows are generally small but can increase in size through headscarp retrogression. They may evolve into a larger debris flow.

Velocity of travel

Very slow (solifluction); slow (retrogressive thaw flow); rapid (active layer detachment).

Triggering mechanisms

Above-average summer temperatures, frost wedges, wildfire, and anthropogenic disturbances to insulating peat layer. Such landslides are particularly likely in warming climates.



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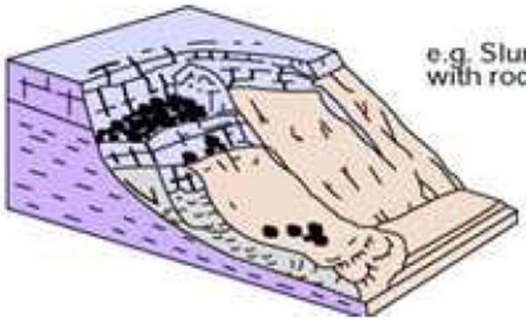
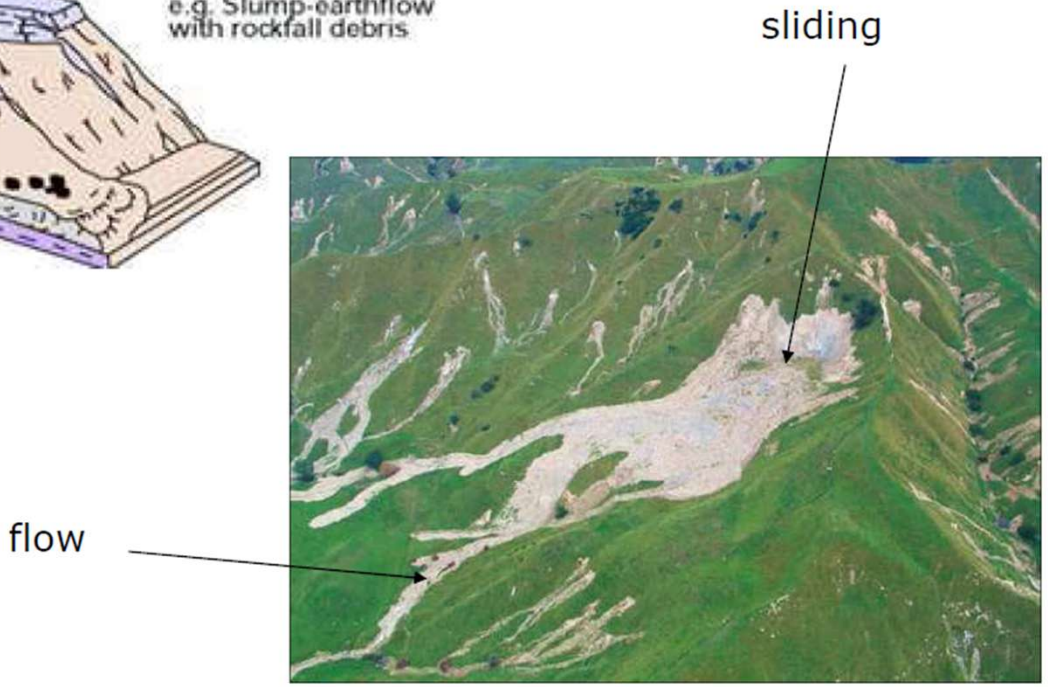
Classification of landslides and mass movements

COMPLEX:

Combination of two or more of the above types is known as a **complex landslide**.





Summary

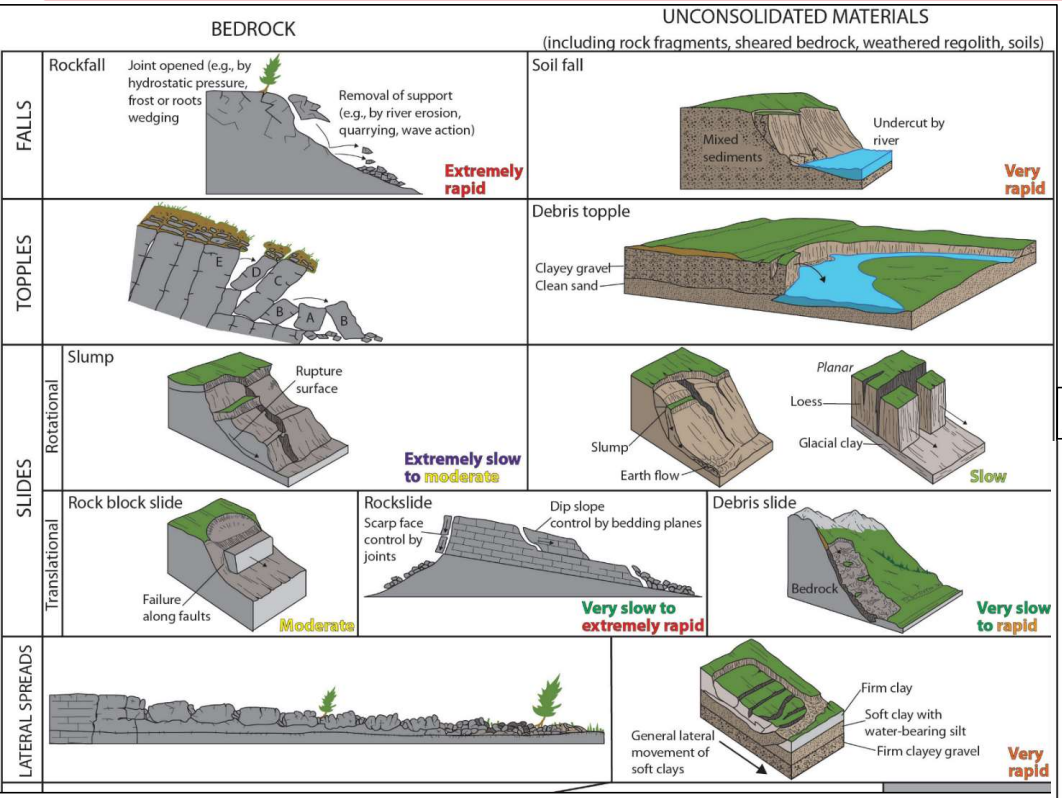
Summary of the proposed new version of the Varnes classification system. The words in italics are placeholders (use only one)

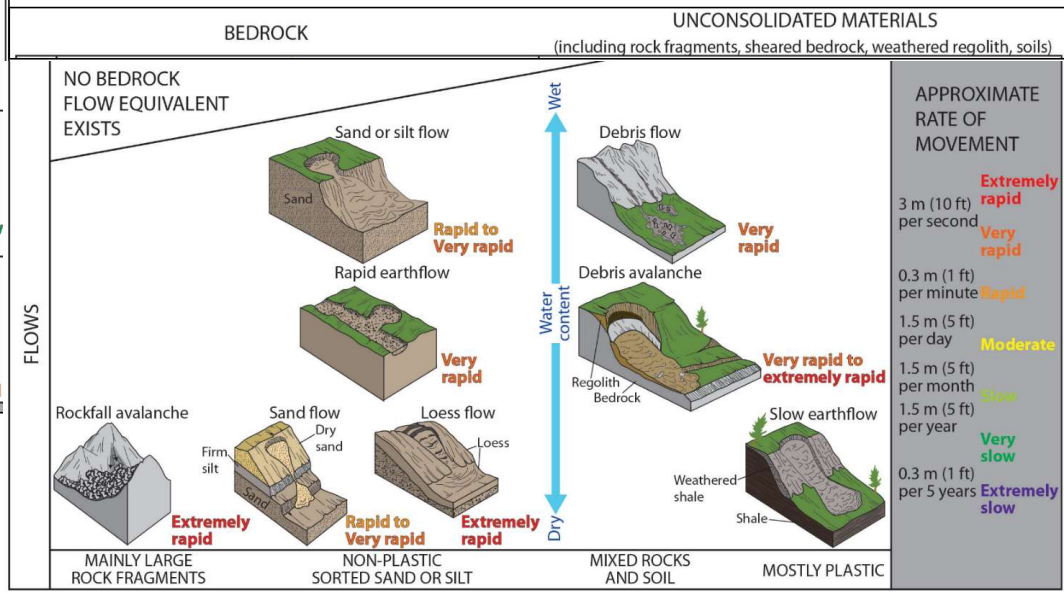
Type of movement	Rock	Soil
Fall	1. *Rock/ice* fall[a]	2. *Boulder/debris/silt* fall[a]
Topple	3. Rock block topple[a]	5. *Gravel/sand/silt* topple[a]
	4. Rock flexural topple	
Slide	6. Rock rotational slide	11. *Clay/silt* rotational slide
	7. Rock planar slide[a]	12. *Clay/silt* planar slide
	8. Rock wedge slide[a]	13. *Gravel/sand/debris* slide[a]
	9. Rock compound slide	14. *Clay/silt* compound slide
	10. Rock irregular slide[a]	
Spread	15. Rock slope spread	16. *Sand/silt* liquefaction spread[a]
		17. Sensitive clay spread[a]
Flow	18. *Rock/ice* avalanche[a]	19. *Sand/silt/debris* dry flow
		20. *Sand/silt/debris* flowslide[a]
		21. Sensitive clay flowslide[a]
		22. Debris flow[a]
		23. Mud flow[a]
		24. Debris flood
		25. Debris avalanche[a]
		26. Earthflow
		27. Peat flow
Slope deformation	28. Mountain slope deformation	30. Soil slope deformation
	29. Rock slope deformation	31. Soil creep
		32. Solifluction

For formal definitions of the landslide types, see text of the paper.

[a] Movement types that usually reach extremely rapid velocities as defined by Cruden and Varnes (1996). The other landslide types are most often (but not always) extremely slow to very rapid

Summary


BEDROCK
UNCONSOLIDATED MATERIALS
(including rock fragments, sheared bedrock, weathered regolith, soils)
FALLS
Rockfall
Joint opened (e.g., by hydrostatic pressure, frost or roots wedging
Removal of support (e.g., by river erosion, quarrying, wave action)
Extremely rapid
Soil fall
Mixed sediments
Undercut by river
Very rapid
TOPPLES
Debris topple
Clayey gravel
Clean sand
SLIDES
Rotational
Slump
Rupture surface
Extremely slow to moderate
Slump
Earth flow
Planar
Loess
Glacial clay
Slow
Translational
Rock block slide
Failure along faults
Moderate
Rockslide
Scarp face control by joints
Dip slope control by bedding planes
Very slow to extremely rapid
Debris slide
Bedrock
Very slow to rapid
LATERAL SPREADS
Firm clay
Soft clay with water-bearing silt
Firm clayey gravel
General lateral movement of soft clays
Very rapid


BEDROCK
UNCONSOLIDATED MATERIALS
(including rock fragments, sheared bedrock, weathered regolith, soils)
FLOWS
NO BEDROCK FLOW EQUIVALENT EXISTS
Sand or silt flow
Sand
Rapid to Very rapid
Debris flow
Very rapid
Rapid earthflow
Very rapid
Debris avalanche
Regolith
Bedrock
Very rapid to extremely rapid
Rockfall avalanche
Extremely rapid
Sand flow
Dry sand
Firm silt
Sand
Rapid to Very rapid
Loess flow
Loess
Extremely rapid
Slow earthflow
Weathered shale
Shale
Water content
Wet
Dry
MAINLY LARGE ROCK FRAGMENTS
NON-PLASTIC SORTED SAND OR SILT
MIXED ROCKS AND SOIL
MOSTLY PLASTIC
APPROXIMATE RATE OF MOVEMENT
3 m (10 ft) per second
Extremely rapid
Very rapid
0.3 m (1 ft) per minute
Rapid
1.5 m (5 ft) per day
Moderate
1.5 m (5 ft) per month
Slow
1.5 m (5 ft) per year
Very slow
0.3 m (1 ft) per 5 years
Extremely slow

Thank you very much for your kind attention and time!

Question time