CE/SC 10110-20110: Planet Earth

Mass Movements

Earth

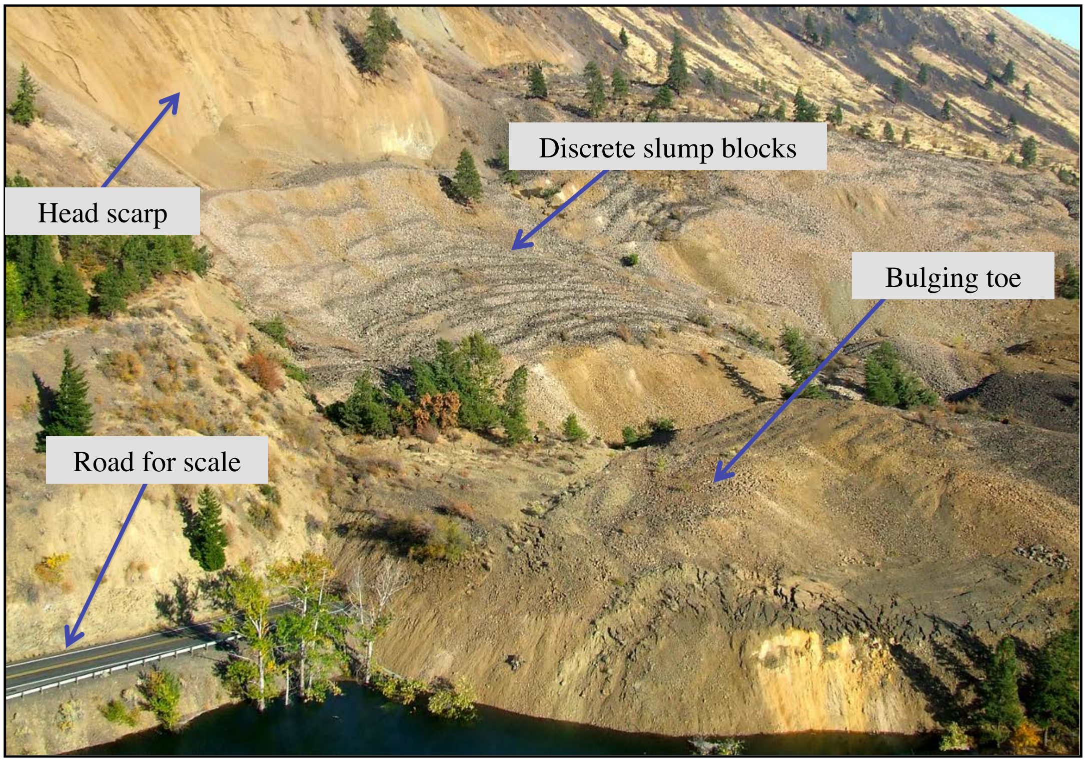
Portrait of a Planet

Fifth Edition

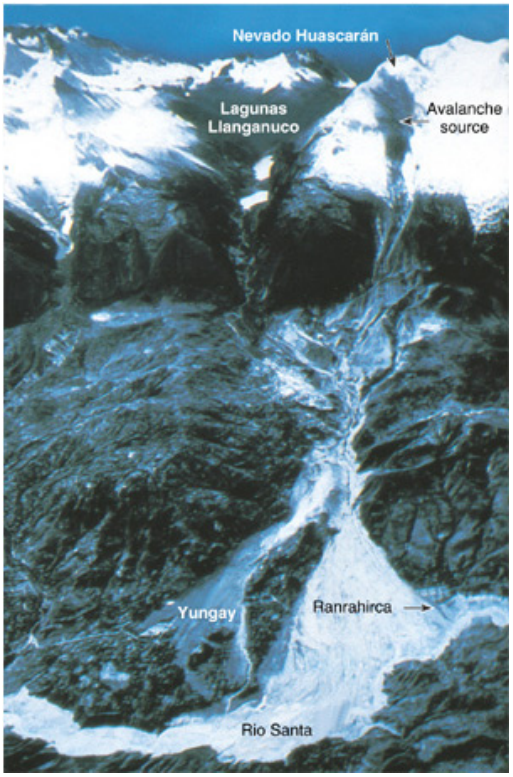
Chapter 16

Mass movement (or mass wasting) is the downslope motion of rock, regolith (soil, sediment, and debris), snow, and ice.

General Anatomy



Disaster in the Andes: Yungay, Peru, 1970



Fractures rock, loosens soil particles.

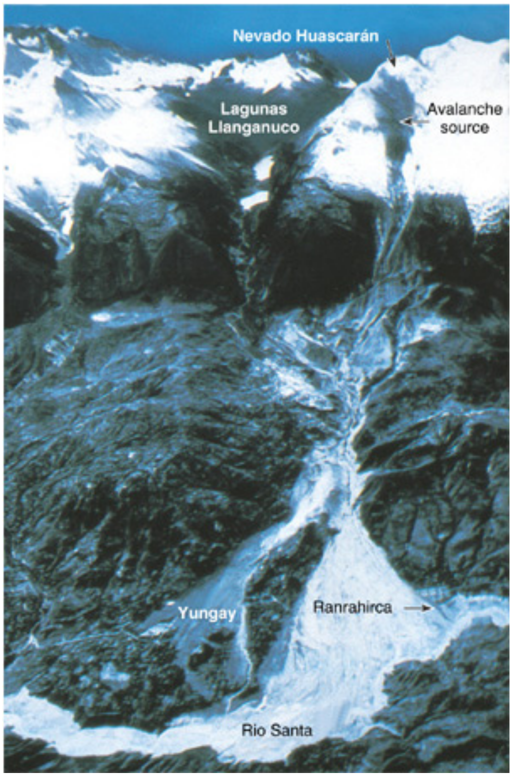
Seismic energy overstresses the system.

Yungay, Peru, in the Santa River Valley beneath the heavily glaciated Nevado Huascarán (21,860 feet).

May, 1970, earthquake occurred offshore ~100 km away - triggered many small rock falls.

An 800-meter-wide block of ice was dislodged and avalanched downhill, scooping out small lakes and breaking off large masses of rock debris.

Disaster in the Andes: Yungay, Peru, 1970



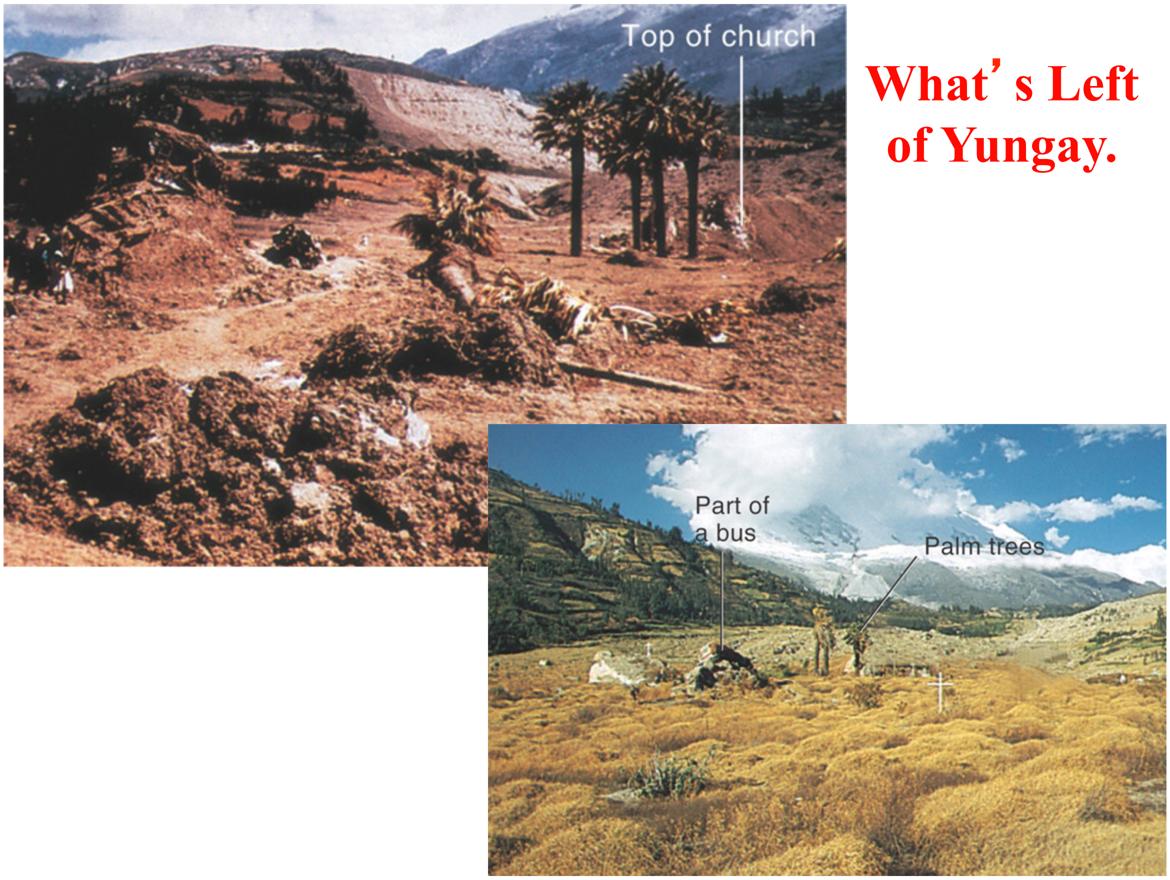
More than 50 million cubic meters of muddy debris traveled 3.7 km (12,000 feet) vertically and 14.5 km (9 miles) horizontally in less than 4 minutes!

Main mass of material traveled down a steep valley, blocking the Santa River and burying ~18,000 people in Ranrachirca.

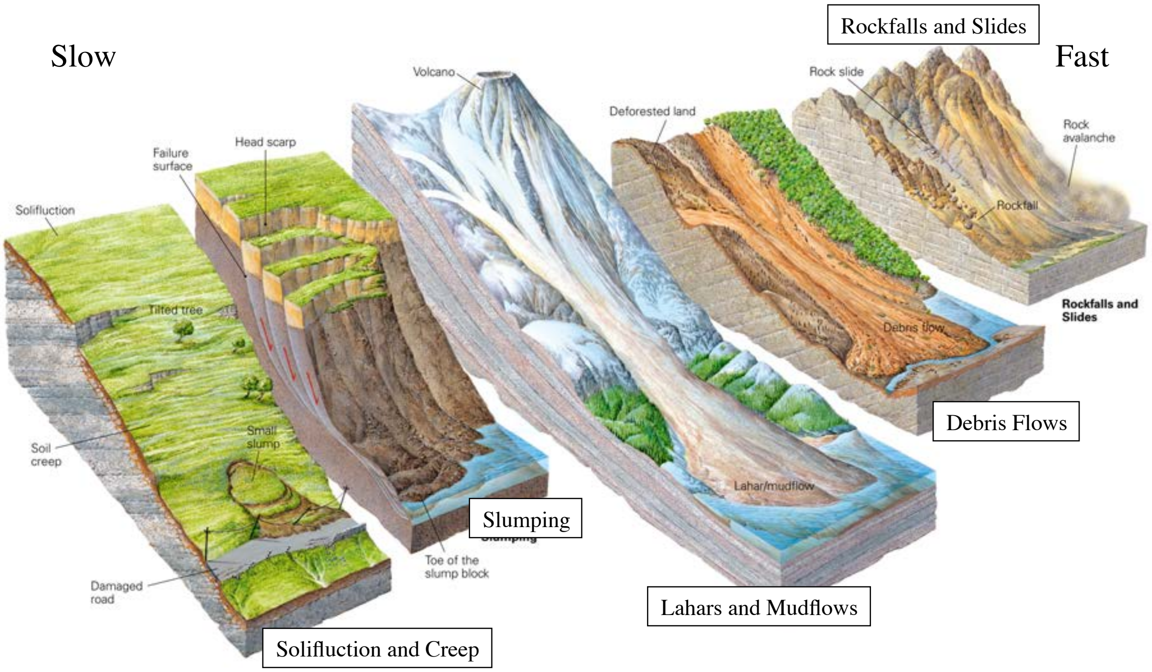
A small part shot up the valley wall, was momentarily airborne before burying the village of Yungay. Estimated death toll = 17,000.

Disaster in the Andes: Yungay, Peru, 1970

What's Left of Yungay.



Common Mass Movements



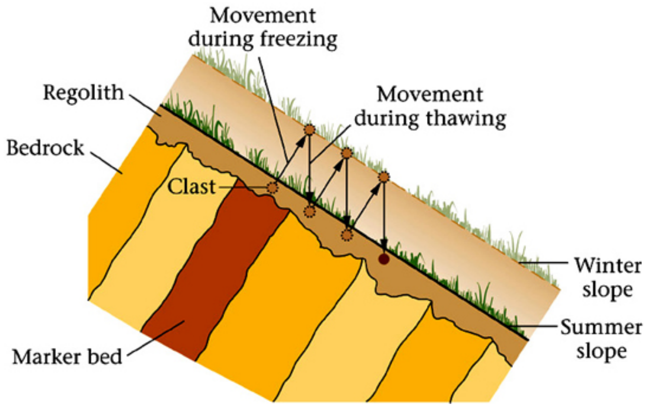
These different kinds of mass movements are arranged from slowest (left) to fastest (right).

Types of Mass Movement

Different types of mass movement based on 4 factors:

1) Type of material involved (rock, regolith, snow, ice);
2) Velocity of the movement (slow, intermediate, fast);
3) Character of the movement (chaotic cloud, slurry, coherent mass;
4) Environment (subaerial, submarine).

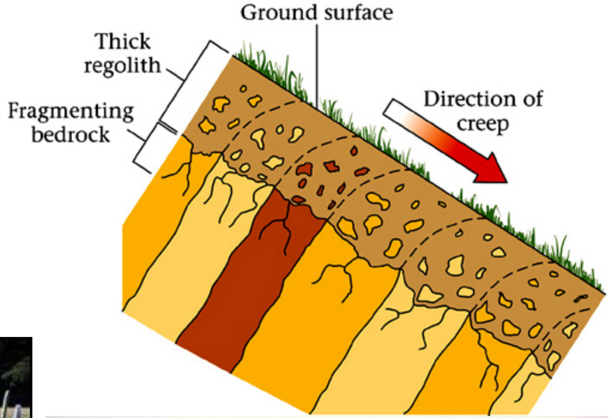
Ice = 9.2% expansion over water. Freeze-thaw cause movement down slope = **CREEP**.



Types of Mass Movement

Creep

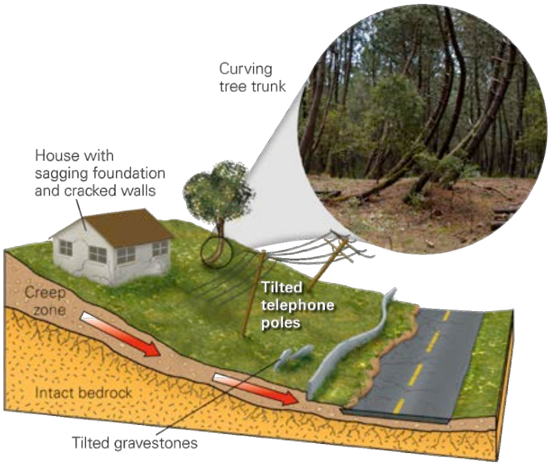
Imperceptibly slow down-slope movement, <1 cm/year. Affects the upper few meters only.



Types of Mass Movement

Creep

Enhanced by frost heaving, wetting and drying cycles, washing away of fine particles.



Types of Mass Movement

Solifluction

Thawing above permafrost on slopes promotes slow downhill movement.

Rock Glaciers: slow movement downhill of rock fragments and ice (rock > ice).
Develop where debris volume falling into a valley exceeds ice accumulation.

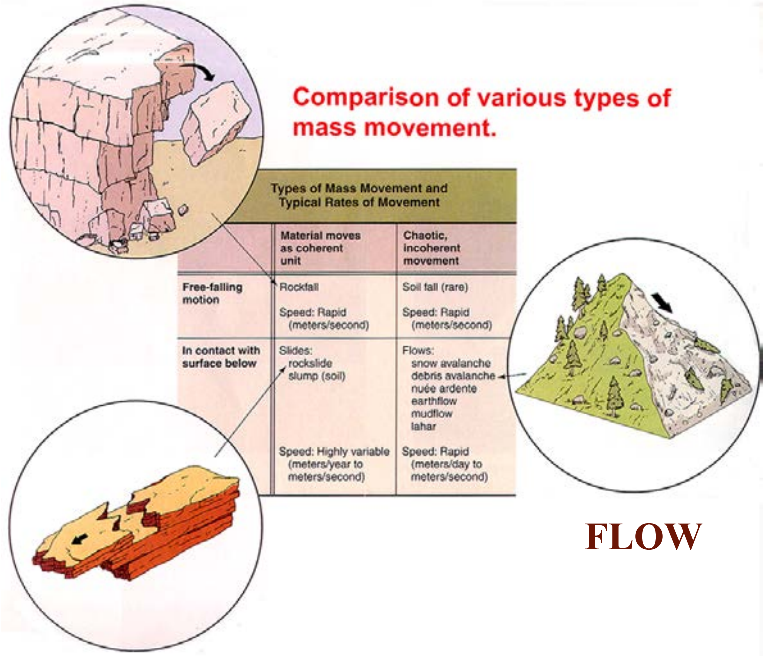
Types of Mass Movement

Mass movements can be classified on the basis of type of material moved and the characteristic type or form of movement.

FALL

SLIP

FLOW



Comparison of various types of mass movement.

Types of Mass Movement and Typical Rates of Movement

	Material moves as coherent unit	Chaotic, incoherent movement
Free-falling motion	Rockfall Speed: Rapid (meters/second)	Soil fall (rare) Speed: Rapid (meters/second)
In contact with surface below	Slides: rockslide slump (soil) Speed: Highly variable (meters/year to meters/second)	Flows: snow avalanche debris avalanche nuée ardente earthflow mudflow lahar Speed: Rapid (meters/day to meters/second)

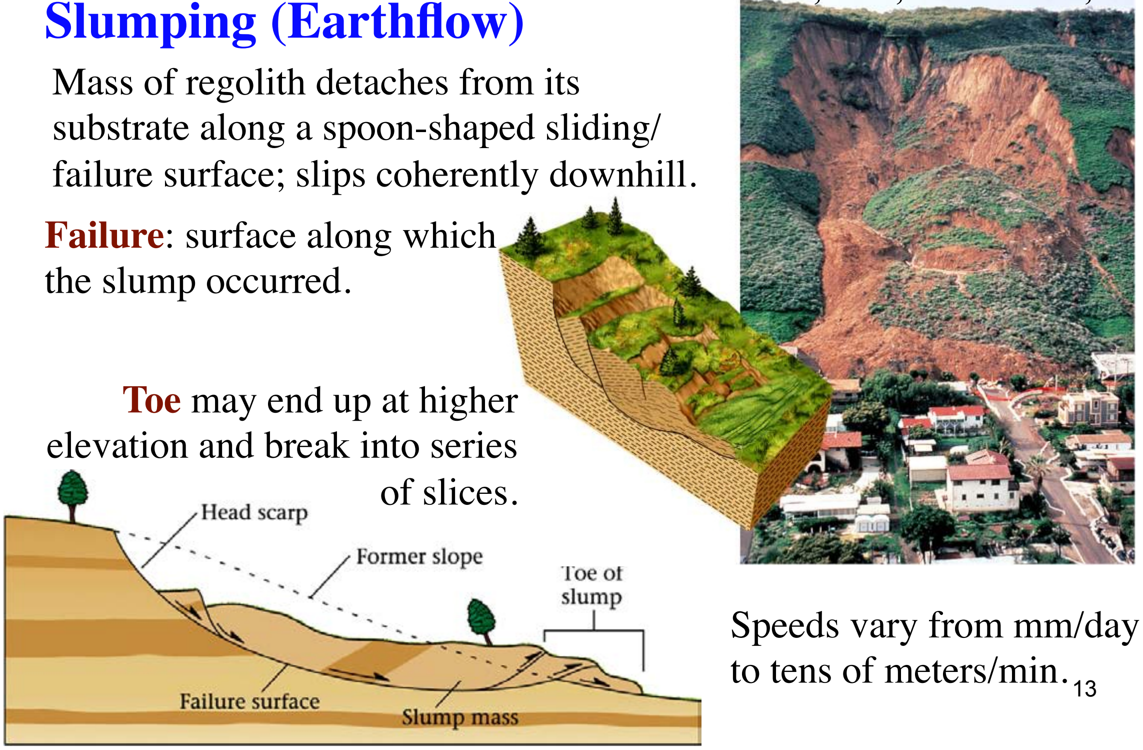
Types of Mass Movement

Slumping (Earthflow)

Mass of regolith detaches from its substrate along a spoon-shaped sliding/failure surface; slips coherently downhill.

Failure: surface along which the slump occurred.

Toe may end up at higher elevation and break into series of slices.

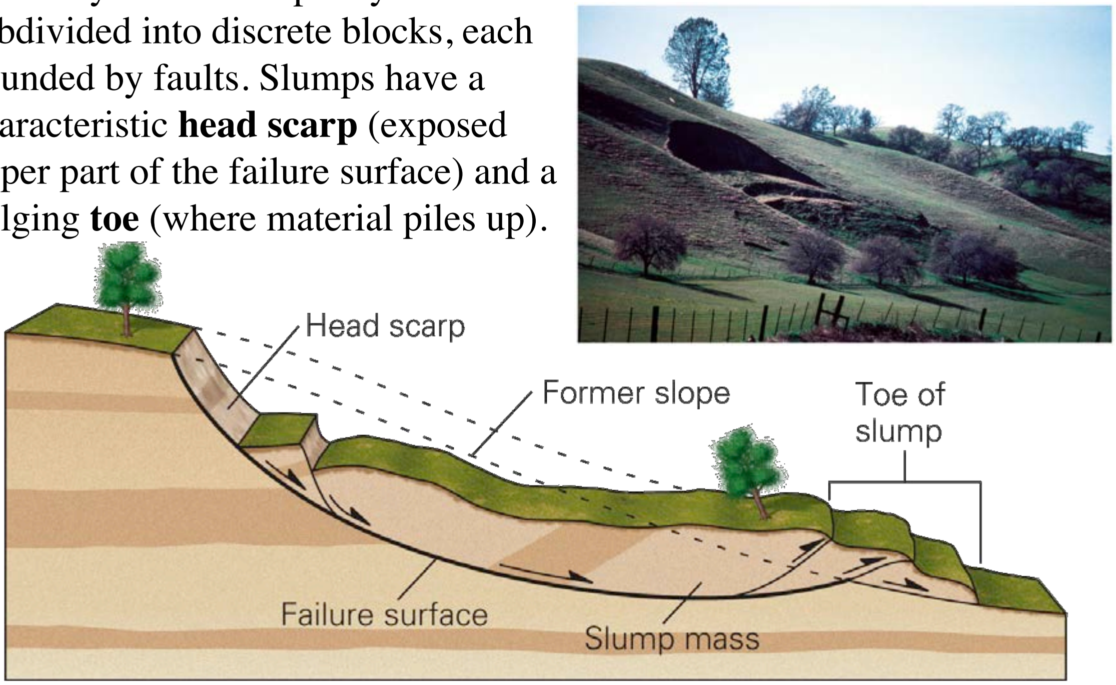


March, 1985; La Conchita, CA

Speeds vary from mm/day to tens of meters/min.

Slumping

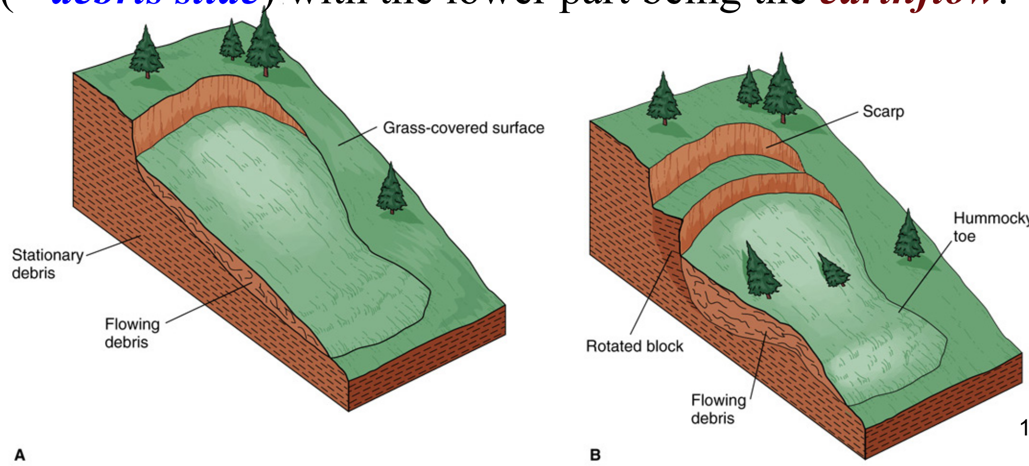
The body of the slump may be further subdivided into discrete blocks, each bounded by faults. Slumps have a characteristic **head scarp** (exposed upper part of the failure surface) and a bulging **toe** (where material piles up).



Types of Mass Movement

Earthflow: debris moves downslope as a viscous fluid, slow or rapid movement typically after heavy rains. Produces a scarp at the top and a hummocky toe or lobe at the end.

Rotational sliding typically occurs in the upper part (= ***debris slide***) with the lower part being the ***earthflow***.



Types of Mass Movement

Mudflow: flowing mixture of debris and water, usually moving down a channel.

Can occur after heavy rainfall or due to volcanic activity.

Typically occurs in areas where vegetation is sparse.

Mudflows

Dried Mudflow, Peru.

Mudflow from Mount St. Helens.

A mudflow is a slurry of water and fine sediment.

Mudflows are common in tropical settings with deep weathering of soils and abundant rainfall, especially tropical storms and hurricanes.

Types of Mass Movement

Lahars: Type of mudflow occuring on young volcanoes - unconsolidated ash. Volcanic ash from recent or ongoing eruptions mixes with water from heavy rains or melted glacial ice.

Case History of a Lahar: Nevado del Ruiz Volcano in the Colombian Andes

The eruption melted some of the mountain’s snowcap. Melt water mixed with ash and raced down river valleys. Armero was buried, killing 20,000 residents in their sleep. The volcano erupted the night of November 13, 1985.

Types of Mass Movement

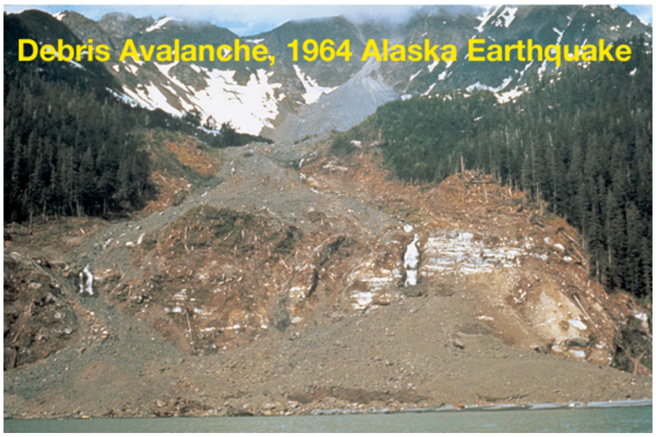
Debris Flow: mudflow is mixed with large rock fragments. Speed is dependent upon slope angle and water content.

Debris Avalanche: very rapidly moving, turbulent mass of debris, rock and water.

Air trapped under rock mass creates an air cushion.

Reaches speeds in excess of 700 km/hour.

For example, Yungay, Peruvian Andes.

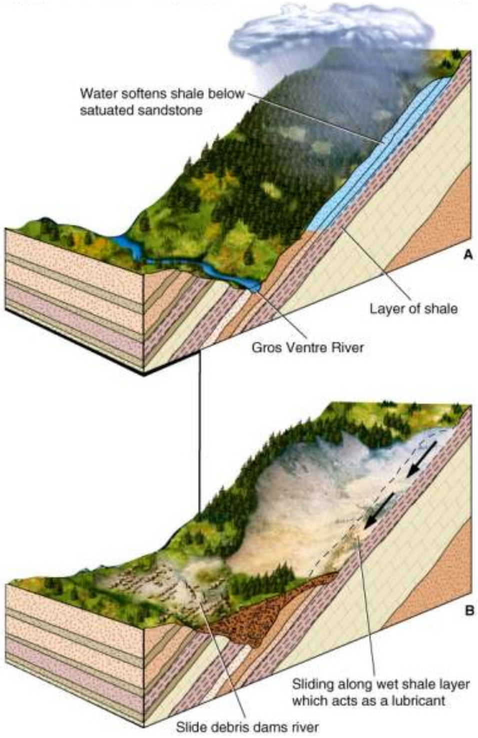


Types of Mass Movement

Landslides

Rockslide: Coherent mass moves. Movement along a plane parallel to the surface.

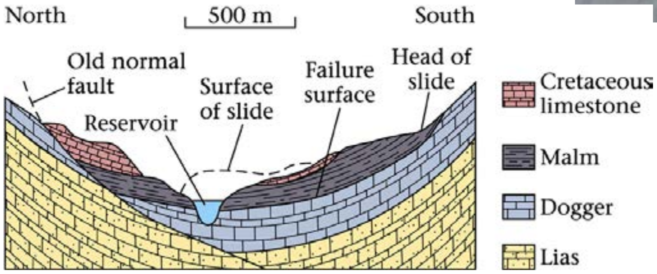
See also **Debris Slide** (where regolith slides).



Types of Mass Movement

Landslides

Rockslide: Vaiont Dam, Monte Toc, Italian Alps. Weak bed of shale produced the slide.
On October 9, 1963, 600 million tons of limestone slid into the reservoir. The resulting wave crested the dam and flowed down the valley, destroying villages and killing 2,600 people.



The dam now retains the rock slide.

Types of Mass Movement

Avalanches

Turbulent clouds of debris mixed with air that rush down steep slopes. Hugs the ground and acts as a viscous liquid that is cushioned by air - acts as a bulldozer.
If it consists of fragments of rock and dust = Debris Avalanche.

Avalanches tend to occur repeatedly in the same area that create pathways called ***avalanche chutes*** that contain no mature trees.

Types of Mass Movement

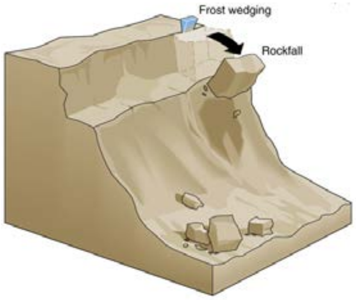
Avalanches

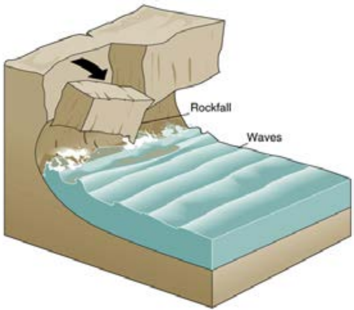
Wet avalanches behave like a viscous slurry, hugging the slope and entraining little air. As a result, they move relatively slowly (usually <30 km per hour).

Dry avalanches move cold, powdery snow. They move above the ground surface on a layer of pressurized air. They move rapidly (up to 250 km per hour).

Types of Mass Movement

Rockfall – rock free-falls due to undercutting [e.g., cliff (natural) or road cutting (man-made)].

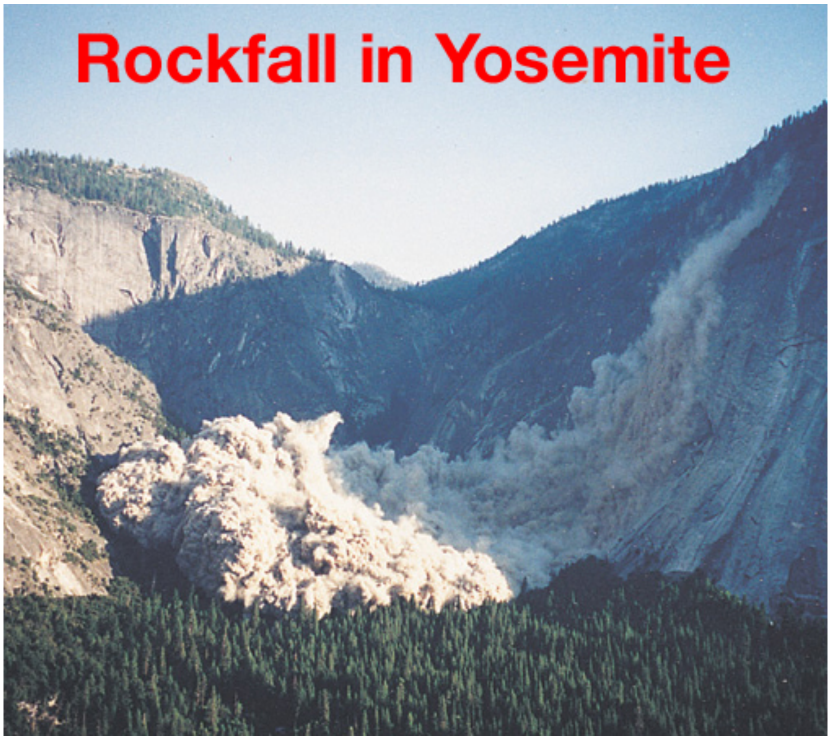




Debris Fall: free fall of regolith-dominated material.

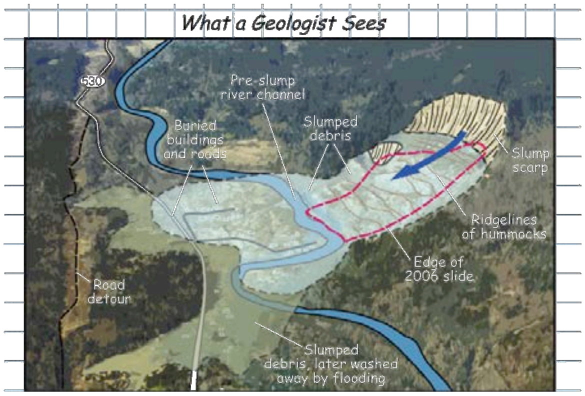
Both can cross a valley and travel up the other side.

Types of Mass Movement



Case Study: Oso, WA, 2014


(a)



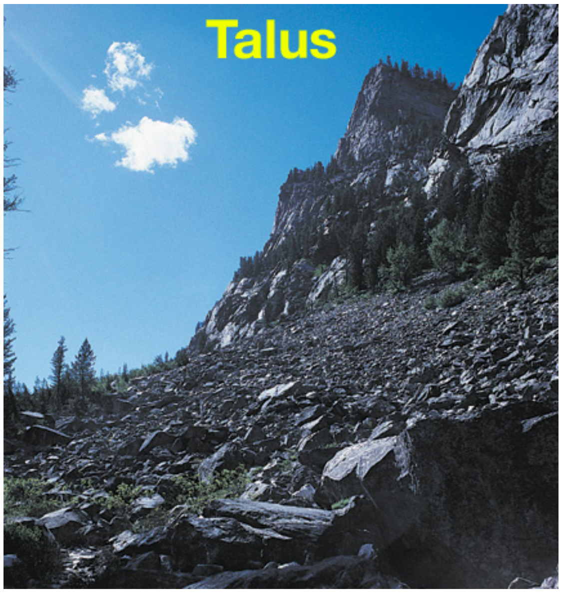
(b)

Types of Mass Movement

Deposits

Colluvium: sediment deposited by mass wasting. Poorly sorted, poorly stratified or unstratified.

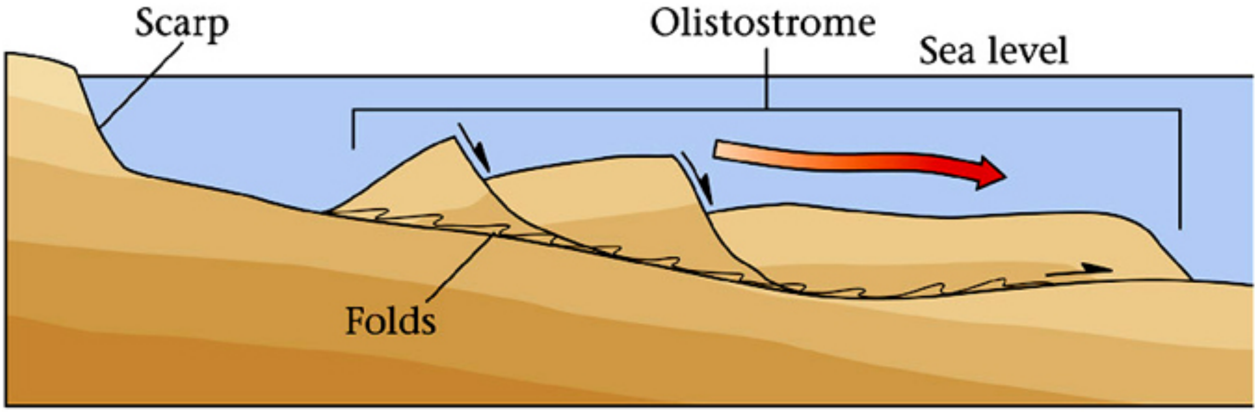
Talus: apron of debris sloping outward from cliffs.



Types of Mass Movement

Submarine Mass Movements. Three Types

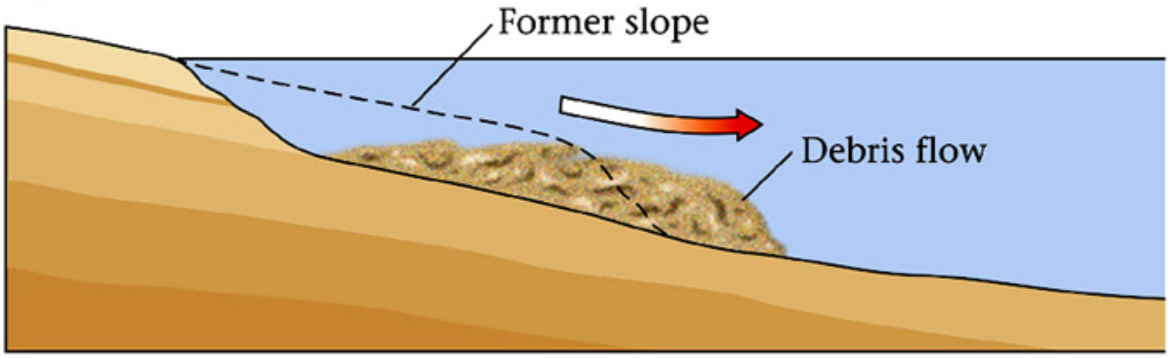
Submarine Slumps - semi-coherent blocks (**olistostromes**) slip downslope on weak mud detachments. Occasionally, the layers constituting the blocks become contorted as they move.



Types of Mass Movement

Submarine Mass Movements. Three Types

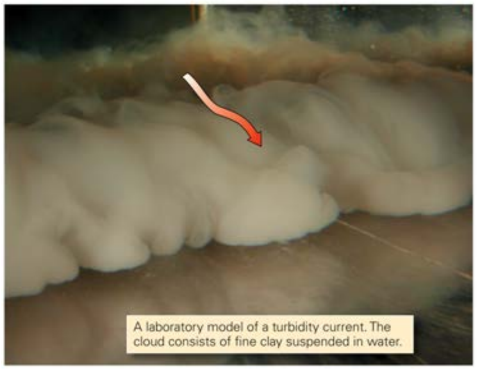
Submarine Debris Flows - the moving mass breaks apart to form a slurry containing larger clasts (pebbles to boulders) in a mud matrix.

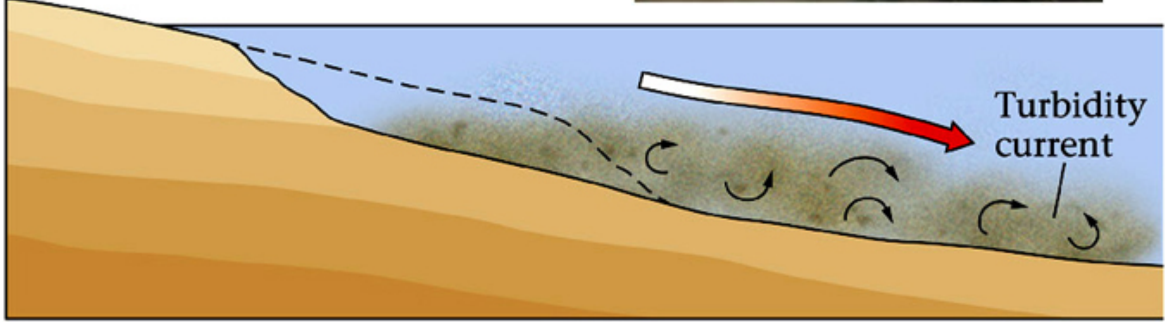


Types of Mass Movement

Submarine Mass Movements. Three Types

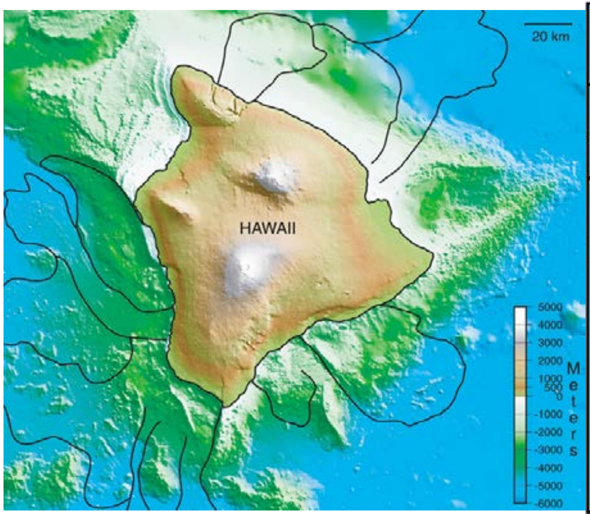
Turbidity Currents - sediment disperses into water forming a turbulent cloud of sediment that settles out to form graded bedded sediments.

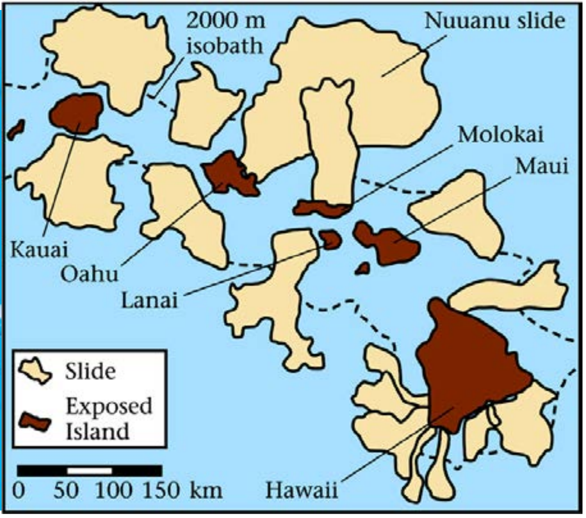

A laboratory model of a turbidity current. The cloud consists of fine clay suspended in water.



Types of Mass Movement

GLORIA: Geologic LOng-Range Inclined Asdic (sonar).
Maps out submarine slumps that may have caused major tsunamis.





Setting the Stage for Mass Movements

Mass movements can occur because of:

Fracturing and weathering;
Development of relief.

Jointing occurs during rock formation and faulting occurs in tectonically active regions, which also develop relief.
Weathering occurs along joints/faults, which breaks down the interlocking nature of minerals.

Dry regolith held together by friction;
Slightly wet regolith is also held together by surface tension;
Saturated material is not held together well because the water in filled pores pushes grains apart.

Slope Stability

Movement of rocks and soil (debris) down-slope due to gravity without a flowing medium.

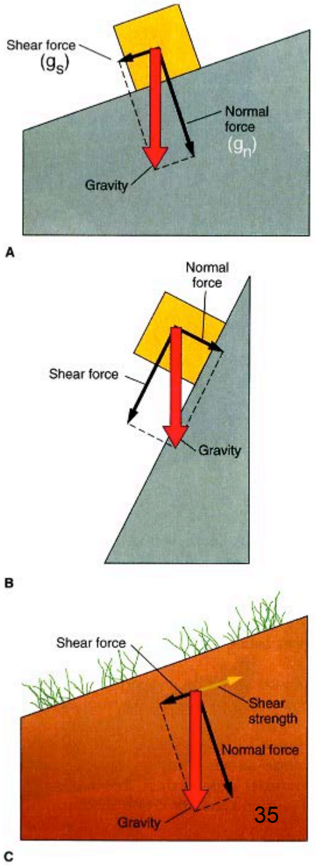
Controlling Factors

Force of gravity (g) is resolved into two components, g_n (normal) and g_s (shear).

Movement caused when
$g_s > g_n$ + cohesion + friction.

A block's movement will be controlled by friction at its base. Friction increased by chemical bonding and interlocking minerals.

In a debris flow, there are many grains and blocks – the shear strength (resistance to shearing) depends upon the cohesion of the particles.

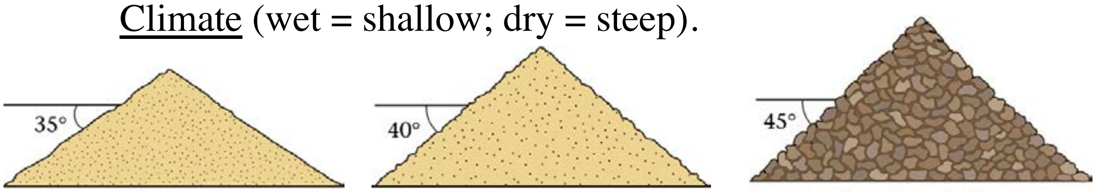


Slope Stability

Angle of Repose. maximum stable slope, which is a function of:

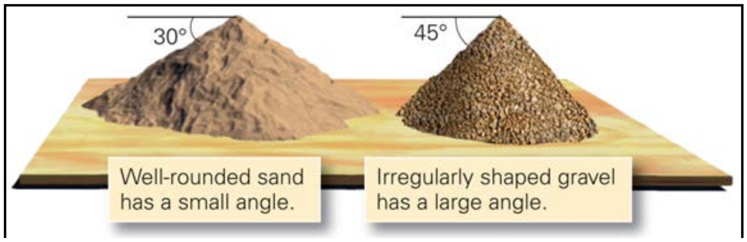
Rock type: flat beds – slope of layer depends upon rock strength; folds – arcuate ridges with unequal slope; faults – valleys and mountain ranges with unequal slope.

Climate (wet = shallow; dry = steep).



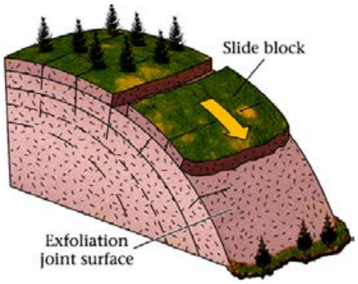
Fine sand Coarse sand Angular pebbles

Size and shape of grains, which determine the amount of friction across boundaries.

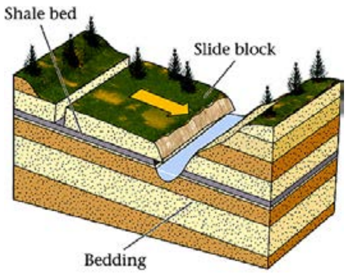


Slope Stability

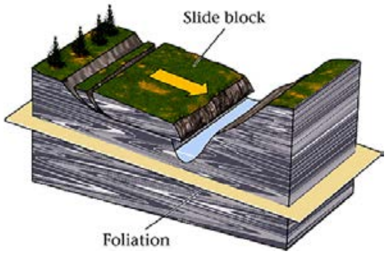
Resistance force is less than might be expected because of a weak interface at depth (e.g., Vaiont Dam). Several different kinds of weak surfaces that are prone to failure.



Exfoliation



Bedding

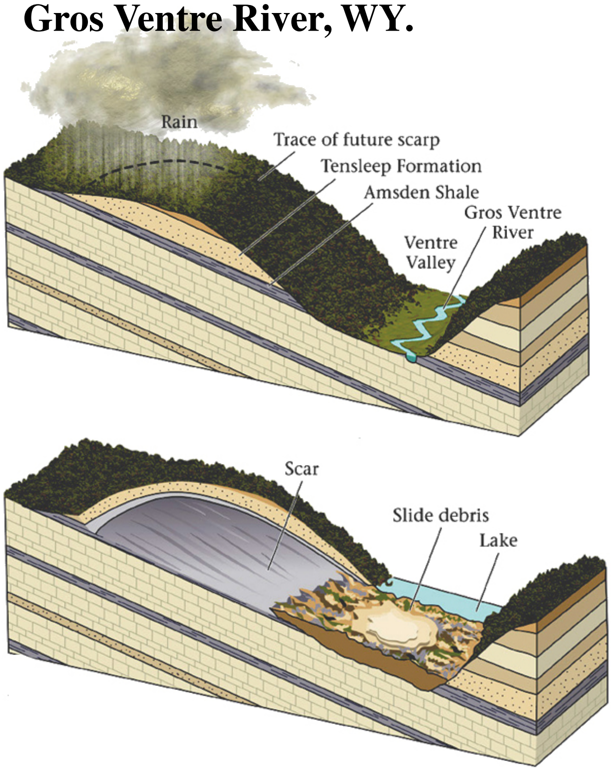


Foliation

Gros Ventre River, WY. 40 million cubic meters of rock, soil & forest detached after heavy rains and formed a natural dam. Flank of the mountain was a dip slope with interbedded sandstones and shales.

Slope Stability

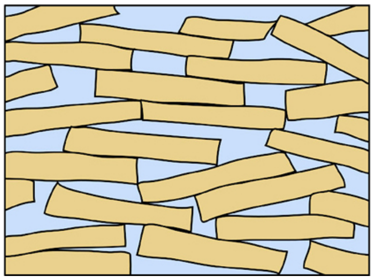
Gros Ventre River, WY.

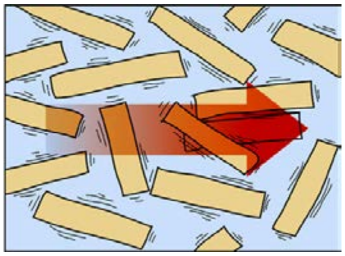


Slope Stability

Earthquake shaking produces:

Quick clay: damp clay flakes behave as a solid when still - water-coated flakes held together by surface tension.





Shaking separates the flakes and suspends them in water.

Liquefaction: shaking of wet sand causes grains to try and fit together more closely, which increases pore pressures, thus destroying cohesion and forming a slurry.

Slope Stability

Three factors influence the strength of slopes:

Weathering;
Vegetation cover;
Water.

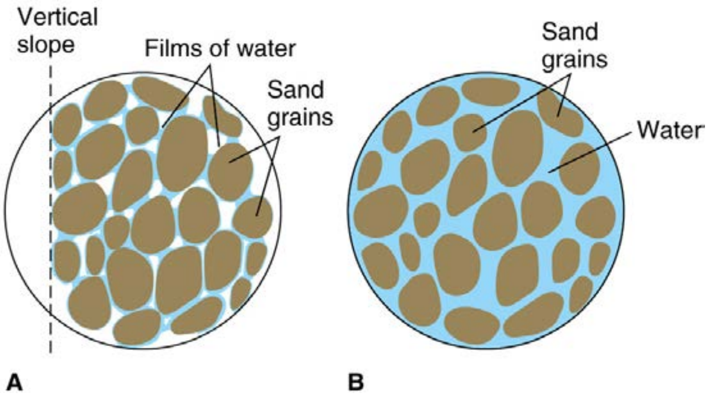
Weathering - chemical weathering produces weaker minerals; physical weathering breaks rocks apart.
Vegetation cover - roots bind loose regolith together. Deforestation promotes slope instability.
Water - too much reduces cohesion.

Swelling clays - addition of water promotes swelling of clays as water is absorbed between clay sheets. Dehydration causes shrinkage. Cracking of roads, foundations, etc.

Slope Stability

Cohesion and friction may be reduced by:

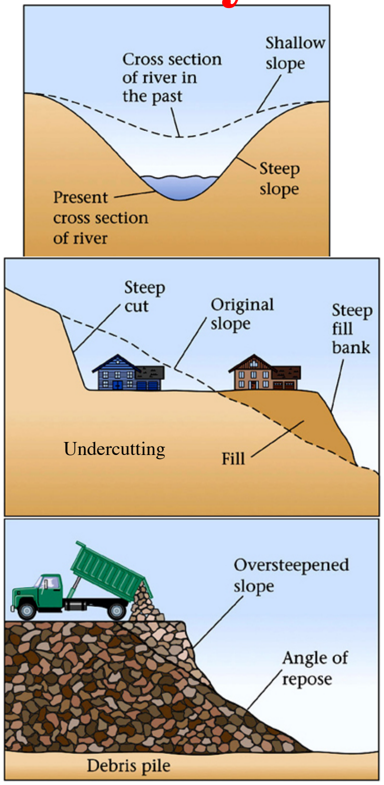
- **Weathering** – removes mineral constituents.
- **Earthquakes** – disturbs grain contacts.
- **Water** – lubricates debris by forcing grains apart. Sand grains are actually held together by the surface tensions of the water films – increasing the water decreases the tensions.



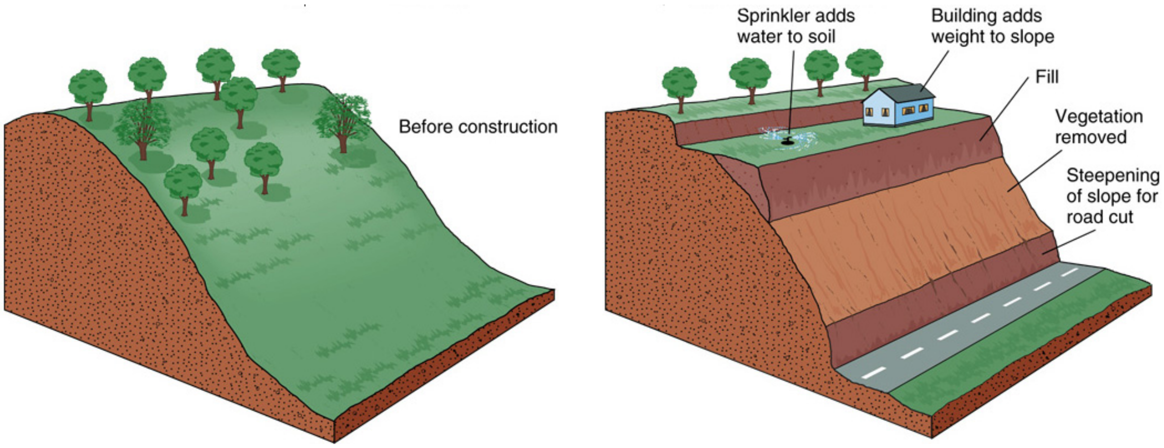
Causes of Instability

Changing Slope Angle

LS~1.MOV



Causes of Instability



Slope undercutting.
Removal of vegetation.
Loading of slopes, especially the upper parts.
Adding water.
NOT understanding the local geology.

St. Francis Dam, California

The dam broke in 1928, one year after it was completed.

200 feet high concrete dam.

The wall of water killed 400 people in 2 counties.

East edge of the dam was against foliated metamorphic rocks.

Natural landslides scarred the landscape.

Base of the dam was on a fault zone.

Western edge was built against rock that dissolves in water!

Geologic surroundings NOT taken notice of by the engineers.

St. Francis Dam, California

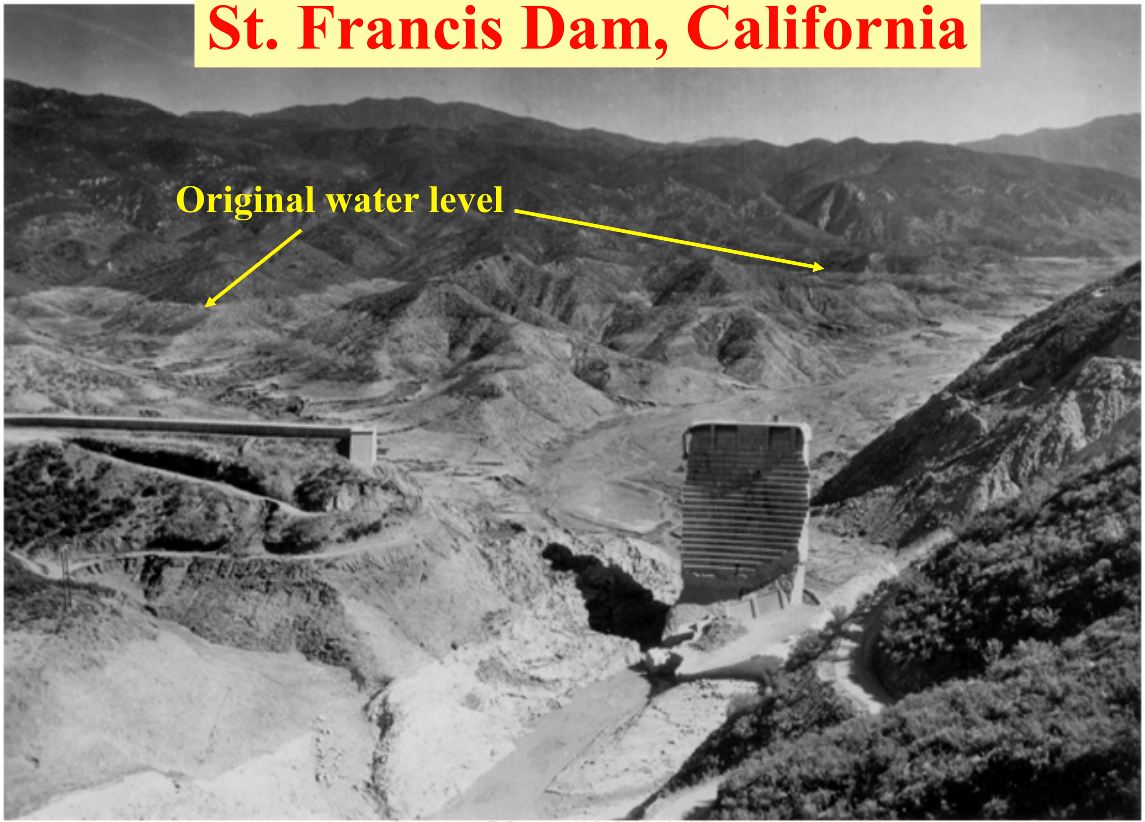
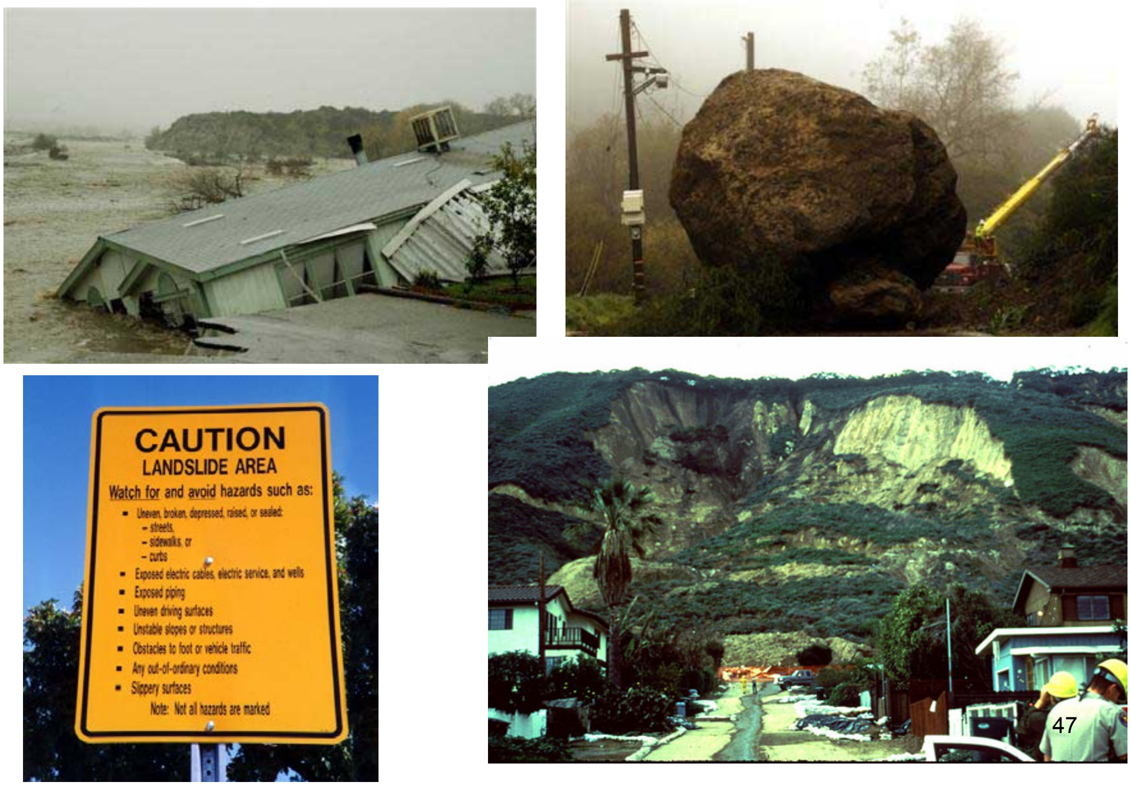


Photo by H. T. Stearns, U.S. Geological Survey

La Conchita, CA, January, 2005

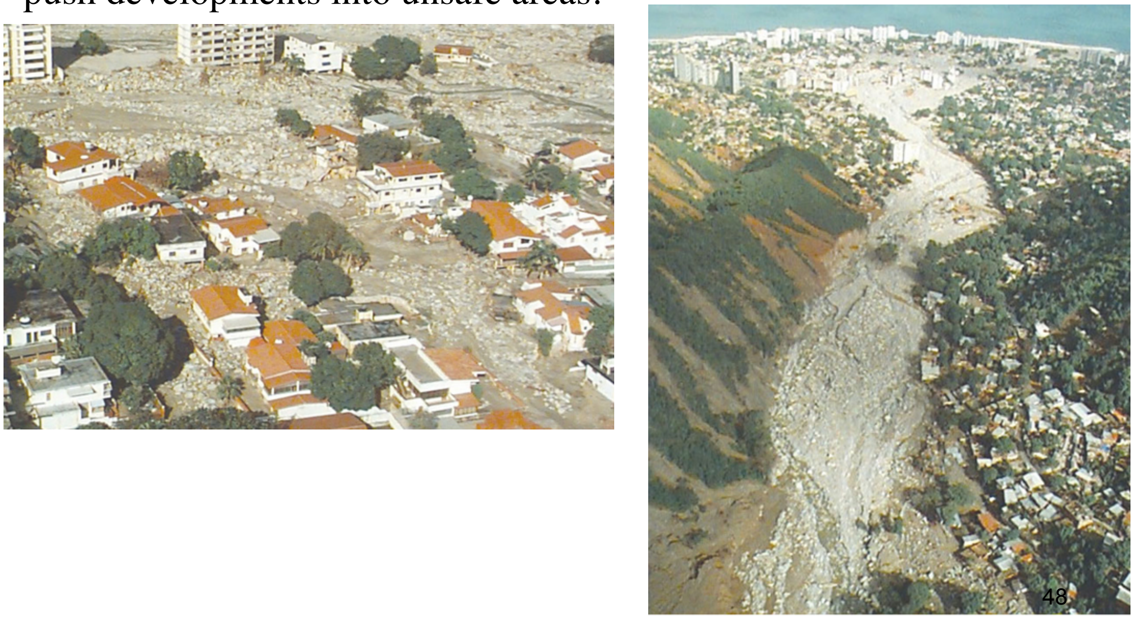
LaConchita0105_sm.mov

Californian Landslides, 2005



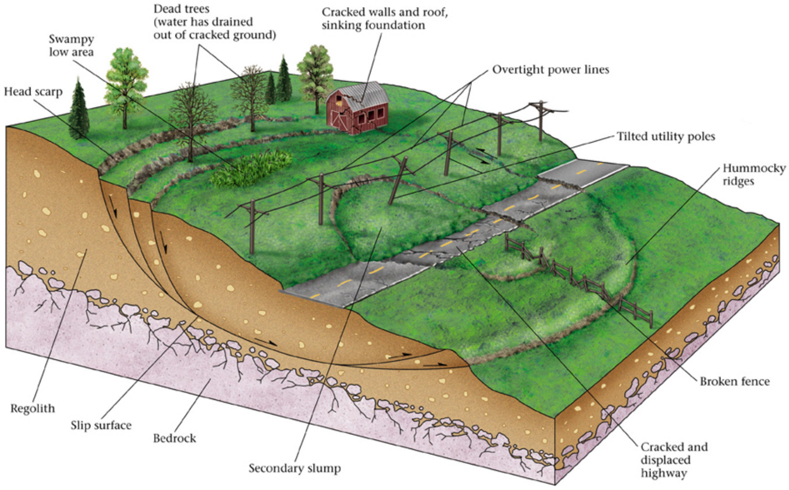
Possible Preventive Measures

Developments may already exist in areas prone to mass movements, economic pressure may be strong, also population pressure may push developments into unsafe areas.



Identifying Regions at Risk

Features of slope instability



Slope Reduction

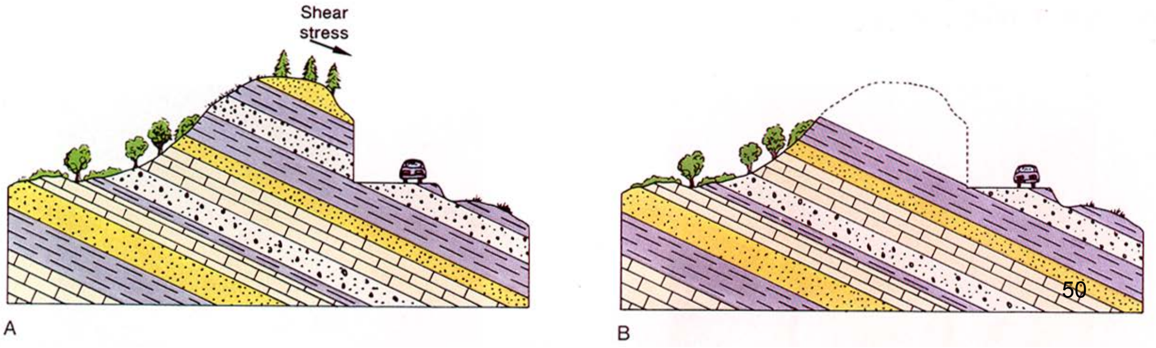
Dangers need to be minimized – if the danger is relatively localized, it may be economical to build structures to mitigate the danger.

If the slope is too steep:

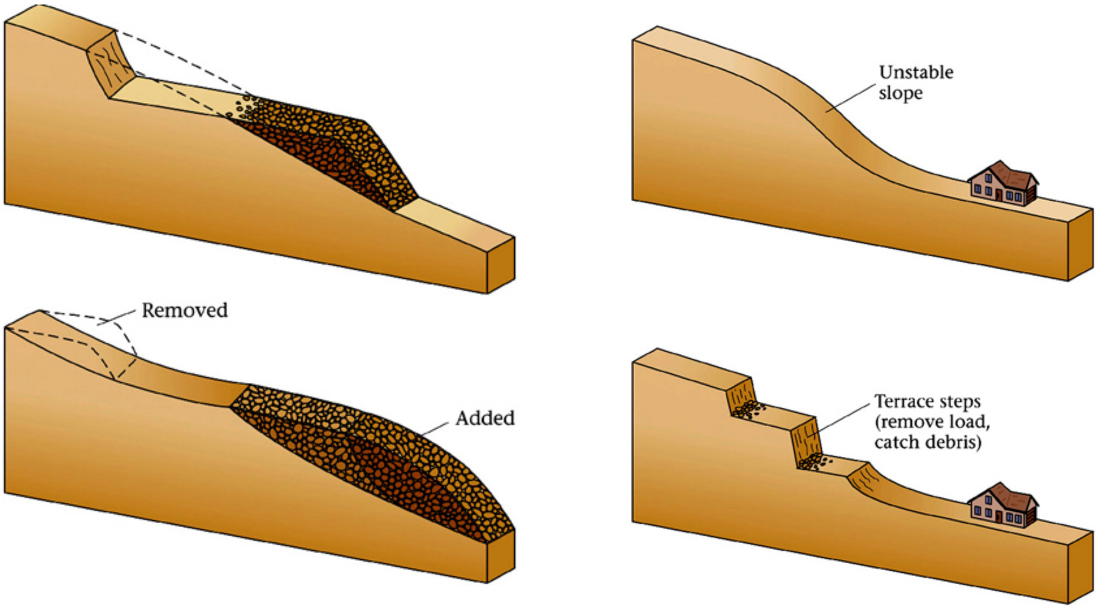
Reduce the slope angle;

Place additional supporting material at the foot of the slope to prevent a slide or flow;

Reduce the load (weight, shearing stress) on the slope by removing some of the rock/soil/structures high on the slope.

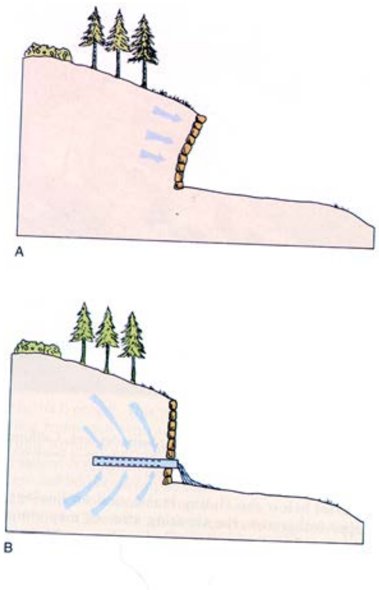


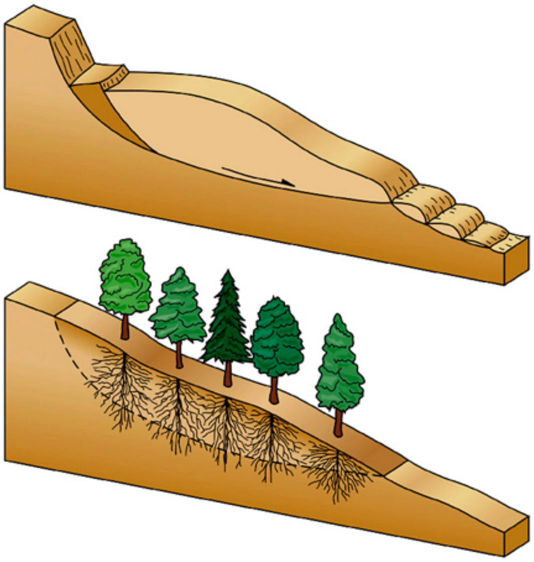
Slope Reduction



Slope Stabilization

Planting vegetation may be enough to stabilize a slope.

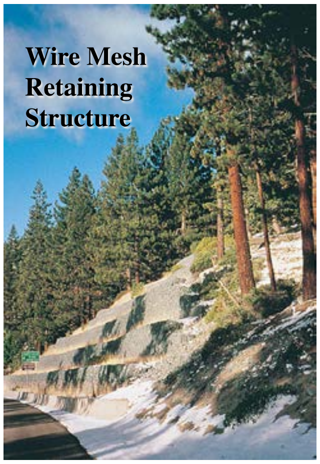


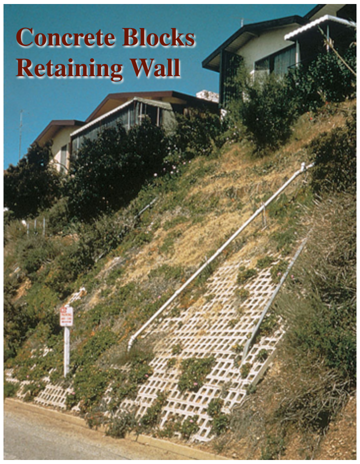


If not, retaining walls can be built, but these need to be sturdy and allow drainage through it.

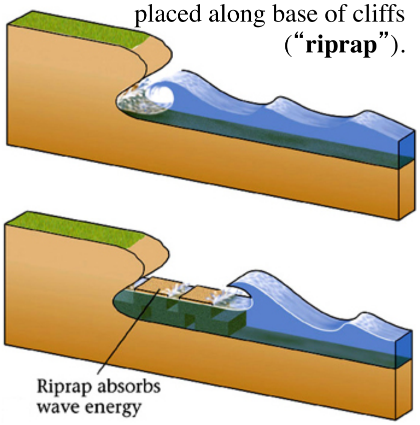
Slope Stabilization

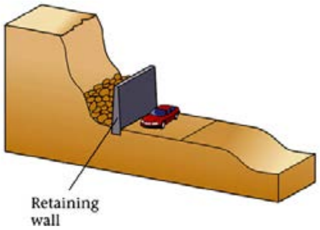
Stabilization Structures





Prevent undercutting: large blocks placed along base of cliffs (**"riprap"**).





Avalanche-Protection Structure

Fluid Removal

Decrease water content of the mass to increase frictional resistance. This can be done by:

Covering the surface with an impermeable layer;

Install subsurface drainage where the substrate is permeable;

Blow hot air through boreholes in impermeable strata to help dry it out.

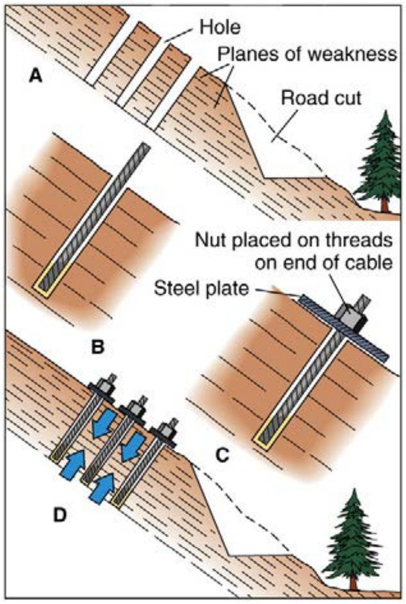
Drainage

Concrete sheet on hills are not effective

Other Preventive Measures

Drive pilings into the toe of a slide to stabilize slides, but the mass needs to be coherent and angle low.

Rock bolts – giant steel bolts driven into stable rocks below slip planes. Works best on thin slide blocks of coherent rocks on low-angle slopes.



For unconsolidated material, the best way to mitigate mass movement is to reduce the slope angle.

Other Preventive Measures

Landslide Potential Maps

Recognition of mass movement potential in different landscapes is vital for proper urban planning and development.
Landslide potential maps rank regions according to the likelihood that a mass movement will occur.

Factors used in determining this likelihood:

1) Slope steepness;
2) Strength of substrate;
3) Degree of water saturation;
4) Orientation of bedding, joints, or foliation relative to the slope;
5) Nature of the vegetation cover;
6) Potential for heavy rains;
7) Potential for undercutting to occur;
8) Earthquake potential.

Summary

Types of Mass Movement: Creep; Fall, Slip, Flow; Solifluction; Rock Glaciers; Slumping (Earthflow); Mudflow (lahar); Debris Flow, Debris Slide, Debris Avalanche; Rockslide; Rockfall; Debris Fall.

Deposits: Collurium; Talus.

Submarine Mass Movements: Slumps (Olistostromes); Debris Flows; Turbidity Currents.

Initiating Mass Movements: Joints/Fractures/Faults; Weathering; Relief.

Slope Stability: Angle of Repose; Friction vs. Gravity; Cohesion and Friction; Exfoliation; Bedding; Foliation; Quick Clay; Liquefaction; Changing Slope Angle; Weathering, Vegetation Cover, Water; Swelling Clays.

Causes of Instability: Slope Undercutting; Vegetation Removal; Overloading Slopes; Adding Water; NOT Understanding the local Geology.

Mitigation: Slope Reduction; Revegetation; Retaining Structures; Drainage; Avalanche Bridges; Rock Bolts; Landslide Potential Maps.